SISM 2026

SAMARKAND INTERNATIONAL SYMPOSIUM ON MAGNETISM

Dedicated to the memory of Anatoly Vedyaev

17 — 23 August, 2026 · Samarkand, Uzbekistan

BOOK OF ABSTRACTS

Samarkand 2026

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SAMARKAND INTERNATIONAL SYMPOSIUM ON MAGNETISM

17 — 23 August, 2026 · Samarkand, Uzbekistan

Book of Abstracts

The text of abstracts is printed from original contributions.

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MAIN TOPICS

— High Frequency Properties and Metamaterials

— Magnetophotonics (linear and nonlinear magnetooptics, magnetophotonic crystals)

— Spintronics and Magnetotransport

— Neutrons and synchrotron X-rays for magnetism

— Magnetism in Biology and Medicine

— Multiferroics

— Magnetism and Superconductivity

— Magnetic Shape-memory Alloys and Magnetocaloric Effect

— Soft and Hard Magnetic Materials

— Magnetic Soft Matter (magnetic polymers, complex magnetic fluids and suspensions)

— Magnetic Nanostructures and Low Dimensional Magnetism

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SCIENTIFIC PROGRAM

Main building of Samarkand State University (University Boulevard 15).

Engineering Physics Institute Building (SamDUMuhandislikfizikasiinstituti).

SCIENTIFIC PROGRAM

Samarkand International Symposium on Magnetism was contributed by scientists from 17 countries. Total numbers of accepted contributions is 331.

Scientific agenda of the conference includes 8 plenary lectures with a duration of 45 min. Each conference session in the period from 17th to 23th of August is subdivided into four parallel sections focused on one topic of interest in the field of magnetism each. Sections are composed of Invited Talks (30 min including discussion), Invited Reports (15 min including discussion) and Oral Talks (15 min including discussion). Poster sessions will take place on the 18th and 19th of August. The poster contributions should be presented on display from 18:00 till 20:00, with a scheduled session in the evening during which there will no other program in parallel.

The official language of SISM is English. It will be used for all printed material and presentations. No translation services will be provided

PROCEEDINGS

Proceedings of the conference are planned to be published in Journal of Superconductivity and Novel Magnetism, Physics of Metals and Metallography, and Bulletin of the Russian Academy of Sciences: Physics.

CONFERENCE DINNER & CULTURAL PROGRAM

We are pleased to welcome you to the Conference Dinner on 20th of August at a charming countryside venue in Samarkand (exact location details to follow).

Guided tour to Bukhara is planned for the conference members on 22th of August. Bukhara is Islamic culture centers with more than 150 monuments of the Middle Ages included in the UNESCO World Heritage List.

Samarkand is a city with authentic architecture, and it offers its visitors numerous attractions withing the city and in the surroundings.

CLIMATE

The temperature in August exceeds +30oC, and UV index in the afternoon reaches 9-10. We extremely encourage our members to take care of personal sun and heat protection as well as to avoid long-lasting activity in the unshielded places in the middle of the day.

VENUE

Samarkand is included in the UNESCO World Heritage List under the name “Samarkand –Crossroads of Cultures”. Samarkand State University is one of the oldest classical universities in Uzbekistan, known far beyond the country. Its history begins in the Timurid era, when on September 21, 1420, the great scholar Muhammad Havofimade a scientific report on the theory of Claudius Ptolemy in front of more than 100 listeners.

CONTENTS

18 AUGUST — TUESDAY

Plenary Lectures **14**

Oral Sessions I **17**

Spintronics and Magnetotransport 17

Soft and Hard Magnetic Materials 22

Magnetophotonics 28

Multiferroics 34

Oral Sessions II **40**

Magnetic Soft Matter (magnetic polymers, complex magnetic fluids and suspensions) 40

Heusler alloys and phase transitions 46

Theory 52

Neutrons and synchrotron X-rays for magnetism 59

Poster Sessions **64**

Spintronics and Magnetotransport I 64

Magnetic Materials I 76

Magnetic Soft Matter + Magnetism in Biology and Medicine+Neutrons 109

Magnetic Nanostructures and Low Dimensional Magnetism I 118

Theory + Superconductivity 127

19 AUGUST — WEDNESDAY

Plenary Lectures **145**

Oral Sessions I **148**

Spintronics and Magnetotransport 148

Magnetophotonics 153

Magnetism and Super- Conductivity 159

Soft and Hard Magnetic materials 165

Oral Sessions II **171**

Magnetic Nanostructures and Low Dimensional Magnetism 171

Magnetophotonics 177

Magnetism and Super-conductivity 183

Soft and Hard Magnetic materials 191

Poster Sessions 200

Magnetic Materials II 200

Magnetic Nanostructures and Low Dimensional Magnetism II 232

NANOCOMPOSITES 241

Multiferroics 256

Miscellaneous 262

Spintronics and Magnetotransport II Magnetophotonics 270

20 AUGUST — THURSDAY

Plenary Lectures **281**

Oral Sessions I **284**

Spintronics and Magnetotransport 284

Magnetic Nanostructures and Low Dimensional Magnetism 292

Magnetism in Biology and Medicine 298

Magnetic Materials 305

Oral Sessions II **313**

Magnetic Soft Matter (magnetic polymers, complex magnetic fluids and suspensions) 313

Low Dimensional Magnetism 320

High Frequency Properties. Nanocomposites 325

Magnetic Nanostructures 334

21 AUGUST — FRIDAY

Plenary Lectures **341**

Oral Sessions I **344**

Soft and Hard Magnetic Materials 344

Theory 351

Multiferroics 356

Oral Sessions II **363**

Miscellaneous 363

Neutrons and synchrotron X-rays for magnetism 370

SPINTRONICS 376

AUTHOR INDEX **383**

Plenary

Tuesday, 18 August, 10:30 - 12:00

MODERN LIFE APPLICATIONS OF MAGNETIC MATERIALS

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Optimization of magnetic properties of functional materials for specific technological applications in energy efficient energy conversion like in electrical transformers, generators or for novel approaches in magnetic refrigeration and biomedical theranostics [1] in cancer treatment requires a detailed atomistic understanding of the dynamic and static magnetic responses and the identification of the dominant magnetic interactions.

In this talk I will provide a personally biased review of important discoveries for the understanding of magnetic properties in thin films, nanoparticles and bulk materials. The importance of a critical analysis of interface properties -even with atomic accuracy- is discussed. Novel ideas on how to extend the dynamic range of magnetization dynamics to the THz range [2], how to unconventionally analyze spin transfer effects [3] and how to design magnetocaloric materials and permanent magnets, for example by exploiting the vast opportunities that high entropy alloys [4,5] offer, will be discussed. The magnetism of the later -as an example - are shown to depend on the synthesis and processing conditions resulting in new options for tuning their magnetic and secondary (chemical and mechanical robustness) functionalities.

Finally, a challenging recount on recent results [6] on the navigational sense of pigeons will be given.

The author thanks all collaboration partners and students who contributed to this overview.

Funding from the Deutsche Forschungsgemeinschaft (DFG), CRC/TRR 270 (Project-ID 405553726) is acknowledged,

[1] P. Steinkraus, et al *ACS Applied Nano Materials* **8** (2025).
[2] J. Wiemeler, M. Farle and A. S. Semisalova, *Physical Review* B **112** (2025) 094433.
[3] T. Feggeler, et al, *ACS Applied Materials & Interfaces* **16** (2024), 54139–54145.
[4] N. F. Shkodich, et al, *Faraday Discuss* **264** (2026), 453–473
[5] N. Polin, et al, *Acta Materialia* **307** (2026) 121906
[6] C. Lisowski, et al, *Science* **392** (2026) 985–991.

PARADOXES OF ULTRAFAST ANTIFERROMAGNETISM AND WRITING OF ANTIFERROMAGNETIC BITS

Kimel A.V.

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Ultrafast spin dynamics in antiferromagnets is paradoxical. While commonly accepted Curie-Neumann's principle states that "the symmetries of the causes are to be found in the effects" [1] and implies that a magnetic field cannot control antiferromagnetic Néel vector, rapidly changing THz magnetic field appears to "violate" this principle and can effectively excite spins in antiferromagnets . In this ultrafast regime, laser-induced spin dynamics in antiferromagnets is intrinsically non-linear [2-4], where new channels of spin-lattice interaction open-up [2,3], the principle of superposition fails, i.e. 1+1>2 [4], and antiferromagnets appear to host even more channels to excite spins [5-7] than one can find in ferromagnets. We will review recent progress in ultrafast antiferromagnetic spin dynamics, highlight the recently discovered mechanism enabling control of antiferromagnetic spins by a THz electric field [6], and discuss the conditions required for reliable writing of stable antiferromagnetic bits [8].

[1] P. Curie,"On Symmetry in Physical Phenomena, J. Phys. Theor. Appl, 393–415 (1894).
[2] E. A. Mashkovich et al, "Empowering Control of Antiferromagnets by THz-Induced Spin Coherence", *Science* 374, 1608-1611 (2021).
[3] T. Metzger et al, "Magnon-phonon Fermi resonance in antiferromagnetic CoF_2"*Nature Communications* 15, 5472 (2024).
[4] T. G. H. Blank et al, *Phys. Rev. Lett*. 131, 096701 (2023).
[5] Y. Behovits et al, "Terahertz Néel spin-orbit torques drive nonlinear magnon dynamics in antiferromagnetic Mn_2Au" *Nature Communications* 14, 6038 (2023).
[6] V. Bilyk et al, "Control of spins in collinear antiferromagnet Cr_2O_3 by terahertz electric fields"*Newton* 1, 6100132, (2025).
[7] R. M. Dubrovin, A. V. Kimel, A. K. Zvezdin, "Competition between terahertz magnetoelectric and Néel spin-orbit torque driven spin dynamics in metallic antiferromagnets" *Phys. Rev. B* 112, 064402 (2025).
[8] N. Khokhlov *et al*. (submitted).

ORAL SESSION

Spintronics and Magnetotransport

Tuesday, 18 August, 14:00 - 15:45

SPINTRONICS BEYOND MRAM: STOCHASTIC MTJS AND P-BITS FOR PROBABILISTIC COMPUTING

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Spintronics has traditionally been associated with magnetic data storage, from hard disk drives to the commercial deployment of magnetic tunnel junction (MTJ)-based MRAM. Yet the same physical mechanisms that made MRAM possible - spin-transfer torque, spin-orbit torque, magnetoresistance, and thermally activated magnetic switching, also provide a rich foundation for new computing paradigms. As CMOS scaling faces increasing limitations in power, variability, and data movement, spintronic devices offer a route toward computation based directly on device physics rather than purely deterministic Boolean logic.

This talk focuses on one of the most promising directions beyond MRAM: probabilistic computing with stochastic magnetic tunnel junctions, or p-bits. Unlike conventional MRAM cells, where thermal stability is maximized to ensure reliable data retention, p-bit devices intentionally exploit controlled magnetic stochasticity. A superparamagnetic or low-barrier MTJ can fluctuate between resistance states, producing a tunable probabilistic output. When biased electrically, such a device behaves as a hardware building block for probabilistic bits whose state can be continuously controlled by input current or voltage.

We will discuss how stochastic MTJs can be used to build networks of interacting p-bits, enabling hardware implementations of probabilistic models such as Ising machines, Boltzmann samplers, and Bayesian inference engines. These systems are especially attractive for combinatorial optimization, sampling, machine learning, and quantum-inspired computing, where randomness is not a defect but a computational resource. Compared with conventional CMOS approaches to random-number generation and probabilistic sampling, spintronic p-bits offer compactness, intrinsic stochasticity, compatibility with MTJ-based technology platforms, and the potential for improved energy efficiency.

A key part of the talk will address the physical and technological requirements for practical p-bit hardware: energy barriers, thermal fluctuation rates, readout via tunnel magnetoresistance, device-to-device variability, coupling architectures, and integration with CMOS control circuitry. We will also discuss the relation between p-bit devices and more established spintronic technologies such as MRAM, emphasizing that p-bits are not a replacement for memory but a complementary computational primitive enabled by the same MTJ platform.

Altogether, this talk argues that the future of spintronics lies not only in better memory, but in new forms of physics-driven computation. In this vision, thermal noise, magnetic dynamics, and non-volatility are no longer parasitic effects to be suppressed, but active resources for probabilistic inference, optimization, and energy-efficient AI hardware.

[1] S. I. Kiselev et al., *Nature* **425**, 380–383 (2003).
[2] A. Tulapurkar et al., *Nature* **438**, 339 (2005)

SPINTRONICS WITH RASHBA SYSTEMS

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In non-centrosymmetric systems, the non-vanishing gradient of the electrostatic potential gives rise to a momentum-dependent magnetic field in the rest frame of the electrons. The coupling of this field to the electron spin lifts the spin degeneracy of the bands in an otherwise non-magnetic system and leads to complex spin textures in reciprocal space. Depending on the symmetry, these spin textures may exhibit Rashba, Dresselhaus, persistent, or more intricate configurations that are important for spintronic applications.

We show, based on symmetry considerations, that in nonpolar chiral systems, bands with specific orbital characters around a high-symmetry point whose little group is D_2 may admit a single spindependent term in the low-energy model Hamiltonian that naturally gives rise to a persistent spin texture (PST). Considering a two-dimensional plane in the Brillouin zone, we further argue that in such chiral systems the PST emerges due to comparable strengths of the Dresselhaus and Weyl (radial) interaction parameters, both of which are allowed by D_2 symmetry.

Next, we show that in the polar compound Ta_2CS_2, a representative member of the MXene family, local symmetries and orbital compositions are responsible for the nontrivial band splitting and characteristic spin textures at various high-symmetry points in the Brillouin zone. First-principles calculations, supplemented by a **k.p** model Hamiltonian, reveal the presence of both linear and higherorder Rashba terms at the Brillouin-zone center, where the system exhibits C_{3v} little-group symmetry. Additionally, we observe valley-dependent Zeeman-type spin splitting at the non–time-reversalinvariant momentum (non-TRIM) points (K) and (K').

Furthermore, we identify that the opposite spin splittings at the (K) and (K') points arise from a complex orbital composition that induces an intrinsic orbital moment, which influences the nature of the spin splitting and is important for spin-orbitronics. Finally, we show that such systems with novel orbital and spin textures can exhibit an intrinsic orbital and spin Hall effect

[1] K Dutta and I Dasgupta, Physical Review B **110** , 235162 (2024)
[2] H S Sarmah, K Dutta, S Ghosh, and I Dasgupta, Physical Review Materials **9** 074004 (2025)
[3] Kunal Dutta, Anupam Mondal, Sayantika Bhowal, Subhradip Ghosh, Indra Dasgupta arXiv:2605.01271 (2026)

COMPLETE MAGNONIC BAND GAPS IN YIG WITH CU HOLE ARRAYS FOR Z-SHAPED SPIN-WAVE WAVEGUIDING

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Spin waves (SWs) carry and process information with far less Joule heating than moving electrons, making them attractive for energy-efficient circuits. Realizing complex functions such as multi-input logic requires bent waveguides, but conventional ridge-type waveguides formed by etching the magnetic film suffer from severe SW intensity loss at bends because of the nonuniform internal magnetic field, a central obstacle to practical SW circuits.

We designed a two-dimensional magnonic crystal (MC) of a 10-μm-thick yttrium iron garnet (YIG) film and a 2-μm-thick Cu film with a hexagonal hole array, where neighboring holes are connected through thin slits. Unlike our earlier Cu-disk MC on YIG [1], this hole-array design opens a complete magnonic band gap (CMBG). Using the finite integration technique, we obtained a gap of width 15.1 MHz at a center frequency of 1.811 GHz for forward volume spin waves (FVSWs). To our knowledge, this is the first CMBG in a magnetic-garnet 2D MC. A Z-shaped line defect with two 120° turns was introduced into the optimized MC. At the CMBG center frequency, FVSWs launched at the input reached the output through both corners, confined within the defect by the CMBG. A ridge waveguide of the same shape could not transmit SWs, because the inhomogeneous internal field narrows the effective width. Near the output (propagation length of 14 mm), the SW energy of the present waveguide was 5.7×10^3 times greater than that of the ridge waveguide. The approach avoids SW depression and uses an unetched YIG film, offering directional FVSW control toward integrated SW circuits [2].

This work was partly supported by Nos. 20H02593, 23H01439, 23K17758, and JPJSBP120249401 from JSPS, NEDO No. JPNP20004, the Inamori Foundation, and the Amada Foundation.

[1] K. Mori, T. Koguchi, T. Watanabe, Y. Yoshihara, H. Miyashita, D. Grundler, M. Inoue, K. Ishiyama, and T. Goto, *Phys. Rev. Appl.***21**, 014061 (2024).
[2] K. Mori, T. Koguchi, T. Watanabe, H. Miyashita, D. Shabaev, D. Grundler, M. Inoue, K. Ishiyama, and T. Goto, *Phys. Rev. Appl.* **25**, 054067 (2026).

ALTERNATING SPINTRONICS

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This work investigates the time-dependent spin transport in magnetic heterostructures under alternating-current (AC) excitation via a time-dependent spin diffusion framework, revealing a tunable transition between resistive and capacitive impedance in spin valves governed by their magnetic configuration. We demonstrate that spin valves exhibit distinct dynamic responses: the parallel magnetic state maintains dominant resistive behavior, while the antiparallel state displays prominent, nearly pure capacitive response at frequencies where the AC driving timescale matches the spin relaxation time (see figure on the right). This capacitive effect originates from the out-of-phase spin accumulation induced by AC currents, offering a new mechanism for magnetic state readout complementary to conventional magnetoresistance methods.

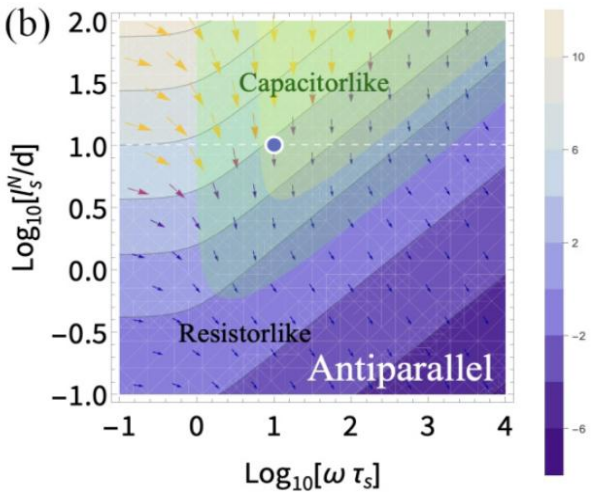

Figure 1. A spin valve in anti-parallel configuration can function as a pure capacitor.

Based on this finding, we propose a novel spintronic device—the spin resonator (see figure below), which functions as a reconfigurable LC resonant circuit without conventional charge-based capacitors. The resonator can be dynamically toggled between an LR damper (parallel magnetization) and a high-frequency LC resonator (antiparallel magnetization) via magnetic configuration switching, with an estimated resonant frequency reaching the terahertz (THz) regime and a decent quality factor for THz applications. Our study bridges the gap between DC-dominated spintronics and high-frequency AC spin dynamics, highlighting the potential of alternating spintronics for compact, tunable THz devices and advanced high-frequency information processing systems.

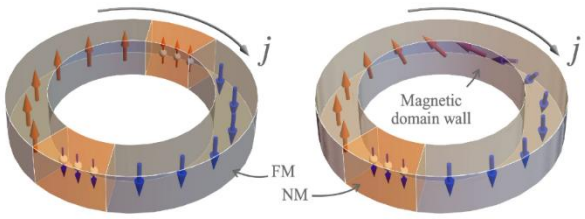

Figure 2. Two constructions of spin resonator.

[1] Liu, Y. & Xiao, J. Alternating spintronics: Capacitive behavior of spin valves and resonator applications. Phys. Rev. B **113**, L020403 (2026).

ORAL SESSION

Soft and Hard Magnetic Materials

Tuesday, 18 August, 14:00 - 15:45

MAGNETIC AND MAGNETOCALORIC PROPERTIES OF RMN_2SI_2 AND RMN_2GE_2 COMPOUNDS

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The ternary RMn_2X_2 (*R* is a rare-earth metal; *X* - Si or Ge) compounds crystalize in the $ThCr_2Si_2$-type (space group *I*4/*mmm*) structure in which each type of the atoms occupy separate layers stacked along the *c*-axis of the tetragonal lattice. In the compounds with magnetic rare-earth metal, the layered structure leads to coexistence and competition of intralayer *R*-*R*, Mn-Mn exchange interactions as well as interlayer *R*-*R*, *R*-Mn, Mn-Mn indirect exchange interactions. As a result, large variety of magnetic structures and magnetic phase transitions can be observed [1].

Detailed neutron diffraction and magnetic studies of RMn_2X_2 compounds revealed the following regularities in the formation of magnetic structures. Magnetic ordering in the Mn sublattice occurs at temperatures of 330-550 K, depending on the type of *R* atom. There exists a critical Mn-Mn distance in the layer, approximately 0.286 nm, above which a structure with antiferromagnetic ordering of Mn moments in the basal plane of each layer (AF*l*) is formed. Below this distance, a canted (AFm*c*) or collinear (AF*il*) structure is formed, with ferromagnetic component of each layer along the *c*-axis, but antiferromagnetic ordering of adjacent Mn layers. For compositions with the Mn-Mn distance above the critical value, when the temperature decreases down to 270-350 K, an antiferromagnetic - canted ferromagnetic (AF*l*-F*mc*) phase transition occurs in the manganese sublattice, which is accompanied by a significant magnetocaloric effect.

The rare-earth sublattice typically becomes ordered at significantly lower temperatures, below 60 K. Due to the *R*-Mn exchange interaction, the ordering of the *R* sublattice can also affect the magnetic structure of the Mn sublattice. The magnetic phase transition associated with disordering of the *R* sublattice can be either first- or second-order. The large magnetocaloric effect accompanying this transition can be used in gas liquefaction systems.

In compounds for which the Mn-Mn distance is close to the critical value, a first-order antiferromagnetic-ferromagnetic (AFm*c*-Fm*c*) phase transition may occur with increasing temperature. This transition is accompanied by an inverse magnetocaloric effect (a decrease in temperature with increasing magnetic field).

We studied magnetic and thermal properties of quasi-ternary compounds $R'_{1-x}R''_xMn_2Si_2$ (*R*', *R*'' = La, Sm, Gd, Tb, Dy, Er). In these systems, substitution of different *R* atoms allows us to change gradually the interatomic distances, interlayer exchange interactions and contributions of *R* and Mn magnetic subsystems to the magnetic anisotropy of the compounds. Field-induced magnetic transitions were studied in high pulsed magnetic fields. The adiabatic temperature change and the isothermal magnetic entropy change were determined by indirect and direct methods. The obtained results show a significant role of the Mn-Mn and *R*-Mn exchange interactions and magnetic anisotropy in magnetic phase transitions and magnetocaloric effects observed in these layered intermetallic compounds.

Support by Russian Science Foundation (project No. 23-12-00265-P) is acknowledged.

[1] A.M. Bartashevich et al., *Mater. Today Phys.*, **59** (2025) 101905.

POLARIZING-MICROSCOPE IMAGING OF ANTIFERROMAGNETIC DOMAINS AND THEIR RESPONSES TO EXTERNAL FIELDS

Kinoshita Y.

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Antiferromagnetic (AFM) domain structures play a central role in magnetoelectric (ME) functionalities of multiferroic materials, yet their direct observation remains challenging due to the absence of net magnetization. We have developed magneto-optical imaging techniques based on a polarizing microscope, including a system operable in magnetic fields up to 14 T [1], enabling real-space visualization of AFM domains and their responses to external electric and magnetic fields. Using this approach, we have investigated AFM domain nucleation and evolution in $(Fe,Zn)_2Mo_3O_8$ [2], a derivative of $Fe_2Mo_3O_8$ exhibiting giant ME responses and multiple field-induced phase transitions [3]. We have also explored related domain behaviors in correlated systems such as the skyrmion-hosting compound $GdRu_2Si_2$ [4].

As a representative example, we spatially resolve the linear ME effect in Cr_2O_3 by directly imaging the electric-field-induced magnetization. Figure 1(a) illustrates the measurement principle. A magneto-optical sensor placed on the sample converts the stray magnetic field into an optical signal via Faraday rotation. When an electric field is applied along the *c* axis, a magnetization $\Delta M = \alpha_{33} E$ is induced, generating a detectable local magnetic field. This enables real-space mapping of the local ME response and AFM domain structure.

Figure 1(b) shows an image obtained at 280 K under an electric field of ±30 kV/cm applied along the *c* axis. The contrast reflects both the sign and magnitude of the stray magnetic field, which corresponds to the linear ME coefficient α_{33}, revealing a multidomain structure with a characteristic size of several hundred micrometers. The contrast disappears above the Néel temperature, confirming its magnetic origin. Furthermore, the single domain structure is observed when electric and magnetic fields are simultaneously applied below the Néel temperature.

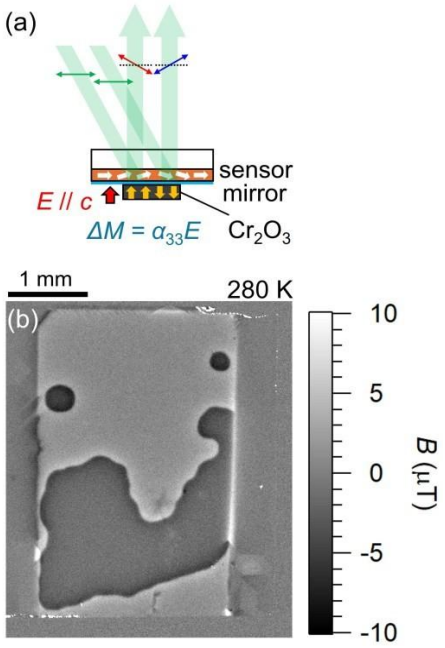

Fig. 1. (a) Schematic of the principle of measurement. (b) the image at 280 K.

These results demonstrate that magneto-optical imaging provides a powerful platform for probing AFM domains and magnetoelectric responses in real space.

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EMERGENT MAGNETIC ORDER AND PHASE TRANSITIONS IN $Co_2Co_{1-X}Fe_X(Bo_3)O_2$ (0.0 < X ≤ 1.0): INSIGHTS FROM EXPERIMENTAL AND DFT STUDY

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Numerous studies have been devoted to the unusual magnetic properties of $Co_3(BO_3)O_2$ and $Co_2Fe(BO_3)O_2$ ([1, 2], for example), but no subsequent study of solid solutions has been presented. The quasi-two-dimensional magnetic structure in the former transforms into a three-dimensional one in the latter, which is accompanied by the appearance of an additional magnetic transition with a Néel temperature T_N = 112 K. The origination of this transition remains open. This issue was addressed in the experimental and theoretical study of the solid solutions $Co_2Co_{1-x}Fe_x(BO_3)O_2$ (0.0 < x ≤ 1.0) with successive substitution of high-spin Fe^{3+} for low-spin Co^{3+}.

Single crystals were grown using flux [3]. The average and local crystal structures were studied using X-ray diffraction and Mössbauer spectroscopy combined with density functional theory calculations. The calculations of the electric field gradient and quadrupole splitting have allowed the assignment the experimental hyperfine structure parameters to the crystallographically nonequivalent iron sites. The calculated quadrupole splittings are QS = 1.81–2.60 mm/s, which is attributed to the Fe^{3+} ions at the Fe1 (2a) and Fe3 (4g) positions; 0.92–1.17 mm/s at the Fe4 (4h) position; and 0.50–0.70 mm/s at the Fe2 (2d) position and are in quantitative agreement with the experimental values. The confined oxygen atoms mainly contribute to the tetragonal distortions of the coordinated octahedra, while the unconfined oxygen atoms are responsible for the covalent effects. The cationic framework is split into two complexes: enriched in iron up to 90% (Fe4–Fe2–Fe4) and depleted in iron by only 10% (Fe3–Fe1–Fe3).

DC magnetization and heat capacity measurements revealed that the solid solutions undergo magnetic phase transitions at T_1 = 48, 66, 82, and 112 K for x = 0.3, 0.5, 0.7, and 1.0, respectively. Additional magnetic transitions are observed upon cooling (T_2). The long-range magnetic order occurs at T_1 and manifests itself as a rather narrow anomaly in $C(T)$, the intensity of which increases with increasing concentration. The amount of magnetic entropy released in the main transition is 70% of the total magnetic entropy for x = 0.0, 84% (0.50), and 97% (1.0). The Fe4 and Fe2 sites are assumed to create additional exchange pathways that contribute the formation of the new magnetic order.

This study was supported by the Russian Science Foundation and Krasnoyarsk Regional Fund of Science and Technology Support, Grant No. 24-12-20012, https://rscf.ru/project/24-12-20012/.

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COMPETITION OF SUPEREXCHANGE INTERACTIONS IN INSULATING MANGANITES: FRUSTRATED "BRICKS" OF MAGNETIC STRUCTURE

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The great variety of magnetic structures of pseudoperovskite rare-earth manganites with the general formula $R_{1-x}A_xMnO_3$, where R^{3+} is a rare-earth ion or Bi^{3+}, A^{2+} is an of alkaline earth ion, and x is the concentration of impurity, includes ferromagnetic, antiferromagnetic, and essentially non-collinear orders [1–4].

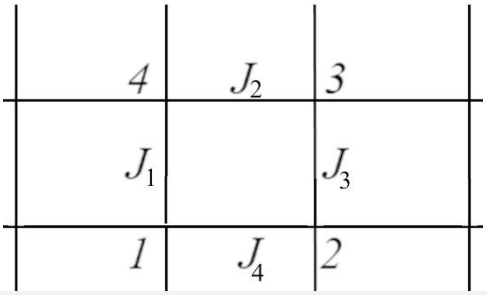

Fig. 1. The magnetic cell square "brick" with competing exchange interactions

The most interesting orderings are magnetic structures with competing exchange interactions that cause magnetic frustration. Equilibrium magnetic ordering depending on the orbital and charge orders in such compounds cannot be established using the Goodenough-Kanamori rules alone [1]. In pseudocubic magnets, such as the compounds under consideration, the frustration state is usually associated with the competition of superexchange interactions between the nearest and next-nearest magnetic neighbours [4]. In overdoped manganites (x=2/3, 3/4, 4/5) and in $BiMnO_3$ at low temperatures, there is a competition of superexchange interactions between the nearest neighbours in the basic plane [5, 6]. Superexchange parameters can take both positive and negative values, depending on the orbital and charge structures.

The main building element of a magnetic cell with competing exchange interactions is a planar square of Mn^{3+} or Mn^{4+} ions (see Fig.1). In charge-ordered overdoped manganites, three superexchange bonds of the square are antiferromagnetic (J_1, J_2, $J_3>0$, $J_4<0$), and one is ferromagnetic. In $BiMnO_3$ crystal, the frustrated "brick" of the magnetic cell contains three ferromagnetic and one antiferromagnetic bond (J_1, J_2, $J_3<0$, $J_4>0$).

The study considers the orbital-dependent mechanisms of the formation of frustrated parts in the magnetic cells of manganites. The magnetic structures of these "bricks" were obtained separately from a large multi-sublattice magnetic cell. The effect of a frustrated fragment on the equilibrium magnetic structure of a manganite crystal depending on the ratios of exchange parameters is shown.

Support by Alfa Future Grants for academic staff – financial support program by Alfa Bank. is acknowledged.

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THE EFFECT OF HYDROGEN ON MAGNETIC PHASE TRANSITIONS IN $R_2Fe_{14}B$ COMPOUNDS

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Intermetallic compounds composed of rare-earth (RE) and 3d transition metals form a broad and technologically important class of materials. Among them, $R_2Fe_{14}B$ compounds are particularly attractive due to their exceptional permanent-magnet properties, including high saturation magnetization and coercivity. The presence of 3d elements ensures high Curie temperatures and strong magnetic moments, while light rare-earth elements such as Nd and Pr provide significant uniaxial magnetocrystalline anisotropy, which is essential for achieving highly coercive magnetic states. The introduction of hydrogen into the crystal lattice of $R_2Fe_{14}B$ compounds, or its spontaneous absorption, leads to substantial modifications of their magnetic properties and has therefore attracted considerable scientific interest.

It is known [1] that $R_2Fe_{14}B$ compounds crystallizing in the $Nd_2Fe_{14}B$-type structure contain several types of interstitial voids capable of accommodating up to 5–5.5 hydrogen atoms per formula unit. During hydrogenation, the crystal structure generally remains preserved, whereas the magnetic structure undergoes significant changes [2]. Hydrogen incorporation influences both spontaneous and magnetic-field-induced spin-reorientation phase transitions [3]. Figure 1 presents the dependence of the spin-reorientation transition temperature in $Gd_2Fe_{14}BH_x$ as a function of hydrogen concentration x. In the parent $Gd_2Fe_{14}B$ compound, no spin-reorientation transition is observed, whereas hydrogenation induces distinct magnetic phase transitions. Based on these studies, magnetic phase diagrams for $R_2Fe_{14}BH_x$ compounds were constructed.

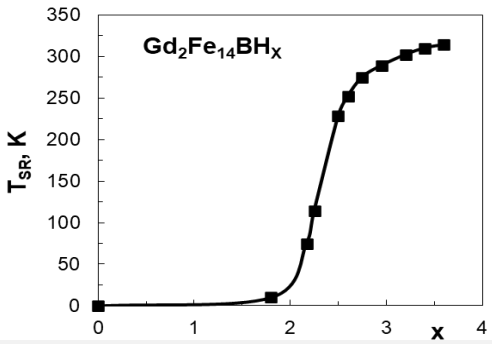

Fig. 1. Spin-reorientation transition temperatures for $Gd_2Fe_{14}BH_x$ versus the hydrogen content x.

The application of high external magnetic fields enabled detailed investigations of spin-reorientation transitions and complete magnetization processes in $R_2Fe_{14}B$ compounds and their hydrides containing heavy rare-earth elements such as Ho, Er, and Tm. It was found that hydrides with higher hydrogen content exhibit magnetic phase transitions at significantly lower magnetic fields compared to the parent compounds.

The study was conducted under the state assignment of Lomonosov Moscow State University.

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ORAL SESSION

Magnetophotonics

Tuesday, 18 August, 14:00 - 15:45

SHAKEN OR STIRRED? ULTRAFAST PHONONIC MANIPULATION OF FERROIC ORDER

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Vibrations of the crystal lattice have a significant impact on the orbital dynamics of the electrons, and through it, on spins. Recently, ultrafast optical techniques have provided new insights into the coherent coupling of individual phonon and spin modes [1]. Ultrafast excitation of phonons resulting in drastic repopulation of phononic system was even shown to be able to modify the fundamental magnetic interactions [2]. And last but not least, very recently time-resolved X-ray scattering and electron diffraction experiments demonstrated the angular momentum transfer from magnetization to the phonon system, on a femtosecond time scale, dubbed ultrafast Einstein-de-Haas effect [3,4]. It should therefore be possible to realize the opposite process, by changing the lattice and thus controlling the magnetization, on the same time scale - in femtoseconds!

We have recently demonstrated how the resonant excitation of circularly-polarized optical phonons in paramagnetic substrates can permanently reverse the magnetic state of the overlayer [5]. With the handedness of the phonons steering the direction of switching, such effect offers a selective and potentially universal method for ultrafast non-local control over magnetic order. The helicity-dependence of the switching implies that the lattice vibrations excited in the substrate deliver a directional field that pushes the magnetization towards a switched or non-switched state. The nature of such field is however completely unknown at present.

Moreover, a different and ultimately universal behaviour, characterized by displacive modification of crystal potentials, is driven by linearly-polarized excitation. The magnetic switching was shown to create very peculiar quadrupolar spatial patterns [6], confirming the mechanism. The mechanism appears to be very universal, as observed in variety of systems [7]. The dynamics of the domain formation was shown to proceed via a strongly inhomogeneous magnetic state resulting in a self-organization of magnon-polarons [8] and formation of magneto-elastic solitons.

I thank the technical staff at FELIX for providing technical support. I also acknowledge support from the European Research Council ERC Grant Agreement No. 101141740 (INTERPHON)..

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TERAHERTZ COHERENT MAGNONICS IN ANTIFERROMAGNETS

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Magnonics aims to employ quanta of spin waves, magnons, to carry, transport and process information, avoiding the dissipation of energy inherent to electronics. Experiments on magnons in regular (ferro)magnets have yielded demonstrations of basic logic devices, albeit macroscopic (mm-scale) in size and operating at GHz frequencies. Recently, the spotlight has shifted towards the use of antiferromagnets, in which neighbouring spins are aligned antiparallel to each other. This alternating order leads to significantly higher spin wave propagation velocities and might enable devices operating at terahertz (trillion of hertz) clock-rates. However, the absence of the net magnetisation also makes antiferromagnets magnetically 'invisible': it is very hard to detect and influence the antiferromagnetic order. Yet, in some antiferromagnets strong spin–orbit coupling results in canting of the spins, thereby producing net magnetization. The canted antiferromagnets combine antiferromagnetic order with phenomena typical for ferromagnets and hold a great potential for spintronics and magnonics. In this way they can be identified as closely related to the recently proposed novel class of magnetic materials, called altermagnets. In my talk I will discuss a new functionality of canted antiferromagnets and altermagnets for magnonics and show that these materials facilitate mechanisms allowing to generate, detect and convert propagating magnons at the nanoscale [1-4].

Support by EPSRC Grant UKRI1237; Department for Science, Innovation and Technology and Royal Academy of Engineering under Green Future Fellowships scheme, grant agreement GFF2425-1B-129 is acknowledged.

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PLASMON-INDUCED HOT-ELECTRON INJECTION IN AU-BI:YIG METASURFACE

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Plasmon-induced hot-electron injection is an ultrafast interfacial charge-transfer process in which photoexcited carriers generated by plasmon decay in a metal acquire enough excess energy to cross the metal-semiconductor or metal-dielectric barrier before thermalization, thereby transiently modifying the electronic population and dielectric response of the adjacent medium. In multiresonant systems, however, the transient optical response usually contains overlapping contributions from several nonequilibrium processes, which makes the signature of this interfacial transfer difficult to disentangle. The present work addresses this problem for a multiresonant Au-Bi:YIG metasurface and shows that the joint analysis of plasmonic and waveguide resonances makes it possible to isolate the signature of plasmon-induced hot-electron injection across the metal-dielectric interface. We develop and apply a mode-resolved modeling framework that combines an extended two-temperature model with spectral decomposition of resonant modes, enabling us to separate an interface-specific contribution to the ultrafast response of a metasurface. A hybrid magnetoplasmonic metasurface is a two-dimensional square array of gold nanospheres embedded in a Bi:YIG layer, that supports both lattice resonances and waveguide modes in the visible range.

Using pump-probe time-resolved spectra as an input to the model, we reconstruct the dynamics of nonthermal electrons, thermalized hot electrons, and phonons in gold, and map these quantities onto the amplitudes and spectral positions of surface lattice and quasi-waveguide resonances. To separate these contributions, the transient response near the plasmonic resonances was first analyzed within an extended two-temperature model including nonthermal electrons, thermalized hot electrons, and phonons in gold. This analysis reproduces the dynamics of the quadrupole and dipole surface lattice resonances and yields electron temperatures up to about 1100 K and phonon temperatures up to about 340 K under the chosen excitation conditions. The same set of gold-related dynamics, however, fails to account for the temporal evolution of the quasi-waveguide resonances unless an additional exponentially decaying contribution with a characteristic time of about 7 ps is introduced. Because this slower component is absent in a reference Bi:YIG film and is not consistent with known relaxation channels confined solely to the gold nanoparticles or the garnet layer, it is attributed to an interfacial process at the Au-Bi:YIG boundary. The interfacial charge transfer transiently modifies the local dielectric environment and becomes especially visible through the dynamics of the quasi-waveguide modes, whose electromagnetic field is concentrated predominantly in the dielectric region.

This work was financially supported by Russian Science Foundation, project No. 24-12-00210.

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PINNING OF MAGNETIC DOMAIN STRUCTURE IN IRON GARNET FILMS

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Studies of different types of domains in rare-earth garnet films are continuously a subject of high interest due to the important role played by domain structure in functioning of magnetic and magneto-optical devices [1]. In spite of intense research carried out in this field, some important issues remain to be less studied. Among those are the structure and arrangement of (surface) closure domains, as well as the development of pinning mechanisms of surface and bulk domains by artificial magnetic metasurfaces. Such studies require, on the one hand, non-invasive and highly surface sensitive probes, and precise composition of the pinning nanostructures on the other. Here we describe our recent studies in this research field. Our experimental approach is based on the combination of linear and nonlinear magneto-optical (MO) microscopy techniques in transmission geometry to visualize both bulk and interface magnetic structures.

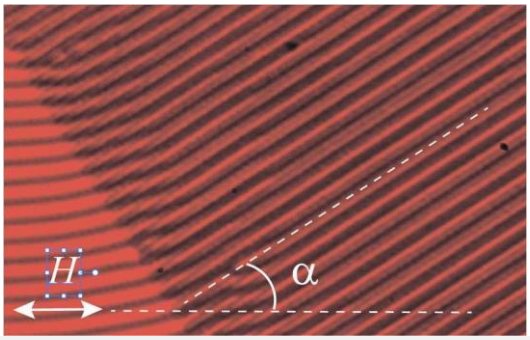

Fig. 1. Optical image of the garnet layer with the surface grating (right part of the image) after the sample was magnetized by dc magnetic field H applied at α=33º to the stripes of the grating.

Two types of structures were analyzed: (i) 2D arrays of Co/Au or $(Co/Pt)_n$ particles and (ii) 1D gratings of the same composition with different periods; such metasurfaces were formed on the surface of BiLu-substituted epitaxial garnet layers by electron beam lithography of magnetic metallic films deposited by magnetron sputtering. The periods of the structures were chosen to be close to the domains' sizes of each sample. with respect to the gratings' stripes and then switched off; (ii) the appearance of a plateau in the dependence of the period of domain structure on H – that is nearly absent in the case of a pristine garnet film. Similar effects were observed in the case of a rectangular lattice of magnetic nanoparticles formed on the surface of the garnet film [2].

Domain wall pinning was revealed through (i) alignment of stripe domains of garnet close to the ferromagnetic gratings; Fig. 1 shows the MO image of a 5 μm thick garnet film partially covered by a CoAu grating with the period of 2.5 μm after the magnetic field was applied at the angle of 33 º

Moreover, formation and pinning of lattices of magnetic bubble domains in such garnet-based structures were studied as well, and the control over them in the presence of metal magnetic metasurfaces was demonstrated. These findings are promising for improving the stability of garnet-based magneto-optical devices.

Support by Russian Science Foundation, grant № 26-12-00150 https://rscf.ru/en/project/26-1200150/ is acknowledged.

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OXIDIZED PERMALLOY NANOFILM AS A GASOGYROCHROMIC MATERIAL

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The development of hydrogen energy technologies has heightened the importance of safety monitoring. In this context, optical hydrogen sensors offer significant advantages, including intrinsic safety, room-temperature operation, and the potential for enhanced sensitivity through utilizing optical resonances in a chosen spectral range ~~resonant structures~~. Such sensors typically employ gasochromic materials combined with catalytic metals, whose optical properties change upon exposure to the target gas [1]. In the case of the H_2 influence on the magneto-optical (MO) properties of a material, detection becomes possible through measurements of the light polarization state. This approach can consider not only the Faraday or Kerr effects [2] but also magnetic circular dichroism [3]. A particularly promising direction in photonics is the investigation of magnetic oxides as a gas-sensitive media.

In our work, we investigate the magneto-optical properties of oxidized permalloy ($Ni_{80}Fe_{20}$) nanofilms with an initial thickness of 20 nm. The dependence of their physical properties on annealing temperature has been thoroughly examined in Ref. 4. Notable, annealing at 425 °C resulted in an increase of the Faraday rotation angle (AFR) by more than an order of magnitude in the near-infrared range. To evaluate hydrogen sensitivity, a 5-nm-thick Pt layer was deposited onto the oxidized permalloy nanofilm exhibited the strongest MO response ($NiFeO_x$). Figure 1 shows that exposure to 0.5 vol.% H_2 in N_2 induces a change in both the AFR and magnetic circular dichroism (MCD) of $NiFeO_x$/Pt. The maximum changes amounted to 0.05° at 1000 nm (AFR) and 0.15° at 1500 nm (MCD). Additionally, the sample transmittance changed by 0.07 for λ = 1500 nm. It is worth noting that the MO response of both the as-deposited NiFe/Pt film and $NiFeO_x$ sample without a Pt layer remained unchanged upon hydrogen exposure.

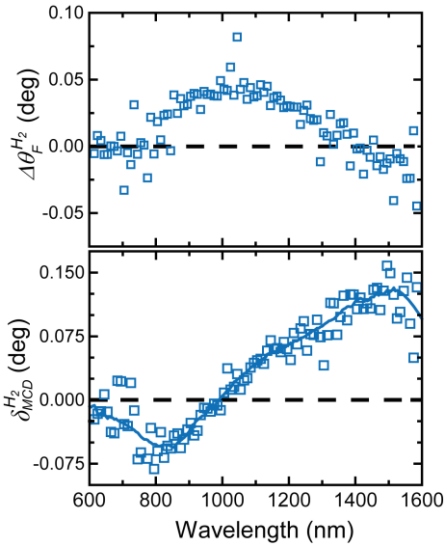

Fig. 1. H_2-induced change of AFR and MCD of $NiFeO_x$/Pd.

Multipass measurements of the $NiFeO_x$/Pt AFR confirmed the non-reciprocal nature of the observed effect: the hydrogen-induced change in the MO response multiplied when the light passes through the sample several times. This phenomenon is attributed to alterations in the oxygen environment of magnetic ions within the oxides of metals that compose NiFe alloy, driven by redox reaction in H_2. To the best of our knowledge, our work presents the first demonstration of the gasogyrochromic effect–the H_2-induced changes in the MO properties of magnetic oxides.

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ORAL SESSION

Multiferroics

Tuesday, 18 August, 14:00 - 15:45

MAGNETOELECTRICITY AS AN EDGE EFFECT: EMERGENT PHENOMENA AT DOMAIN WALLS AND INTERFACES

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It is well known that the diversity of life is greatly enhanced at the boundary between two distinct zones. Similar wisdom in physics was coined by Nobel Laureate Herbert Kroemer: “the interface is the device”, i.e. the boundary between two phases has physical properties that each of the distinct phases is lacking.

In this report we consider the manifestation of inhomogeneous magnetoelectric interaction on two types of boundaries: magnetic domain walls as “mobile interfaces” and crystal edges as a stationary structural interface.

Recently several groups have reported the giant magnetoelectric effect observed at the domain boundaries of iron garnet films [1-3]: the domain wall movement in the gradient electric field provided by tip electrode touching the surface of the sample [1,2] or the transformation of its shape (“refraction”) [4] in the electric field of stripe electrode deposited on the surface [4]. These phenomena are ascribed to inhomogeneous magnetoelectric interaction. It is proportional to the spatial derivatives of magnetization and electric field, i.e. it implies the emergence of Coulomb interaction between the electrode (as a source of electric field) and the domain wall (as a transient zone with the spatial modulation of magnetization).

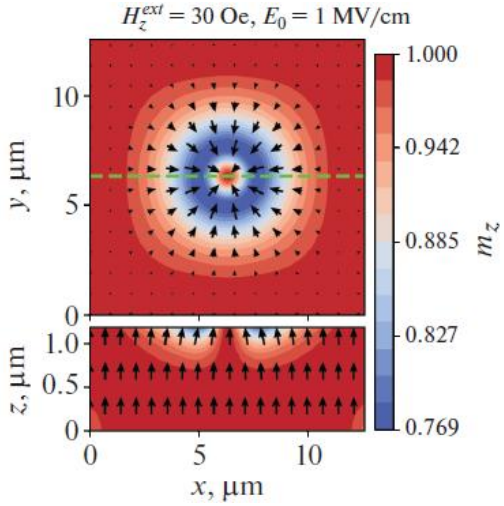

Fig. 1. The electric field-induced micromagnetic configuration at the edge of the magnetic crystal (the source of electric field of E_0 = 1 MV/cm is a point charge, the initial magnetization distribution was homogeneous).

The effect of static electric field on the homogeneous magnetization distribution is less evident although it becomes possible at the edge of magnetic crystal. Indeed, the conventional boundary condition in micromagnetism implies that the spatial derivative of magnetization along the normal to the interface is zero. In this report we propose the modified boundary condition with the additional term proportional to electric field, and the constant of inhomogeneous magnetoelectric interaction. This term manifests itself in the formation of electric field-induced skyrmion-like structures (Fig.1) from the initial homogeneous magnetization distribution.

Support by Russian Science Foundation (Grant No. 25-79-30019) is acknowledged.

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ULTRAFAST MAGNETO-ELECTRICITY AND OPTO-MAGNETO-ELECTRIC RECORDING

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Ultrafast magnetism explores spin dynamics and eventually spin switching in magnets excited by ultrashort (sub-100 ps) stimuli [1]. Progress in the field is predominantly driven by experimental research, where ultrafast spin dynamics is typically triggered by femtosecond laser pulses and investigated as a function of parameters of laser excitation, temperature and magnetic field. Here, we show that also electric field, whose effect on magnets is often ignored, can have a substantial effect on ultrafast spin dynamics and result in spin switching, in particular.

First, we demonstrate the impact of an electric field on laser-induced magnetization dynamics in ferrimagnetic iron garnet $(BiLu)_3(FeGa)_5O_{12}$. For the experiments we employed epitaxially grown iron garnet film on $Gd_3Ga_5O_{12}$ substrate with (110)-orientation [2,3]. Applying an E-field of 0.5 MV/m, we observe remarkable changes in oscillations amplitude, frequency and damping (Fig. 1a). Additionally, depending on magnitude of magnetic field B, the application of E-field decreases the damping of magnetic oscillations up to 1.5 times.

In the second experiment, we employed antiferromagnetic (AFM) crystal of Cr_2O_3, which is known to be an archetypal magneto-electric material [4]. Particularly, its magnetic state could be defined by the dot product of electric and magnetic fields **E·B**. We used the fact to manipulate AFM domain wall in c-cut crystal of Cr_2O_3 with thickness of 0.5 mm. In the experiments, we applied uniform B-field and localized E-field in the vicinity of the AFM domain wall. As a result, the direction of wall motion and covered distance depend on the sign and magnitude of **E·B** (Fig. 1 b,c). Furthermore, we established the combination of **E·B** and sample temperature for robust

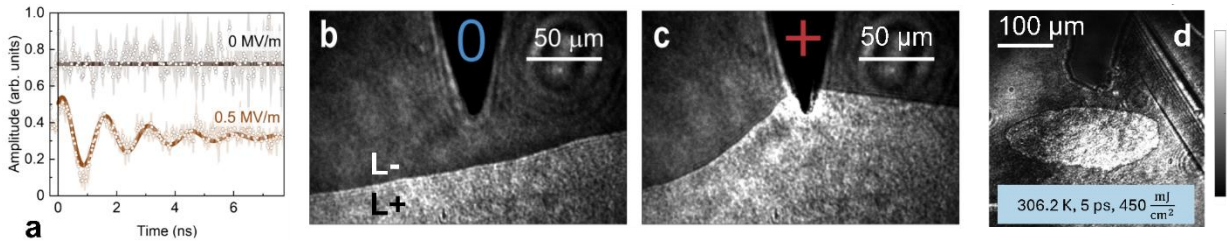

Fig. 1. (a) Laser-induced spin dynamics detected via the magneto-optical Faraday effect in electrically gated $(BiLu)_3(FeGa)_5O_{12}$. (b,c) Antiferromagnetic domains in Cr_2O_3 visualized with the help of second harmonic generation (SHG). A combination of electric and magnetic fields can cause a displacement of the domain wall. (d) Single-shot optical writing of AFM bit in Cr_2O_3 in a combination of uniform B-field and localized E-field.

writing of antiferromagnetic patterns with a single laser pulse (Fig. 1 d) [5].

The series of experiments opens new chapters in the research areas targeting to reveal novel principles for the fastest and most-energy-efficient information processing—ultrafast magnetism, antiferromagnetic spintronics, and THz magnonics.

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SPIN-FLOP DYNAMICS IN METALLIC ANTIFERROMAGNETS

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Antiferromagnetic materials have recently become a focus of intense research activity due to their potential for ultrafast and high-density spintronic applications. Among conducting antiferromagnets, CuMnAs and Mn_2Au stand out for their high Néel temperatures (~480 K and ~1351 K, respectively), excellent conductivity, and demonstrated capability for current-induced switching of antiferromagnetic order [1].

In this report, we investigate the spin dynamics in these materials to uncover the features that distinguish them from conventional antiferromagnets and to reveal the physical mechanisms responsible for the novel effects.

One interesting manifestation of spin dynamics in metallic antiferromagnets is the magnetogalvanic effect, which arises under the application of an alternating magnetic field $\boldsymbol{H}(t)$. This effect is related to the symmetry - allowed electrical polarization induced by an external magnetic field in tetragonal antiferromagnets, which in turn give rise to an electrical current.

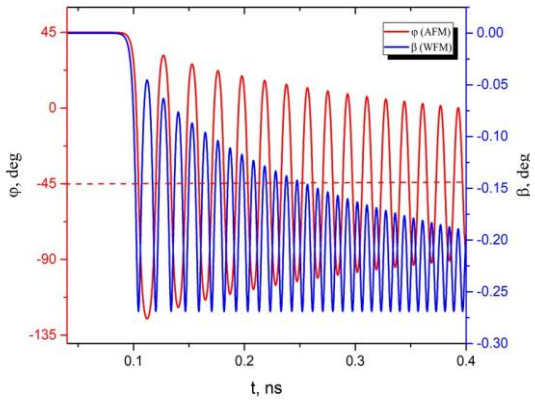

Fig. 1. Time dependences of the angles φ and β that determine the positions of antiferromagnetic vector and net magnetization after the spin – flop transition

Another key phenomenon we investigate is the spin-flop transition in the metallic antiferromagnets CuMnAs and Mn_2Au. We show that crossing the spin-flop threshold triggers coherent terahertz oscillations of the Néel vector and the induced magnetization (Fig.1). The oscillation frequencies depend on the material parameters, the external magnetic field, its amplitude and the sweep rate. In accordance with the magnetoelectric concept [2], in materials with broken spatial inversion and time-reversal symmetries, this dynamics generates a magnetogalvanic current that directly reflects the Néel vector dynamics.

We show that the resulting terahertz current reaches nA–μA amplitudes under realistic conditions. These results establish the spin-flop transition as a mechanism for tunable terahertz current generation and electrical readout of antiferromagnetic order.

Z.V.G. acknowledges the support by the Ministry of Science and Higher Education of the Russian Federation (state assignment for the implementation of scientific research by laboratories, order No. 075-03-2024-123/1 on 15 February 2024).

P. Wadley et al., *Science*, **351** (2016) 587.

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MAGNETOELECTRIC EFFECT IN COMPOSITE STRUCTURES BASED ON MONOCRYSTALLINE PIEZOELECTRICS

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Magnetoelectric (ME) effects in composite layered ferromagnetic-piezoelectric (FM-PE) heterostructures arise as a result of the combination of magnetostriction and piezoelectricity due to mechanical coupling between the layers. The effects manifest as a mutual transformation of magnetic and electric fields. Such structures are primarily promising for the creation of new highly sensitive dc and ac magnetic field sensors, controlled devices of passive and microwave electronics, new memory elements and low-power energy harvesters [1]. Traditionally, PE layers are made from various types of ceramics, such as lead zirconate titanate. However, in recent years, there has been significant progress in the study of ME effects in composite structures based on monocrystalline piezoelectrics [2]. The most promising and interesting crystalline materials include magnesium niobate-lead titanate, lithium niobate, langatate, quartz, and various piezoelectric semiconductors.

The use of piezoelectric crystals allows for increased efficiency in field conversion in heterostructures. Unlike ceramics, crystals have several times higher piezoelectric modulus to dielectric constant ratio and an order of magnitude higher acoustic quality factor. This made it possible to achieve record values of the ME coefficients: $\alpha_E \approx 12500$ V/(Oe·cm) for structures with PMN-PT, 5600 V/(Oe·cm) for structures with quartz, 1710 V/(Oe·cm) for structures with lithium niobate and 710 V/(Oe·cm) for structure with langatate. It is also possible to use crystallographic anisotropy to control the parameters of ME effects, extend the operating temperature range of ME heterostructures, improve the performance of existing devices, and develop new types of ME devices.

The report was prepared based on an analysis of the results from studies on ME effects in heterostructures with monocrystalline PE layers. It discusses the main types of piezocrystals and the applications of ME effects in these structures. Promising areas of research on ME effects in single crystal structures are also formulated, taking into account the advantages and disadvantages of using single crystals in ME structures.

Support by Ministry of Science and Higher Education of the Rusian Federation (Project No. FSFZ-2026-0003).

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MAGNETOSTRICTIVE FIBER COMPOSITES: FUBRICATION, PROPERTIES AND APPLICATIONS

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Improvements in the performance of magnetic devices are largely due to the development of new magnetic materials with enhanced properties. Recently, a new type of material has been proposed and manufactured: magnetostrictive fiber composites (MFCs), which hold promise for applications in magnetic field sensors and actuators [1]. MFCs are arrays of magnetostrictive ferromagnetic (FM) fibers arranged parallel to one another in a single layer within a polymer matrix or on a dielectric substrate. Fibers are made from metals (Ni, Co) or amorphous Fe-containing alloys such as Metglas with high magnetostriction (MS). Typical fiber diameters range from tens to hundreds of micrometers, and lengths range from a few to tens of millimeters.

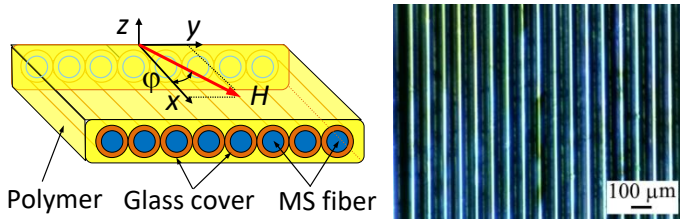

Fig. 1. Schematic and appearance of MFC with Ni fibers.

MFCs are produced by embedding a set of fibers in adhesive matrix (Fig.1), laminating them between two polymer films, etching a FM film on a substrate [2], or by laser cutting a thin FM tape. A distinctive feature of MFCs is a strong in-plane aniso-tropy of magnetic properties, arising from the anisotropy of demagnetization along and across the fiber's length (Fig. 2). The anisotropy of the MFCs properties can be controlled by varying the distance between the fibers. The use of piezoelectric substrates allows the creation of flexible structures based on the MFCs that exhibit a magnetoelectric effect, that is a mutual conversion of magnetic and electric fields [3]. Such structures can find application in magnetic field sensors, sensitive to magnetic field orientation, in magnetically controlled actuators, and in multifunctional electronic and micro system devices tunable by magnetic and electric fields [4].

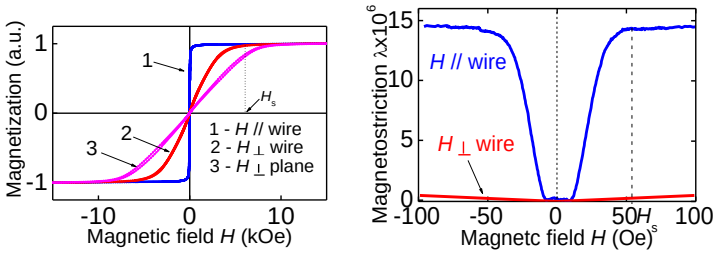

Fig. 2. Schematic and appearance of MFC with FeBSiC fibers.

This work was supported by the Russian Science Foundation, grant № 25-29-00264.

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ORAL SESSION

Magnetic Soft Matter (magnetic polymers, complex magnetic fluids and suspensions)

Tuesday, 18 August, 16:00 - 18:00

MAGNETOACTIVE POLYMER MATERIALS FOR 3D-PRINTED SOFT ROBOTS

Bakanov K.K. [1], *Olenich E. A.* [1], *Gorodov V.V.* [1], *Kostrov S.A.* [2], *Milenin S.A.* [1], *Zou J.* [3,4], *Kramarenko E.Yu.*[1,5]

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The rapid evolution of soft robotics has opened new horizons in creating devices that can safely interact with humans and adapt to unstructured environments. Unlike their rigid counterparts, soft robots made from compliant materials excel in mimicking biological movements and performing delicate tasks in medical, exploration, and rescue applications. Their functionality fundamentally relies on actuation mechanisms, with magnetic actuation emerging as a highly promising approach due to its wireless control and rapid response capabilities. However, widespread adoption is currently hindered by manufacturing limitations. Most existing functional soft materials are based on silicone rubbers or polydimethylsiloxane (PDMS), which are typically processed via mold casting. While effective for simple geometries, this method struggles with complex, multi-material architectures and lacks the design freedom required for advanced robotic systems. Furthermore, silicone-based materials are inherently challenging to process via 3D printing, often yielding poor resolution and limited structural integrity. To overcome these limitations, we propose novel thermoplastic polyurethane-siloxane (TPU-S) matrices as a host medium for dispersing magnetoactive fillers [1,2]. This work systematically explores the relationships between magnetic filler composition, polymer matrix architecture, and the resulting magneto-mechanical performance. By shifting the paradigm from castable silicones to printable thermoplastic composites, we demonstrate that carefully engineered magnetoactive polymers enable the fabrication of complex, wirelessly controlled soft robotic devices. This presentation highlights the potential of tailored thermoplastic materials to unlock new functionalities in soft robotics through advanced additive manufacturing techniques.

[1] E.A. Olenich, V.V. Gorodov, N.V. Demchenko, U.S. Andropova, K.K. Bakanov, A.E. Krupnin, I.O. Kuchkina, S.A. Kostrov, S.A. Milenin, S.N. Chvalun, J. Zou, E.Y. Kramarenko, *Chinese J. Polym. Sci.*, **43** (2025), 2325–2334.
[2] K.K. Bakanov, S.N. Ardabevskaia, K.A. Bezlepkina, K.S. Klokova, A.E. Krupnin, A.I. Buzin, D.A. Khanin, S.A. Kostrov, A.V. Bakirov, F.V. Drozdov, S.N. Chvalun, A.M. Muzafarov, Jun Zou, E.Yu. Kramarenko, S.A. Milenin. *Reactive and Functional Polymers*, **202** (2024) 106005.

AGGREGATE STRUCTURE EFFECTS ON THE DYNAMIC MAGNETIC SUSCEPTIBILITY OF MAGNETOACTIVE COMPOSITES

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Magnetoactive composites are materials in which magnetic nanoparticles (MNPs) are embedded in a soft nonmagnetic matrix. These systems attract significant attention because their properties can be remotely controlled by external magnetic fields, making them promising for applications in sensing, soft robotics, and biomedicine. Recent advances in synthesis techniques enable the fabrication of composites with a wide variety of internal structures. Common approaches involve dispersing MNPs in polymer solutions followed by polymerization or matrix curing. In addition, methods based on doctor-blade technology and 3D printing provide further opportunities for controlling the spatial distribution and aggregation state of MNPs within the composite. Thus, synthesis protocols enable controlled tuning of the internal organization of MNPs inside magnetoactive materials.

The response of magnetoactive composites to external magnetic fields is determined by the reorientation of MNP magnetic moments. In contrast to ferrofluids, where particles can freely rotate and translate throughout the liquid medium, MNPs embedded in a polymer matrix are immobilized by the surrounding material. Under these conditions, the magnetic response is mainly governed by the Néel relaxation mechanism, in which the magnetic moment changes its orientation inside the particle itself. An important characteristic describing the response of such systems to alternating magnetic fields is the dynamic magnetic susceptibility. This characteristic depends not only on the properties of individual MNPs, but also on collective effects arising from dipole–dipole interactions and the spatial organization of MNPs inside the composite.

In this work, we investigate the dynamic magnetic susceptibility of immobilized MNP ensembles with different aggregate morphologies formed either artificially or through self-assembly caused by dipole–dipole interactions. Molecular dynamics simulations were performed to analyze the influence of magnetic anisotropy, dipole–dipole interaction strength, and aggregate structure on the spectra of dynamic susceptibility. The results demonstrate that strong dipole–dipole interactions and aggregate formation increase the separation between characteristic times associated with interwell and intrawell magnetic moment relaxation processes. As a consequence, these processes occur on substantially different time scales, leading to the appearance of a pronounced two-peak structure in the imaginary part of the dynamic susceptibility. The study also identified characteristic aggregate configurations that enhance the dynamic magnetic susceptibility. These findings establish structure–property relationships that can be used to tailor the magnetic response of magnetoactive composites through controlled aggregate formation.

The research was supported by the Russian Science Foundation, Grant No. 23-12-00039-П, https://rscf.ru/project/23-12-00039-П/.

RHEOLOGICAL BEHAVIOR OF CONCENTRATED MAGNETIC SUSPENSIONS SUBMITTED TO AN OSCILLATING SHEAR FLOW

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A discontinuous shear viscosity transition (DST) has been observed in suspensions of iron carbonyl (Cl) particles in ethylene glycol, for sufficiently high volume fractions, generally above 60%. The viscosity jump resulting from this transition can be controlled by applying a weak magnetic field, thus significantly improving the efficiency of magnetorheological (MR) fluids. Here, we present the effect of the magnetic field on the DST transition in the oscillatory regime. We present the results for the conservation modulus G' and the loss modulus G" and show that the modulus variation induced by the field, triggering the DST transition, is much greater than that induced by the magnetic field alone, as is the case in a conventional magnetorheological fluid. We also observe that the critical stress depends on the flow oscillation frequency and the mode of magnetic field application to the suspension. A qualitative explanation is proposed, based on the decrease in the critical strain amplitude, which becomes less than unity for frequencies above 5 Hz. Each particle then oscillates within the cage formed by its neighbors, which reduces the collision frequency and therefore the viscosity. Conversely, at low frequencies, the critical strain is significantly greater than unity, leading to a substantial structural rearrangement of the particles during oscillation. This interpretation is confirmed by the simultaneous measurement of the suspension's magnetic permeability and hydrodynamic stress.

MAGNETOMECHANICAL PROPERTIES OF SOFT MAGNETOACTIVE ELASTOMER COMPOSITES

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Magnetoactive elastomers (MAEs) are promising materials for various applications requiring controlled changes in mechanical properties under the influence of a magnetic field. Understanding the magnetomechanical behavior of MAEs is necessary to optimize their characteristics, particularly their shear modulus (see, for example, Kostrov et al. [1]). The aim of this work is to develop a microscopic model to describe the elastic properties of soft MAEs, taking into account the formation of chains of magnetic particles under the influence of an external magnetic field (an illustration of the model is presented in Figure 1). A theoretical model based on a lattice approach and a hierarchical principle of particle aggregation into chains has been developed. Isotropic and anisotropic MAEs are considered. An analysis of the dependence of the shear modulus on the magnetic field and shear deformation was carried out. Analytical expressions for the shear modulus of MAEs depending on the material parameters and external influences were obtained. It is shown that anisotropic MAEs have higher elastic characteristics compared to isotropic ones.

The theoretical results are in good agreement with experimental data, which confirms the adequacy of the proposed model. The developed model allows us to adequately describe the magnetomechanical behavior of soft MAEs. The formation of chains of magnetic particles plays a key role in determining the elastic properties of MAEs. Anisotropic MAEs are of greater interest for practical applications due to their improved mechanical characteristics.

Authors are grateful to Ministry of Science and Education of the Russian Federation, program FEUZ 2026-0016.

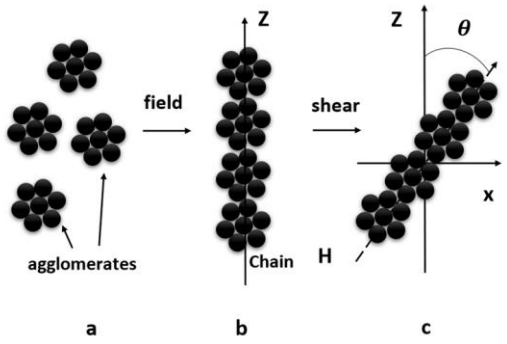

Fig. 1. Illustration of the simulated system.

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BENDING OF MAGNETIC ELASTOMER RODS WITH A NONLINEAR MAGNETIZATION LAW

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This work deals with mutual experimental and theoretical study of bending of a magnetopolymer cylindrical cantilever, placed on a horizontal substrate in a vertical magnetic field. This system presents a simplest model of various soft magnetic actuators, artificial muscles and other high-tech devices. One end of the sample was rigidly fixed, while the other one was free. Under the action of the field, the rod bended upward. Experiments show that the bending starts only when the magnetic field exceeds a certain critical value, which depends of the shape, as well as magnetic and mechanical properties of the sample. Relatively soft and rigid cantilevers qualitatively differently react to the field. The soft ones exhibit an abrupt transition to a maximal bent state with a wide hysteresis loop when the field decreases. The stiffer samples demonstrate smaller deformation jumps followed by gradual bending at the field increase and narrow hysteresis when the field decreases.

The proposed theoretical model of this effect is based on an analysis of energy of initially horizontal soft magnetizable cylindrical rod, deformed under a vertical magnetic field. This energy consists of the elastic, gravitational and magnetic parts, including the demagnetizing shape effects. The magnetic part is estimated beyond the approximation of the linear magnetization. The total cantilever energy is considered as a functional of a deformation function. Analysis shows that, because of the gravity, the spontaneous deformation cannot occur in a totally uniform magnetic field; some vertical gradient of the field, providing ponderomotive magnetic force, exceeding the gravitational one, is necessary for the spontaneous deformation.

Minimization the energy functional with respect to the rod bending leads to a nonlinear fourth-order differential equation with respect to the deformation function. The corresponding boundary conditions follow from the clamped-free geometry of the sample.

Since an analytical solution of this problem is generally impossible, the governing equation was solved numerically. The proposed model qualitatively reproduces the experimentally observed distinction between soft rods with wide hysteresis and rigid rods with the narrow hysteresis.

Thus, the model provides an adequate description of magnetically induced bending of elastomer rods and can be used for analysis and design of magneto-responsive soft elements.

This work has been supported by the Ministry of Science and Higher Education of the Russian Federation (topic no. FEUZ-2026-0016).

ORAL SESSION

Heusler alloys and phase transitions

Tuesday, 18 August, 16:00 - 18:00

THIRTY YEARS OF MAGNETIC SHAPE MEMORY EFFECT IN HEUSLER ALLOYS: HISTORY, CURRENT STATE, PROSPECTS

Buchelnikov V.D.[1], *Khovaylo V.*[2], *Koledov V.V.*[3], *Kamantsev A.P.*[3], *Mashirov A.V.*[3], *Vasiliev A.N.*[4]

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Thirty years have passed since the discovery of large magnetic field-induced straines in Ni_2MnGa single crystals, which were subsequently termed the magnetic shape memory effect A more thorough retrospective analysis reveals a connection with the works of Kurdyumov, Sadovsky, Webster and Zeebeck, among others. The work [1] generated enormous interest, in subsequent years, and led to numerous outstanding physical studies and practical developments worldwide, both in the study of giant magnetically induced straines under the influence of a magnetic field in single crystals and in the study of magnetically induced thermoelastic martensitic transitions and the shape memory effect in polycrystalline Heusler alloys. This work went hand in hand with the study of the giant magnetocaloric effect in a wide range of materials, including Heusler alloys.

Why, despite such remarkable achievements, have all attempts to introduce magnetic shape memory into technology so far met with limited success, perheps only in biomedical technology? Both giant effects require rather expensive technical solutions: the first requires perfect singlecrystal alloys, while the second requires the application of strong magnetic fields exceeding 2 T, which are easily achievable not only in the laboratory but also in practice.

To overcome these obstacles, extensive research currently continues worldwide on ferromagnetic Heusler and related alloys, in which field-inducrd phase transitions are accompanied by giant effects of shape and entropy changes. In recent years, a new trend has emerged toward studying multicomponent, so-called high-entropy alloys, such as alloys composed entirely of transition metals. Figure 1 illustrates the shape memory effect in *all-d* metal ferromagnetic shape memory Heusler alloy, Ni-Co-Mn-Ti melt spun ribbon.

Support by state task of Kotelnikov IRE RAS is acknowledged.

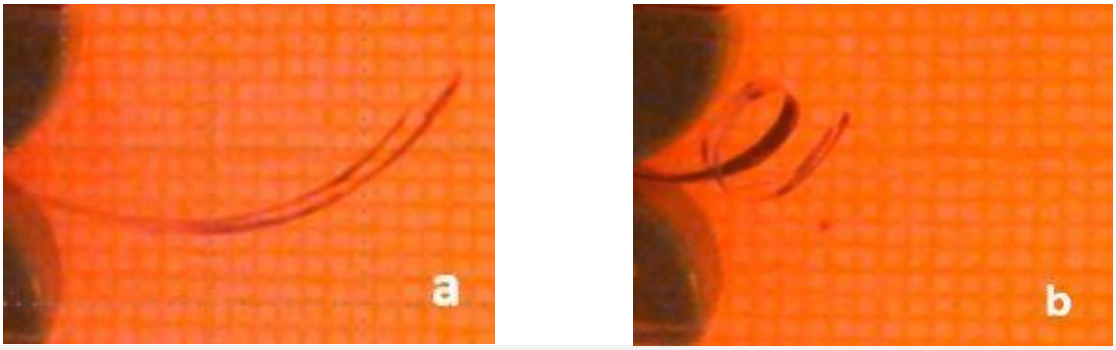

Fig. 1. Shape memory effect in *all-d* ferromagnetic shape memory alloy $Ni_{36.5}Co_{13.5}Mn_{35}Ti_{15}$ melt spun ribbon: (a) sample is in austenitic phase (T = 250 K), (b) in martesite (T = 190 K).

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HALF-METALLIC, SPIN-GAPLESS SEMICONDUCTING AND TOPOLOGICAL HEUSLER COMPOUNDS - NEW QUANTUM MATERIALS FOR SPINTRONICS AND ULTRA-FAST ELECTRONICS

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Institute of Metal Physics, UB RAS, Ekaterinburg, Russia

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The design, synthesis, and study of physical properties of new quantum materials are of great fundamental and applied interest. Spintronic, micro- and nanoelectronic devices require new electronic and magnetic materials whose charge carriers have high spin polarization and mobility and can be easily controlled by external influences [1-3]. Examples of such systems are Heusler compounds where half-metallic ferromagnet (HMF), spin-gapless semiconductor (SGS), and topological semimetal (TSM) states can be realized [4-9].

We present a review of theoretical, first-principles and experimental investigations of the band structure, electronic and magnetic properties of HMF, SGS and TSM Heusler and related compounds. These materials can have unusual electronic properties, such as a large anomalous Hall effect, spin Hall effect, spin Nernst effect, thermal Hall effect, etc. Their magnetic properties are also very diverse, including conventional ferrimagnets or antiferromagnets, compensated ("half-metallic") ferrimagnets and frustrated antiferromagnet, and topological antiferromagnets with a kagome-type lattice.

Peculiar features and evolution of electronic structure and physical properties in each of the HMF-, SGS- and TSM-states and during the transition between them are considered. Knowledge of the patterns of electronic and magnetic characteristics of such quantum materials provides the conditions for targeted control of their properties and opens up prospects for their practical application in spintronics, micro- and nanoelectronics.

In conclusion, the existing problems and unresolved issues in this area, possible solutions, and prospects for further fundamental and applied research are considered.

The work was carried out within the framework of the state assignment of the Ministry of Science and Higher Education of the Russian Federation for the IMP UB RAS.

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THERMOELECTRIC PROPERTIES OF $X_2ZZ'Y_2$ DOUBLE HALF-HEUSLER ALLOYS

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In this study, we investigate the thermoelectric properties of seven double half-Heusler alloys using a combined theoretical and experimental approach. The alloys under consideration are Zr_2Ni_2InSb, $V_2FeNiGe_2$, Ti_2Pt_2InSb, Ti_2Ni_2InSb, $Ti_2FeNiSb_2$, $Nb_2FeNiSn_2$, and $Hf_2FeNiSb_2$. Using density functional theory, the Boltzmann transport equation, and the quasi-Debye approximation, we calculated the Seebeck coefficient (S), electrical conductivity (σ), total thermal conductivity ($\kappa = \kappa_{el} + \kappa_{latt}$), and thermoelectric figure of merit (ZT). Our calculations show that all the studied alloys exhibit low lattice thermal conductivity, ranging from 5.7 to 10 W/(m·K) at room temperature. The ZT values ($ZT = S^2\sigma T/\kappa$) at 300 K fall within the range of 0.16–0.32. At elevated temperatures, ZT is predicted to reach values of approximately 1-2. For instance, the ZT of $Ti_2FeNiSb_2$ reaches 1 at 500 K. The obtained theoretical results are compared with experimental measurements of the properties for selected alloys [1], confirming their potential for application in thermoelectric devices.

Support by the Russian Science Foundation (RSF) under grant No. 24-12-20016 is acknowledged.

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MICROSTRUCTURAL MODEL OF THE BEHAVIOR OF MAGNETIC SHAPE-MEMORY ALLOYS IN MAGNETIC AND FORCE FIELDS

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Ferromagnetic shape-memory alloys, such as the Heusler alloy Ni_2MnGa, exhibit giant magnetic field-induced strains in the martensitic state due to the reorientation of twinned martensite variants. Variants favourably oriented relative to the applied magnetic field grow at the expense of unfavourably oriented ones. This reorientation, commonly referred to as detwinning, can be driven or suppressed by external mechanical loads, making these materials highly attractive for actuators, sensors, and adaptive microsystems.

In this work, we develop a coupled micromechanical-micromagnetic model to describe the structural transition associated with twin reorientation under the action of combined magnetic and force fields. Instead of integrating the full time-dependent Landau-Lifshitz-Gilbert equation, we use a simplified version that ensures collinearity between the unit magnetization vector and the effective magnetic field [1]. This significantly reduces computational costs and allows for the rapid generation of results suitable for further analysis of magnetomechanical processes in materials. The demagnetizing field is calculated using a scalar magnetic potential satisfying magnetostatic equations, allowing for consideration of sample geometry, edge effects, and inhomogeneous magnetization in both two- and three-dimensional space. The variational equations corresponding to these relations and the boundary conditions for them are constructed. This allowed us to reduce the requirements for the smoothness of the desired solution and facilitates numerical implementation of the problem using the finite element method with an iterative algorithm for sequentially refining the magnetization orientation and magnetic potential.

The mechanical response is formulated within a special case of elastic moment theory, where the stress tensor is split into a symmetric part describing tetragonal elastic anisotropy and a skew-symmetric part, depending only on the magnetic field. The kinematics of twinning and detwinning processes are described by the Hadamard compatibility condition. Its analytical solution determines the shear planes, shear directions, and shear magnitude [2].

The model was validated using experimental data for Ni_2MnGa single crystals under transverse magnetic field and axial compression. The calculated macroscopic magnetization curves and demagnetization tensor components demonstrate excellent agreement with experimental measurements and reference solutions. The critical values of shear stresses on the shear planes initiating the reorientation of martensitic variants were determined, and the dependence of the critical shear force on normal pressure was established.

This paper was prepared in the framework of a large scientific project with the financial support of the Ministry of Science and Higher Education of the Russian Federation (Agreement No. 075-15-2024-535 of 23 April 2024).

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REENTRANT SYMMETRY RECOVERY DRIVEN BY ELECTRONIC STRUCTURE IN HEUSLER ALLOYS

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Heusler metamagnetic shape memory alloys (MetaMSMAs) exhibit remarkable multifunctional properties, including giant magnetocaloric, elastocaloric, and barocaloric responses associated with firstorder martensitic transformations. While these phenomena have been extensively studied from crystallographic and magnetic viewpoints, the underlying electronic mechanisms remain incompletely understood.

In this talk, I will discuss the electronic origin of reentrant martensitic transformation in Co-based Heusler alloys [1,2], focusing particularly on the quaternary compound Co-Cr-Ga-Si. In this unusual system, the low-symmetry tetragonal martensite phase appears only within an intermediate temperature range, whereas the high-symmetry cubic ferromagnetic phase re-emerges upon further cooling. Such “symmetry recovery” at low temperatures is highly counterintuitive in condensed matter physics and raises a fundamental question: why does a more symmetric phase become stabilized at lower temperatures?

To address this issue, we have performed bulk-sensitive spectroscopic studies using hard X-ray photoelectron spectroscopy (HAXPES) and soft X-ray magnetic circular dichroism (XMCD), combined with first-principles calculations. Our results reveal that a high density of states near the Fermi level, originating from Co 3d and Cr 3d states, drives lattice instability and stabilizes the martensitic phase at intermediate temperatures. Upon cooling, however, the development of ferromagnetic exchange splitting opens a half-metallic gap, which energetically stabilizes the cubic phase and induces the reentrant transition.

These findings demonstrate that delicate competition between lattice instability and spin-dependent electronic structure can produce unconventional symmetry recovery phenomena in Heusler alloys. The results further suggest new routes toward designing multifunctional materials through precise control of electronic structures and half-metallicity.

If time permits, related spectroscopic studies on Mn-based metamagnetic Heusler alloys [3] will also be discussed.

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ORAL SESSION

Theory

Tuesday, 18 August, 16:00 - 18:00

SPIN AND SPECTRAL DIFFUSION DURING DYNAMIC POLARIZATION OF AS NUCLEI IN SI

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The use of terahertz radiation and low temperatures in EPR gives possible significant dynamic polarization of impurity nuclei and the host lattice to be achieved under steady-state conditions at relatively low pump levels [1-3]. In several experimental studies, this has enabled the observation of hole "burning" in signal spectra [2-3]. This effect is since, for a finite natural absorption linewidth, spin packets with a resonant frequency differing from the original by the amount of inhomogeneous broadening contribute to it (this phenomenon is like negative luminescence, which occurs in semiconductors and dielectrics in the optical range).

The cited papers experimentally investigated the EPR spectra of silicon doped with shallow P and As donors at temperatures around 1 K and magnetic field inductions of ~5 T, which corresponded to resonant transition frequencies of about 1 THz. The lattice of "natural" silicon contains about 5% of the ^{29}Si isotope with a spin of ½, and those nuclei located near the impurity atom can be dynamically oriented. In [1-3], significant polarization of the spins of impurity nuclei and the lattice was achieved, which was recorded by the transfer of signal intensities from various transitions with preservation of the nuclear spin projection, and in [3], a decrease in the EPR signal (a dip in the spectrum) was detected in the center of the resonance line corresponding to the transition with preservation of the spin projection of the impurity nucleus and a specific ^{29}Si atom. The latter observation, the microscopic cause of which was not disclosed in these papers, is especially interesting. It is believed that the dips, and in some cases the increase in the EPR signal, can be caused by two reasons: nuclear spin diffusion or the so-called spectral diffusion. The first mechanism is possible because the polarization of the nuclear spin is accompanied by an increase in the population of the upper spin sublevel of the electron and, consequently, reduces the EPR signal at this transition, i.e. leads to a "dip" in the spectrum. Nuclear spin diffusion reduces the magnitude of the polarization, and this means that the dip in the spectrum will decrease over time. This behavior of the signal is observed in [3]. Spectral diffusion is also caused by stochastic processes - random spin flips of 29Si nuclei over time. The interaction of the spins of ^{29}Si nuclei with the spin of a localized electron is the cause of inhomogeneous broadening of the EPR lines, so that a spin flip of the nucleus of such silicon will violate the resonance conditions and reduce the signal.

The report discusses both possibilities in detail, presenting calculation results demonstrating the effectiveness of the various factors responsible for these spectral features. A comparison with experimental results is also provided. The developed theory explains the signal intensity transfer and the significant difference between the calculated cross-relaxation transition times and the experimentally observed ones. The diffusion coefficient of nuclear spin in silicon near the donor is estimated (previously, it was very roughly assumed that the diffusion coefficient in this region was zero).

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MAGNETIC-SEMICONDUCTOR VAN DER WAALS HETEROSTRUCTURES

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Magnet-semiconductor interfaces in van der Waals heterostructures present a unique opportunity to investigate and to manipulate the spin and valley degrees of freedom. In the past few years, van der Waals heterostructures [1] comprising a variety of 2D layered materials have emerged as potential building blocks for future ultrafast and low-power electronic and spintronic devices. the discovery of 2D magnets realizes a step-change for the nascent field of wholly van der Waals based spintronics [2]. The emergence of ferromagnetism in 2D van der Waals crystals com-bined with their rich electronic and optical properties could open a wide variety of opportunities for 2D magnetic, magneto-electric and magneto-optic applications [3].

Here, we present a theoretical analysis of valley pseudospin control in the transition metal dichalcogenide monolayer by utilizing the magnetic proximity effect of magnetic monolayer and, for the first time, propose self-consistent analysis of a substantial difference in exciton and trion photoluminescence (PL) polarization under different polarized laser excitations. We attribute this to spin-dependent interlayer charge transfer. The ratio between the electron tunneling timescale and the exciton and trion radiative lifetimes plays an important role. A mechanism for switching PL polarization sign due to the effective electron tunneling between the magnetic and semiconductor monolayers of heterostructure under circularly polarized laser excitations is discussed. This means that a long-distance manipulation of exciton and trion behaviors in multilayer heterostructures can be achieved through spin-selective charge transfer. Obtained result marks a significant advancement in the control of spin and valley pseudospin in multilayer structures [4].

We study indirect exchange interactions (RKKY interaction) between localized spins of magnetic impurities localized on top of transition metal dichalcogenide monolayer in the spinvalley locking regime. The short range exchange interaction between magnetic impurities and conduction electrons causes efficient scattering of electrons between spin valleys in semiconductor with simultaneous spin flips. The difference of the electron wave vectors in the two valleys leads to the chiral exchange interaction. The presence of both RKKY interaction and direct antiferromagnetic exchange interaction between neighboring magnetic impurities results in the common ground state - chiral two-dimensional 120◦N´eel state. Direct antiferromagnetic exchange interaction results in the formation of two phase transitions: Berezinskii-KosterlitzThouless transition for magnetization and the chirality second order phase transition. It was demonstrated that RKKY interaction destroys the chirality second order phase transition and causes critical temperature shifts to the higher temperature for the Berezinskii–Kosterlitz– Thouless transition [5].

The authors acknowledge for support the Russian science foundation grant #24-12-00020.

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ON THE BERRY PHASE OF A SPATIALLY INHOMOGENEOUS DIELECTRIC FERROMAGNETIC

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The use of magnons as information carriers is motivated by a numberof factors: they are uncharged quasiparticles and there foreless susceptible to Joule heating;, they obey Bose statistics, which reduces the role of dissipative processes at low temperatures; magnons propagate over distances exceeding the spin-diffusion length, which is determined by conduction electrons, etc. Among the negative aspects is the lack of response of the magnon system to electric fields. In other words, to excite a magnon flow (spin-wave current), other sources are required.

The kinetics of magnon transport is also unusual, determined both by the interaction with an external perturbing source and by exchange interactions realized in a system of localized magnetic moments. In studies of transport phenomena, both charged and neutral particles, an effective gauge field is present, leading to the implementation of the Berry phase, which has a significant impact on transport phenomena. The Berry curvature characterizes the rate of change of the wave function as a function of the wave vector **k**, and manifests itself in a wide range of wave phenomena. The Berry phase has a profound impact on transport phenomena in both conducting and dielectric magnetic systems. Due to this phase, the group velocity of particles acquires an anomalous term proportional to the Berry curvature. Furthermore, the Berry curvature is responsible for the manifestation of the topological properties of magnetic structures [1].

Among the broad class of magnetic compounds, magnets with competing exchange interactions (Heisenberg and Dzyaloshinskii-Moriya) are of great interest. Over the years, various models have been developed for studying spin-thermal effects in magnetic dielectrics, including the sum of the three main exchange interactions: isotropic Heisenberg, Dzyaloshinskii-Moriya, and magnon energy in a constant magnetic field. In this paper, we would like to focus on the formation of the Berry phase in the continuum approximation, realized when considering a spatially inhomogeneous ferromagnetic dielectric and the role of the unitary transformation in the formation of the phase, leading to an anomalous magnon velocity.

We will show that the field curvature tensor due to the isotropic Heisenberg exchange interaction, is equal to zero. In other words, the gauge field created by the isotropic Heisenberg exchange interaction is a purely gauge field, similar to the vector potential outside an infinitely long solenoid. Dzyaloshinskii-Moriya interaction, calculated in the continuum approximation, leads to a nonzero Berry phase curvature, thereby introducing an additional anomalous contribution to the magnon group velocity. The direction of the anomalous velocity is orthogonal to the magnon flow velocity generated by the temperature gradient and thus ensures the manifestation of spin-thermal effects in magnon kinetics.

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KONDO EFFECT IN Fe-DILUTED TUNGSTEN DITELLURIDE SINGLE CRYSTAL: EXPERIMENT AND THEORY

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We present a comprehensive study of low-temperature magnetotransport properties of the Weyl semimetal WTe_2 doped with 3% iron ($W_{0.97}Fe_{0.03}Te_2$). In contrast to pristine WTe_2, which exhibits nearly perfect electron-hole compensation and large nonsaturating magnetoresistance, Fe doping induces a drastic reconstruction of the electronic system. The residual resistivity ratio drops from 38 to 3.17, the Hall resistivity changes sign indicating the dominance of hole carriers, and a low-temperature minimum appears in ρ(T) followed by a logarithmic increase upon cooling below 10 K.

A key result is shown in Fig. 1, where the low-temperature part of ρ(T) is fitted using the Hamann equation. This fit, together with the observation of an almost quadratic negative magnetoresistance and its suppression by a magnetic field, provides robust evidence for the Kondo effect arising from scattering of conduction electrons on magnetic Fe impurities substituting W sites.

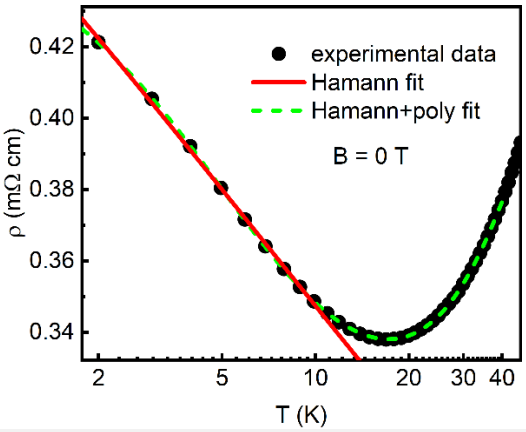

Fig. 1. (a) Low-temperature part of the resistivity of $W_{0.97}Fe_{0.03}Te_2$ at B = 0 T fitted with Hamann equation.

Various approximations to describe the Kondo resistivity in diluted magnetic systems are critically analyzed. We demonstrate that fitting with the Hamann equation alone yields a Kondo temperature $T_K \approx 7.78$ K for S = 2, consistent with magnetic susceptibility data. However, including a polynomial background ($qT^2 + pT^5$) to account for Fermi-liquid and phonon contributions leads to unrealistically small impurity spin values (S ~ 0.2–0.5). The same issue persists when fitting the magnetoresistance data in a magnetic field using a modified Hamann equation with a Brillouin function factor. Thus, while the Kondo effect is unambiguously present, precise extraction of microscopic parameters remains challenging and requires careful treatment of competing scattering mechanisms. This highlights the need for new, more accurate models to describe the Kondo effect.

Our results demonstrate that Fe doping efficiently tunes WTe_2 from a non-magnetic topological semimetal toward a strongly correlated system with Kondo physics, offering a platform for studying the interplay between topology and electronic correlations [1].

The work was carried out within the framework of the state assignment of the Ministry of Science and Higher Education of the Russian Federation for IMP UB RAS and the youth project No. 14-25 (B.M. Fominykh).

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MAGNETIC SUSCEPTIBILITY, FERMI SURFACE AND SPECIAL K-POINTS OF GRAPHITE

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We investigate the magnetic susceptibility of AA- and AB-graphite based on ab initio band structure calculations of these materials. For that we perform high precision determination of their Fermi surfaces and define their characteristic points. Then we calculate the most important contributions to the total magnetic susceptibility: 1) from the Landau diamagnetic contribution, 2) from the Van Vleck paramagnetic and the Langevin diamagnetic contributions, 3) from the Pauli paramagnetic contribution. The largest contribution is by far from the formed Landau levels. The calculation of the Landau magnetic contribution is based on the semiclassical approach of [1], considering various Landau orbitals on the Fermi surface.

Within the Landau diamagnetic response, the largest contribution comes from the conical points (special k-points) of the Fermi surface. We discuss in detail the elimination of the logarithmic divergence of these conical k-points. On the other hand, we demonstrate a good correspondence with the experimental value of magnetic susceptibility of graphite. Our calculations also show the dependence of the magnetic susceptibility on the angle of the applied magnetic field to the graphitic planes.

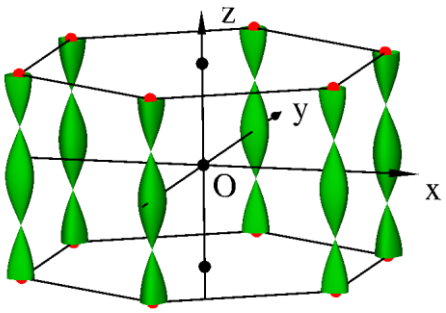

Fig. 1. The Brillouin zone of AA-graphite.

The study was conducted under the state assignment of Lomonosov Moscow State University.

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EXACT SOLUTION FOR THE MAGNETIC MULTILAYERED SYSTEMS WITH PERIODIC DRIVING

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Periodic driving serves as an effective method of control of physical systems properties. Called 'Floquet engineering' [1], it is a broad field of theoretical and experimental activity. Whereas the original Floquet theory was proposed for a system of ordinary differential equations, quantum systems with time-dependent potential require using partial differential equations. Time series is a most common method of analysis of such systems. A general scheme was developed in a number of works [2]. Still, its application to specific problems often faces significant difficulties. In particular, the type of problems describing magnetic multilayers with time-dependent potential (e.g., rotating magnetization of some of the layers) leads to a serious complication of such a problem due to two-component wave function and matching conditions at the interfaces. Taking as an example a two-layer system containing magnetic layer with rotating magnetization, we demonstrate the divergency of infinite time series solutions and construct a class of solutions containing arbitrary yet finite number of terms. The structure of the proposed solution is analyzed. In particular, we show that boundary conditions which seem to be a natural generalization of those for a stationary problem cannot be imposed in the case of rotating magnetizations. The application of the constructed solution to physical problems is discussed. We consider the appearance of edge states at the interface. Also, we discuss the calculation of some transport effects in the system, including anomalous and spin Hall effects [3], Edelstein's effect [4], etc.

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ORAL SESSION

Neutrons and synchrotron X-rays for magnetism

Tuesday, 18 August, 16:00 - 18:00

MAGNETIC LONG-RANGE ORDER IN A PURELY ORGANIC TRIANGULAR MAGNET

Pardo-Sainz M.[1,2], Kamiya Y.[3], Rodríguez-Velamazán J.A.[4], Cai Y.[5], Kojima K.[5], Ohishi K.[6], Ono T.[2], Hosokoshi Y.[2], Campo J.[1]

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Equilateral spin triangles have long been a topic of interest in quantum magnetism, offering a fertile ground to explore phenomena such as frustration [1], spin-electric coupling [2], and multiferroic ordering [3]. Despite substantial progress, realizing ideal triangular spin networks remains a challenge, often hindered by structural distortions. The organic compound TNN·CH_3CN overcomes these limitations with its isotropic organic radical spins, free from Jahn-Teller effects, allowing uniform exchange interactions. This makes TNN·CH_3CN an ideal candidate for exploring novel quantum phases. In fact, the study of its magnetic phase diagram reveals multiferroic behavior, which is the first example for equilateral spin triangles [4].

However, while macroscopic characterization measurements yield valuable insights, they fall short in providing intricate details about the magnetic structure which is developed at atomic or molecular scale within TNN. In this work, we focus on the determination of its magnetic structure at zero-field using single crystal neutron diffraction (SCND) and muon spin relaxation (μSR) experiments. At zero field, the magnetic signal is too weak to be observed in SCND experiments. Nevertheless, by making use of a computational model and DFT calculations, the absence of oscillations in the μSR spectra is shown to be compatible with a high-symmetry magnetic structure at the muon site. The proposed magnetic configuration is consistent with previous studies, as well as with theoretical predictions of its multiferroic nature [5].

Keywords: Neutron scattering, molecular magnetism, muon spin rotation, spin densities

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ON THE DOUBLE-Q CHIRAL STRIPE STATE IN NONCOLLINEAR FRUSTRATED ANTIFERROMAGNETS

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Topological phases of matter are among the hottest topics in condensed matter physics. In particular, they can be realized in magnetic materials. The famous example is the skyrmion lattice observed in many compounds. Importantly, when coupled to itinerant electrons, it leads to peculiar transport properties. The giant topological Hall effect due to the emergent field, originating from topological charge of the skyrmions, was observed in frustrated antiferromagnets on high-symmetry lattices [1,2].

Recently another phase with intriguing properties was observed experimentally and discussed numerically [3,4]. It is called a chiral stripe (CS) state, and it is formed by a double-Q superposition of a helicoid and a transverse spin-density wave (SDW). Despite on average the emergent field is zero, the CS order realizes a superlattice of topological charge with period of several nanometers which can have promising applications for conduction electrons.

Our analytical method, supported by Monte Carlo calculations, shows that the peculiar CS phase arises from an instability in the helimagnon dispersion of the conventional helical ground state. When the exchange interaction allows for several equivalent modulation vectors in high-symmetry lattices, exchange anisotropy can destabilize the excitation spectrum and induce the secondary SDW component. The analytical theory suggests that the CS state should be ubiquitous in triangular and square lattice materials, when spin-orbit coupling and dipolar interactions are taken into account.

In the experimental part of the study, we revisit the phase diagram of triangular-lattice skyrmion host Gd_2PdSi_3. Using Lorentz transmission electron microscopy and resonant elastic X-ray scattering, we show that at low temperatures and in weak magnetic fields the ground state of this compound is the chiral stripe state. Finally, we discuss the effect of stripes of the emergent field on the conduction electrons by performing anisotropic magnetoresistance measurements.

Support by Brain Pool Plus Program through the National Research Foundation of Korea funded by the Ministry of Science and ICT (2020H1D3A2A03099291), National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (RS-2026-25470048), and Creation of the quantum information science R&D ecosystem (based on human resources) through the National Research Foundation of Korea (NRF) funded by the Korean government (Ministry of Science and ICT (MSIT)) (RS-2023-00256050) is acknowledged.

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SPIN TEXTURES AND SPIN WAVES AS SEEN BY X-RAY IMAGING

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The investigation of spin-wave phenomena—magnonics—plays an increasingly central role in modern condensed-matter research [1]. Spin waves are considered promising signal carriers for next-generation spintronic information-processing devices, with the potential to surpass charge-based technologies in both energy efficiency and device miniaturization. A key challenge on this path is the generation, control, and detection of spin waves with nanoscale wavelengths.

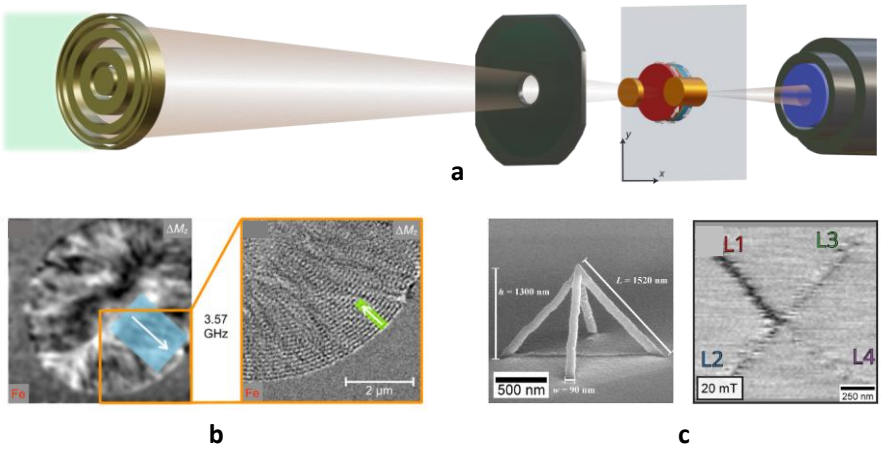

Fig.1: (a) X-ray imaging (schematic) [7], (b) TR-STXM images of non-reciprocal spin waves [5], (c) SEM and STXM images of 3D magnetic structure [8].

In this talk, I will show how time-resolved x-ray microscopy enables direct imaging of nanoscale spin dynamics. Using this technique, it has been demonstrated that ferromagnetic spin textures—particularly vortex cores and domain walls—can act as nanoscale spin-wave emitters and non-reciprocal waveguides [2–7]. I will further discuss recent advances in x-ray imaging of spin-wave dynamics in ferrimagnetic and antiferromagnetic materials, as well as emerging approaches for probing threedimensional magnetic systems [8].

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MAGNETIC PHASE TRANSITION IN $Y_{1-x}Tb_xMn_6Sn_6$ COMPOUNDS

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The magnetic structure of $Y_{1-x}Tb_xMn_6Sn_6$ compounds (x = 0.0, 0.10, 0.25) was studied using smallangle neutron scattering (SANS) in the temperature range from 260 to 400 K, above and below the critical temperature T_C. The dependences of the SANS intensity on the momentum transfer demonstrate the presence of three contributions to the scattering, which differ in the scattering function (Q-dependence of the intensity) and in the evolution of these dependences with temperature. Scattering by large-scale magnetization domains is observed below T_C and is described by the Porod law Q^n. The Bragg peak from the incommensurate magnetic structure is also observed below T_C in the region of large Q. Ornstein-Zernike scattering by critical magnetization fluctuations is most pronounced at high temperatures. The order-disorder transition temperature, determined from the maximum scattering by critical fluctuations, increases with concentration: T_C = 300 ± 2 K, 325± 2 K, 353±3 K for compounds with concentrations x = 0, 0.1, 0.25. An incommensurate magnetic structure with a complex temperature behavior is observed in all compounds, with the period of the structure increasing with concentration x. The ferromagnetic component of magnetization was detected only in Tb-doped compounds at $T < T_C$. Above T_C, the magnetic structure disintegrates into fluctuating ferromagnetic planes, giving the occurring magnetic phase transition a quasi-two-dimensional character.

Critical fluctuations, according to the Mermin-Wagner theorem [1], demonstrate the instability of ferromagnetic order in two-dimensional systems and can be described by a new, nonmagnetic order parameter along the c-axis [2]. We argue that slowly fluctuating ferromagnetic planes are capable of ordering into a variety of spin structures: a complex double helix (x = 0), a conical helix, and a ferrimagnet (x = 0.1, 0.25). The phase transition from the fluctuating phase to the ordered one in YMn_6Sn_6 occurs in a complex manner through a system of crossovers, implying that on the basis of fluctuating ferromagnetic planes with a decrease in temperature in the range [300 - 340] K, it is possible to form first an antiferromagnetic commensurate (but fluctuating) phase, then a spiral (but fluctuating) phase, and, finally, a stable spiral phase at T ≈ 300 K. Doping with a rare earth element simplifies the phase transition and the fluctuating Mn planes are immediately ordered into a collinear magnetic (ferrimagnetic for the Mn-Re plane system) structure. The ferromagnetic component of this ferrimagnetic structure increases with decreasing temperature from T_C to T ≈300 K, and then “freezes”, thereby confirming the hypothesis of a phase transition from a two-dimensional magnetic system to its three-dimensional analogue.

The study was supported by the Russian Science Foundation grant No. 26-62-00030, https://rscf.ru/project/26-62-00030/.

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POSTER SESSION

Spintronics and Magnetotransport I

Tuesday, 18 August, 18:00 - 20:00

METHODS OF CONTROL THE MOTION OF MAGNETIC SKYRMIONS

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Generation and manipulation of skyrmions are currently the most significant problems in the research of magnetic skyrmions [1, 2]. Inhomogeneities of thin films and various defects, which are always present at the micro- and nanoscale, play a significant role in this. The stability of skyrmions in the presence of nonmagnetic defects has been investigated in detail within the framework of Transition State Theory [3], where it was shown that nonmagnetic defects (such as vacancies, impurities, or boundaries) lower the energy barrier required for skyrmion creation.

In this work, we present several models of a magnetic racetrack to study the generation and dynamics of Néel skyrmions by a spin-polarized current. The time dependence of magnetization was calculated using the MuMax3 package [4].

We have presented two methods to eliminate a transverse drift during magnetic skyrmion motion: development of the model of the magnetic racetrack from a synthetic antiferromagnet and the model with nonmagnetic defects. Figure 1 shows one of the ways to control the motion of a skyrmion by a spin-polarized current in the presence of a chain of defects on the racetrack. The defect is a through-hole with a diameter of about 2 nm. The stability of motion is highly sensitive to the size of the defects and the distance between them. As can be seen from the figure, the skyrmion approaches a defect, becomes pinned by it, and then moves in a straight line jumping from defect to defect [5]. Thus, we have successfully solved one of the problems hindering the technological application of skyrmions – the problem of transverse drift called the skyrmion Hall effect.

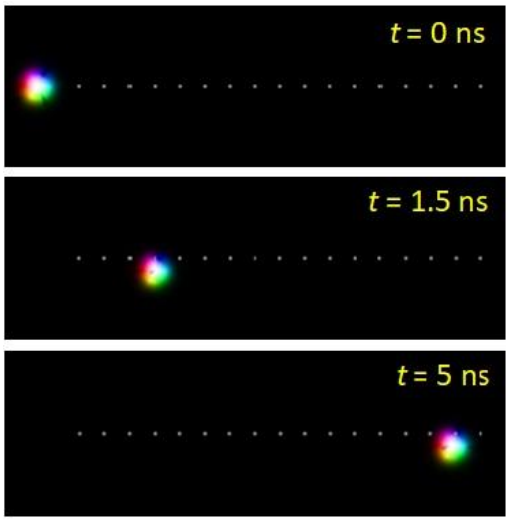

Fig. 1. Motion of a skyrmion on the racetrack with defects driven by a spin-polarized current. Current density $j = 10^{12}$ A/m².

Support by the Russian Science Foundation, project no. 25-22-20086, is acknowledgment.

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MAGNON-PHOTON MODE HYBRIDIZATION IN THE ELECTROMAGNETIC RESONATOR/FERROMAGNETIC SINGLE-CRYSTAL STRUCTURE

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Hybrid magnon-photon structures are of interest due to the possibility of controlling the interaction between magnetic and electromagnetic subsystems. Under strong coupling between a ferromagnetic magnon mode and a microwave resonator mode, hybrid states are formed, which are manifested by an anticrossing of the resonant frequencies [1]. Such systems are promising for tunable microwave devices, spintronics, and hybrid quantum technologies.

This work investigates a planar structure consisting of a microwave resonator and a ferromagnetic yttrium iron garnet (YIG) single crystal. The theoretical description is based on the Landau–Lifshitz–Gilbert equation for magnetization dynamics and a model of two coupled oscillators describing the interaction between magnon and photon modes. In this model, finite coupling leads to the splitting of the resonant frequencies and the formation of two hybrid branches.

Numerical modeling was performed using the ANSYS HFSS software package by the finite element method in the frequency domain. The distributions of the microwave magnetic field and the dependences of the resonant frequencies on the external magnetic field were calculated for different positions of the YIG single crystal relative to the region of the maximum microwave magnetic field. The experimental part included measurements of the spectral characteristics of the fabricated structure, which made it possible to compare the behavior of the real system with the results of numerical modeling.

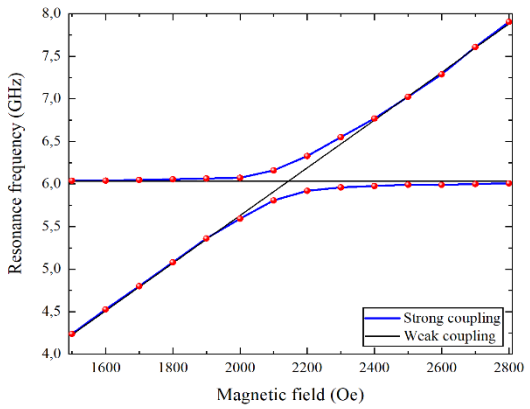

Fig. 1. Numerical simulation results for the dependence of the resonant frequencies on the external magnetic field under weak and strong magnon-photon coupling.

It is shown that when the YIG single crystal is placed in the region of the maximum microwave magnetic field, a pronounced anticrossing occurs, corresponding to the strong magnon-photon coupling regime. According to the numerical simulation results shown in Fig. 1, the relative frequency splitting is on the order of $\Delta\omega/\omega \approx 6 \cdot 10^{-2}$.

This study was supported by the Russian Science Foundation, grant No. 26-79-32004.

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NONLINEAR SPIN PUMPING ON ACOUSTIC MODE FROM AN ANTIFERROMAGNETIC A-FE2O3 DISK RESONATOR TUNABLE BY MAGNETIC FIELD

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State-of-the-art spintronic microwave detectors based on magnetization precession in ferromagnets require a substantial input power to reach the nonlinear regime. Here we propose an alternative approach — the use of magnetoelastic oscillations in the canted antiferromagnet α-Fe_2O_3 in the kilohertz range [1]. The strong dynamic magnetoelastic coupling and the anomalously high magnetoacoustic nonlinearity of hematite make it possible to reach the nonlinear regime at input powers several orders of magnitude lower than those required for conventional FMR-based nonlinear operation [2].

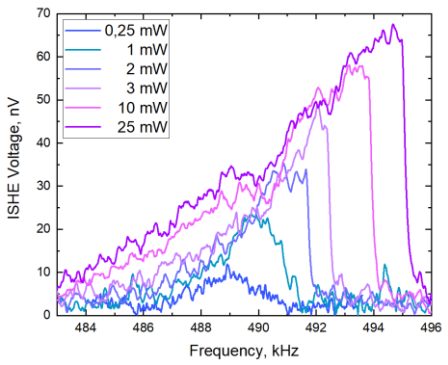

Fig. 1. ISHE voltage response of the α-Fe2O3/Pt structure at various excitation-signal powers.

The experiment was carried out on a single-crystal α-Fe_2O_3 disk resonator coated with a 10-nm platinum layer. Magnetoelastic oscillations were excited by an alternating magnetic field in the 400–600 kHz range produced by an induction coil; a static field H_0 provided tuning of the resonance frequency. The voltage generated by the inverse spin Hall effect (ISHE) was recorded by lock-in detection.

The dependence of the ISHE response on the pump power was studied at H_0 = 220 Oe (Fig. 1). Below 0.5 mW, a linear spin-pumping regime is observed. Above 1 mW the resonance line becomes asymmetric with an abrupt jump (foldover), which is a characteristic signature of nonlinearity.

Further evidence of the nonlinear nature of the response is provided by the frequency hysteresis observed under forward and backward frequency sweeps, indicating the presence of multistable states. The coincidence of the field positions of the magnetoelastic-resonance and ISHE-signal peaks over the 400–550 kHz range confirms that the response originates specifically from the magnetoacoustic mechanism rather than from parasitic electromagnetic pickup.

The results obtained demonstrate the feasibility of energy-efficient spintronic detectors operating in the nonlinear regime at powers several orders of magnitude lower than those typical of microwave devices and open a route toward the development of tunable detectors whose operating point is controlled by an external magnetic field.

The work was carried out within the framework of the state assignment of the Kotelnikov Institute of Radio Engineering and Electronics of the Russian Academy of Sciences.

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NONLINEAR SPIN PUMPING IN $Lu_3Fe_5O_{12}$/Pt HETEROSTRUCTURE

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Spin pumping in ferromagnet/normal metal heterostructures is an efficient method for generating spin current, while its conversion into charge current in Pt via the inverse spin Hall effect enables electrical detection of magnetization dynamics [1,2]. Lutetium iron garnet $Lu_3Fe_5O_{12}$ is considered a promising material for spintronic microwave devices due to its low magnetic losses, narrow ferromagnetic resonance linewidth, and potential for the development of tunable detectors [2,3]. However, the behavior of such structures at high microwave power levels remains insufficiently studied.

In this work, we investigate the nonlinear regime of ferromagnetic resonance and the associated voltage response in a $Lu_3Fe_5O_{12}$/Pt heterostructure under microwave excitation with powers up to 3 W. The $Lu_3Fe_5O_{12}$ film was grown by MOCVD on an Al-doped $Gd_3Ga_5O_{12}$ substrate, while the Pt layer was deposited by magnetron sputtering. The voltage induced by the inverse spin Hall effect was measured during forward and backward frequency sweeps.

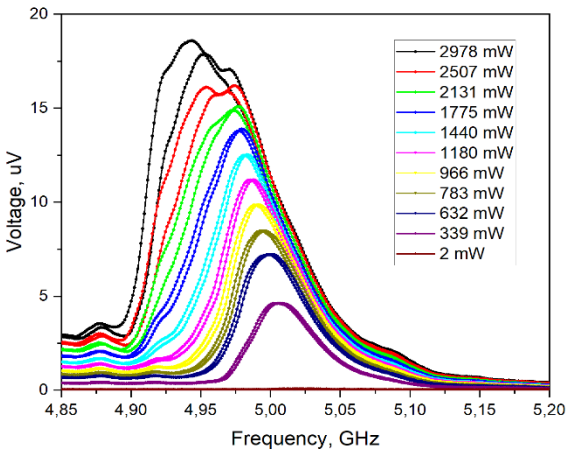

Fig. 1. ISHE voltage spectra of the $Lu_3Fe_5O_{12}$/Pt heterostructure at different microwave powers.

It is shown that at low microwave powers the resonance curve has a nearly Lorentzian shape, corresponding to the linear regime of magnetization precession. With increasing microwave power, a transition to the nonlinear regime is observed: the resonance frequency shifts, the linewidth broadens, the peak shape becomes asymmetric, and the amplitude of the ISHE voltage changes. In addition, frequency sweeps in opposite directions reveal hysteresis, with its width increasing with microwave power. This behavior indicates a nonlinear modification of the magnetization dynamics and enhanced dissipative processes at large excitation amplitudes [1].

The obtained results show that, at high microwave powers, the efficiency of spin pumping in $Lu_3Fe_5O_{12}$/Pt is strongly affected by nonlinear effects. Taking these effects into account is important for the correct interpretation of the ISHE signal and for the optimization of tunable spintronic microwave detectors [2,3].

This study was supported by the Russian Science Foundation, grant No. 26-79-32004.

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MAGNETIC RESONANCE SPECTRUM OF $NiFe_2O_4$ NICKEL FERRITE SINGLE CRYSTALS

Kachurin K.I. [1,3], *Matasov A.V.* [1,3], *Gabrielyan D.A.* [1,3], *Volkov D.A.* [1,3], *Safin A.R.*[1,3], *Nikitov S.A.*[1,2,4]

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Ferrospinels remain one of the fundamental classes of magnetic materials for microwave electronics and spintronics. Among them, nickel ferrite $NiFe_2O_4$ is of particular interest as a chemically stable soft magnetic material whose properties strongly depend on the cation distribution, oxygen stoichiometry, and crystallographic orientation of the single crystal [1].

The aim of this work was to obtain bulk $NiFe_2O_4$ single crystals with minimal deviation from oxygen stoichiometry and to investigate the effect of crystallographic orientation on the parameters of ferromagnetic resonance spectra. Single crystals oriented along the (100), (110), and (100) directions were synthesized by the crucible-free optical floating-zone method [1].

The phase composition and crystal structure parameters were studied by X-ray diffraction. According to energy-dispersive X-ray spectroscopy, the elemental composition can be represented as $NiFe_{2.057}O_{4.085}$, which is consistent with a low concentration of oxygen vacancies.

To study the ferromagnetic resonance spectra, the variation of the transmission coefficient S21 under an applied static magnetic field was considered as the measured quantity. For all investigated orientations, a pronounced resonance minimum was observed at a frequency of 9 GHz; however, the resonance field position and line shape strongly depended on the sample orientation.

The most favorable resonance characteristics were found for single crystals oriented along the (100) direction: the resonance minimum is shifted toward lower magnetic fields, the FMR linewidth is smaller, and the absorption level is higher compared with the (110) and (111) directions.

Thus, the results obtained in this work demonstrate that the ferromagnetic resonance spectra of $NiFe_2O_4$ single crystals are significantly affected by the sample orientation, while the (100) direction is the most promising for the implementation of microwave and spintronic devices.

The work was carried out within the framework of the state assignment of the Kotelnikov Institute of Radio Engineering and Electronics of the Russian Academy of Sciences.

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MODE DYNAMICS OF SPIN WAVES IN THIN MAGNONIC CRYSTALS

Balaeva V.V.[1], *Matveev O.V.*[1], *Morozova M.A.*[1,2]

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In modern magnonic microelectronics, magnonic crystals (MC) - periodic magnetic structures - play a significant role by enabling advanced control of spin wave propagation through the formation of band gaps [1]. Research on spin dynamics in magnetic micro- and nanostructures is motivated by the prospects of creating multifunctional devices for recording, storing, and processing information based on them [2].

Using the MuMax[3] micromagnetic simulation environment, this work investigates magnetostatic spin waves (MSW) in nanoscale MCs made of yttrium iron garnet (YIG), for which the period, width, and thickness are varied. Periodicity is defined by a system of grooves on the MC surface. The external field H = 1200 Oe is applied in the plane of the sample, perpendicular to the direction of the MSW. The ratio of groove depth to MC thickness is 1/10.

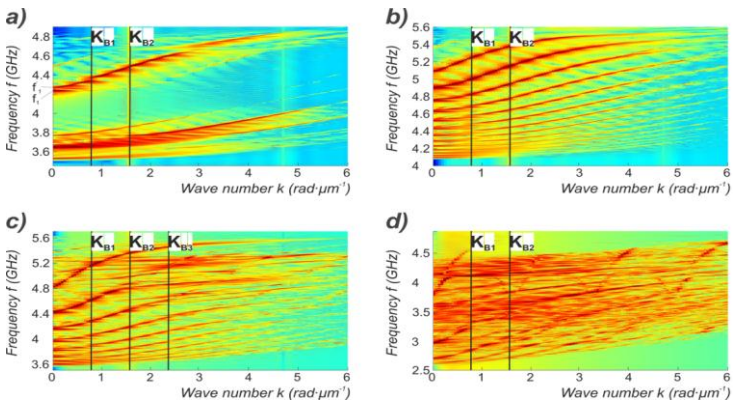

Fig. 1. Dispersion characteristics at (a) D = 200 nm, w = 1 μm; (b) D = 200 nm, w = 6 μm; (c) D = 500 nm, w = 6 μm; (d) D = 2 μm, w = 6 μm. Δ = 4 μm.

MCs with thickness D ranging from hundreds of nanometers to several micrometers and width w corresponding either to narrow waveguides (D/w << 30) or to wide films (D/w ≥ 30) are considered. In thin MC waveguides (up to D ≈ 500 nm), hybridization of width modes with thickness modes occurs, as a result of which each width mode represents a system of modes (Fig. 1a). In such a system, there is a common cutoff at FMR for the width mode and cutoffs for each new mode, among which the "main" mode has the largest energy amplitude. Increasing the MC width when transitioning to a film leads to the thickness modes moving away from the main one both upward and downward in frequency, which transitions into a width-mode state (from Fig. 1(a) to (b)).

Increasing the MC thickness with other parameters fixed (Fig. 1(b–d)) leads to a decrease in the number of observed width modes and an increase in their group velocity [3]. It is found that in an MC waveguide, the frequency spacing between the first and higher modes increases, while the spacing between higher modes decreases, and the higher the order, the stronger the effect. Also, the higher the mode order, the more slowly their group velocity increases at small wavenumbers (Fig. 1d).

The work was supported by the Russian Science Foundation (Project № 23-79-30027).

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OPTICAL CONTROL OF SPIN-WAVE TRANSMISSION IN MULTI-LAYER YIG/SI STRUCTURES

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Traditional electronics faces fundamental limits in miniaturization due to heat dissipation. To overcome this, magnonics offers a promising alternative: using spin waves (magnons) instead of charge carriers for information processing [1]. However, realizing practical devices requires precise control over wave dynamics and efficient integration of magnonic elements directly into semiconductor architectures to enable scalable hybrid devices [2].

By utilizing a specific heterostructure (YIG/Si/mica/YIG), we demonstrate that laser pulses can modulate the conductivity of the silicon spacer layer, thereby dynamically tuning the spin-wave transmission properties [3].

To directly observe dynamic spin-wave modes in the YIG/Si/mica/YIG heterostructure, we employed Brillouin Light Scattering (BLS) spectroscopy [4]. Complementing the experiments, we developed a theoretical model based on coupled wave equations for spin-wave envelope amplitudes. In this framework, the spacer's conductivity is treated as a dynamic variable dependent on optical power and frequency. We observed that increasing laser power at higher frequencies leads to a significant modulation of the group velocity and coupling efficiency. Fig.1 illustrates variation in spin wave transmission coefficients against laser power at different frequencies.

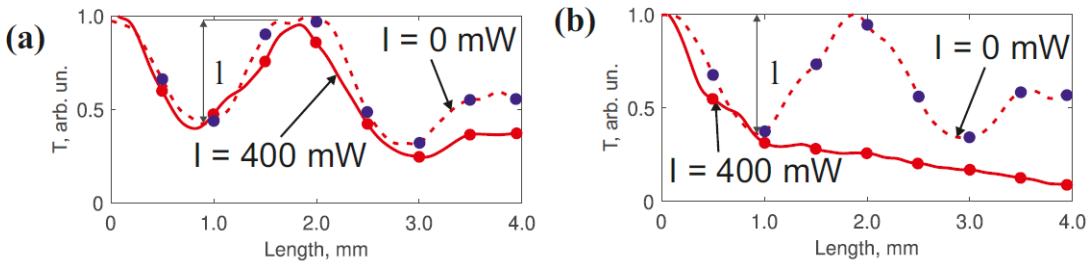

Fig. 1. Transmission coefficient of spin waves in lower YIG layer versus longitudinal coordinate y at (a) *f*=4.093 GHz and (b) *f* = 4.135 GHz, measured without laser irradiation (dashed curves) and at 400 mW laser power (solid curves), under applied magnetic field H0 = 800 Oe.

Thus, the YIG/Si/mica/YIG structure can act as a compact microwave power divider or coupler where signal routing is managed by light. This approach enables the creation of reconfigurable filters and logic gates compatible with standard CMOS technology, paving the way for scalable high-frequency all-optical networks.

The work was supported by Russian Science Foundation (grant № 23-79-30027)

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ELECTRICAL RESISTIVITY, THERMOELECTRIC POWER, HALL EFFECT, AND SATURATION MAGNETIZATION IN Fe AND Ni BASED AMORPHOUS ALLOYS

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The temperature dependences of the Hall coefficient, electrical resistivity, thermoelectric power, and saturation magnetization of amorphous and crystalline Fe–Ni-based alloys with metalloid additives were investigated over a wide temperature range from room temperature up to 1000 K. It was shown that, with increasing temperature, crystallization processes occur in amorphous alloys and are accompanied by the formation of various phases. Using the alloys of composition $Fe_{66,87}Ni_{24,7}Si_{4,93}B_{3,5}$ and $Fe_{22}Ni_{69,85}Si_{4,65}B_{3,5}$ as an example, a scheme of crystallization transformations was proposed.

A correlation between the anomalous Hall coefficient and the saturation magnetization was established: within a certain temperature range, a linear relationship between these quantities was observed. The obtained results provide a deeper understanding of the interrelation between the electrical and magnetic properties of iron-group amorphous alloys.

In amorphous ferromagnetic alloys, the Hall coefficient is practically independent of temperature and, in absolute value, exceeds the corresponding coefficient in crystalline counterparts.

To determine the causes of the abrupt changes in physical properties under the influence of temperature, the samples were heated to temperatures at which anomalies were observed, followed by X-ray analysis.

Based on the obtained results, it can be concluded that the changes in the physical properties (mainly magnetic) of amorphous alloys arise due to changes in the sample composition, i.e., they are associated with the formation of magnetic phases.

The anomalous Hall coefficient is directly related to magnetization. A linear dependence between R_S and I_S^2 exists within a certain temperature range. This dependence is weaker in the amorphous state than in the crystalline state. This indicates that the contribution of phonons to the kinetic properties of amorphous alloys is smaller than in the crystalline state [1, 2].

It is known that an increase in the concentration of metalloids enhances the thermal stability of amorphous alloys. An increase in Ni concentration also affects both the thermal stability and the magnetic properties of the alloys [1]. The absolute value of magnetization decreases, and the Curie temperature is reduced with increasing Ni content in these alloys. Since the magnetic moments per atom of Fe and Ni are 2.6 and 0.6 μB, respectively, substitution of Fe atoms by Ni leads to a significant decrease in magnetization and Curie temperature in amorphous alloys as the Ni concentration increases.

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PINNING OF SPIN POLARONS IN WEYL SEMIMETALS MNZN1-XCRXSB

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Weyl semimetals have various types of spin structures. For example, $Mn_{2-X}Zn_XSb$ exhibits stripes, skyrmions, and a skyrmion lattice, depending on temperature. In the Weyl semimetal $Co_3Sn_2S_2$, localized spin-orbit polarons with a large magnetic moment of topological origin above the Curie temperature were found in the vicinity of a sulfur vacancy [1].

The aim of our research is to determine the localization temperatures of spin polarons above the Curie temperature, accompanied by a change in magnetic and transport characteristics, as a result of the substitution of zinc by chromium ions in solid solutions $MnZn_{1-X}Cr_XSb$ ($X < 0.2$).

Chromium ions can act as centers for localization of conduction electrons, creating a localized magnetization cloud and forming a stable magnetic polaron. Polaron pinning will alter the transport and magnetic characteristics. The difference between spin polarons (ferrons) and spin-orbit polarons can be determined from the temperature dependence of impedance at different frequencies, specifically from the temperature coefficient of resistance 1/RdR/dT in the frequency range of 1 kHz to 1000 kHz, which has an extremum at the pinning temperature. For all $MnZn_{1-X}Cr_XSb$ concentrations, a decrease in the polaron pinning temperature with increasing frequency was observed. The pinning temperature (T_p) of spin polarons (ferrons) shifts toward higher temperatures with increasing frequency of the alternating electric field. This is due to the fact that the frequency dependence of susceptibility is described by the generalized Debye relaxation model. The ferron lifetime (τ) depends exponentially on temperature and from the condition $\omega\tau = 1$, the effective temperature at which pinning is observed increases.

In a spin-orbit polaron, the spin is coupled to the momentum, and when the electron momentum changes in an alternating electric field, the spin direction changes. With increasing frequency of the alternating electric field, the oscillation of the spin-orbit moment increases. This leads to a decrease in the activation energy and to the decay of polaron states at lower temperatures. The pinning temperature of spin polarons is accompanied by an extremum of the derivative of the magnetic susceptibility with respect to temperature. At $T>T_p$, the paramagnetic Curie temperature increases $\theta/T_C = 1.11$ for $X = 0.1$ and $\theta/T_C = 1.21$ for $X = 0.2$. With increasing chromium concentration, the exchange field increases by 14% ($\theta(X = 0.2)/\theta(X = 0.05) = 1.14$). The effective magnetic moment decreases by two to three times with increasing chromium concentration at $T>T_p$.

Thus, in the $MnZn_{1-X}Cr_XSb$ system, a crossover of magnetic and electrical characteristics was detected above the Curie temperature, caused by the pinning of spin polarons.

The research was supported by the Russian Science Foundation (project No. 25-42-10003, https://rscf.ru/project/25-42-10003) and Belarusian Republican Foundation for Fundamental Research (project No. T26RNF-038).

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CONTROLLING OF THE NONLINEARITY OF A NEEL SKYRMION IN GEOMETRICALLY CONFINED NANOSTRUCTURES VIA A BIAS MAGNETIC FIELD

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Magnetic skyrmions are vortex-like magnetization configurations possessing a nonzero topological charge [1]. The growing interest in such inhomogeneous states is due to their stability, the ability to excite their dynamics by spin-polarized current or an external microwave magnetic field, which makes it possible to use skyrmions for designing information recording and storage devices, logic elements, oscillators, and detectors. In this work, the dependences of the oscillation frequency and the nonlinearity coefficient on the bias magnetic field applied perpendicular to the plane of a thin nanocyclinder hosting a Neel skyrmion are derived.

The Thiele model is commonly used to describe the dynamics of a magnetic skyrmion. However, this model does not account for the deformation of the skyrmion shape during its motion toward the boundary. In [2], it was shown that such deformation significantly affects the skyrmion dynamics in a thin magnetic film. The necessity to consider inhomogeneous magnetization distribution at the sample boundary leads to representing of the magnetization as a weighted sum of the skyrmion ansatz, which contains two parameters that are functions of guiding center displacements and the applied bias magnetic field, and a partially displaced circular Neel-type domain wall. The deformation of the skyrmion, in turn, demonstrates the need to derive and use a generalized Thiele model. Subsequent transformations which convert generalized Thiele equation to the quasi-Hamiltonian form lead to the following form of Hamiltonian function

$$H_c = \omega|c|^2 + N|c|^4,$$

where c, c^* are circular coordinates and $|c|^2$ proportional to power of skyrmion precession. The obtained in this work frequency ω and the nonlinearity coefficient N are functions of the applied bias magnetic field, and their dependences are shown in Fig 1. Thus, we demonstrated that for skyrmion oscillator such frequency and nonlinearity can be effectively controlled tuning solely magnitude of the bias magnetic field B, while for the oscillators with uniform ground state requaries also tilt angle variation [3], which is more complicated for practical realization.

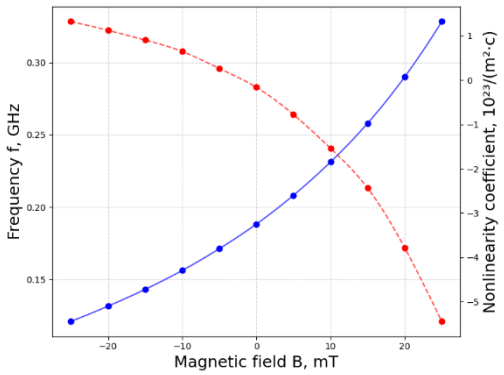

Fig. 1. Dependencies of the oscillation frequency $f = \omega/2\pi$ (blue solid line) and nonlinearity coefficient (red dashed line) on the bias magnetic field.

This study was supported by the Russian Science Foundation, grant No.25-79-20053.

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MAGNETIC PROPERTIES AND ELECTRICAL RESISTIVITY OF FE(NI)-MN-AL MELT-SPUN RIBBONS

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[2] Institute for Physical Research, Ashtarak, Armenia
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Experimental studies of bulk sample [1] and melt spun ribbons [2] of Fe_2MnAl have revealed that it undergoes a long-range magnetic ordering at Curie temperature T_C ~ 150 K and demonstrates a temperature dependence of the electrical resistivity which is uncommon for metals. On the other hand, it has been shown that deviation from the stoichiometry and a partial substitution of Fe for Ni brings about a significant increase in T_C of Fe_2MnAl. What is more important, the off-stoichiometric Ni-substituted Fe(Ni)-Mn-Al polycrystalline Heusler alloys demonstrates superior superelastic properties [3] which are of vital importance for practical applications.

So far, the Fe(Ni)-Mn-Al alloys have been intensively studied with respect to their martensitic transformations and superelastisity. Works devoted to the investigation of other physical properties of these materials are virtually absent in the literature. This motivated us to study basic magnetic and transport properties of polycrystalline $Fe_{43.5}Mn_{34}Al_{15}Ni_{7.5}$ (at.%) prepared by a rapid solidification technique.

Results of magnetic measurements revealed that the isothermal magnetization of $Fe_{43.5}Mn_{34}Al_{15}Ni_{7.5}$ demonstrate behavior inherent to high-permeability ferromagnetic materials. The magnetization M quickly saturates in weak magnetic fields and slightly grows due to paraprocess at further increase in the magnetic field strength H. At T = 10 K, the saturation magnetization M_S is ~ 90 A·m^2/kg which corresponds to the magnetic moment ~3.3 μ_B/f.u.

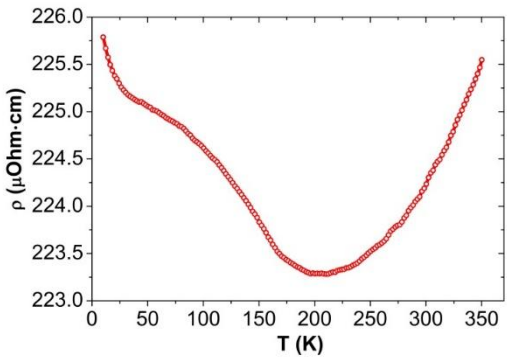

Fig. 1. Electrical resistivity ρ *vs* temperature T in $Fe_{43.5}Mn_{34}Al_{15}Ni_{7.5}$.

Transport properties of the $Fe_{43.5}Mn_{34}Al_{15}Ni_{7.5}$ melt spun ribbons turned out to depend weakly on temperature (Fig. 1). Namely, variation in the absolute value of electrical resistivity ρ did not exceed 2% in the whole measured temperature range ($10 \le T \le 350$ K). Besides, a crossover of ρ from semiconducting-like to metallic-like behavior was observed at ~205 K. Considering absence of structural transformation in this temperature region, it can be suggested that an enhancement of the charge carriers scattering of on magnons when approaching Curie temperature T_C is a possible origin of the observed crossover.

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POSTER SESSION

Magnetic Materials I

Tuesday, 18 August, 18:00 - 20:00

MAGNETIC PROPERTIES OF LANTHANUM FERRITE ($LaFeO_3$)

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Lanthanum ferrite ($LaFeO_3$) has an orthorhombic perovskite structure and is widely studied in the field of magnetic materials due to its strong antiferromagnetic and good dielectric properties. This compound exhibits a high Néel temperature, low magnetic losses, and excellent chemical stability [1, 2]. The Faraday method is a highly sensitive and reliable technique for determining magnetic properties — particularly for weakly paramagnetic and antiferromagnetic materials.

In this work, the magnetic susceptibility $\chi(T)$ of $LaFeO_3$ samples synthesized by the sol-gel method was measured using the Faraday method. The results of two independent samples were compared and benchmarked against literature data.

$LaFeO_3$ samples were synthesized by the sol-gel method: $La(NO_3)_3$ and $Fe(NO_3)_3$ salts were dissolved in stoichiometric ratios, dried at 100°C, and calcined at 800°C for 4 hours. The magnetic susceptibility $\chi(T)$ was measured using a Faraday magnetic balance in the temperature range from 25°C to 800°C. The Néel temperature T_N was identified as the minimum of the $d\chi/dT$ curve. A linear approximation of the Curie-Weiss law $1/\chi = (T - \theta)/C$ was applied to the high-temperature region.

The $\chi(T)$ curve for both samples showed a monotonic decrease with increasing temperature. For sample 1, the Néel temperature was determined to be T_N = 570°C (843 K). Compared to the literature value of 467°C (740 K), the synthesized samples exhibit a notably higher Néel temperature.

Based on the Curie-Weiss analysis, the Curie-Weiss temperature for sample 1 is θ = 471°C with a coefficient of determination R^2 = 0.453. The effective magnetic moment for sample 1 was calculated as μ_{eff} = 1.09 μ_B, which differs significantly from the literature value of 5.92 μ_B. This discrepancy may be attributed to chemical non-stoichiometry in the sample composition or limitations of the measurement range. In $LaFeO_3$ samples measured by the Faraday method, $T_N \approx$ 843 K, which exceeds the literature value of 740 K. This indicates the need for further investigation of synthesis conditions and structural properties of the samples. The low R^2 value of the Curie-Weiss fit suggests that the high-temperature region should be measured over a sufficiently wider range.

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ENHANCEMENT THE COERCIVITY OF Re-Fe-B MAGNETS FREE OF HEAVY RARE EARTH ELEMENTS BY GRAIN BOUNDARY DIFFUSION

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High-energy Re-Fe-B magnets are currently widely used in magnetic systems of various technical devices, often operating at high temperatures. These applications require not only high remanence, but also high coercivity.

To achieve high coercivity an important task is to suppress defects at grain boundaries, where the magnetocrystalline anisotropy field is locally reduced. Substituting terbium for some of the neodymium is effective in increasing the magnetic anisotropy field. However, this leads to a significant reduction in remanent magnetization, as the magnetic moments of the terbium atoms in the compound are aligned antiparallel to those of iron. Diffusion of terbium atoms along grain boundaries by annealing the magnet applying a diffusible coating enriched with a heavy rare earth element allows for the localization of terbium atoms primarily near the grain surface and significantly reduces losses in remanent magnetization.

Thus, the aim of this work is to investigate the effect of diffusion annealing of (Nd,Pr)-(Fe,Co,Cu,Ga)-B magnets using surface contact with rapidly quenched Tb-Cu alloy ribbons on their hysteresis properties. Changes in the phase composition, magnet microstructure, and elemental composition of the grain and intergranular phase with increasing diffusion annealing time are studied in detail.

The use of a modified technique for applying a thin layer of a diffusible coating to the magnet surface, in which no more than 0.02% of the Tb-Cu alloy mass is consumed per unit mass of the magnet, resulted in the diffusion of terbium atoms along the grain boundaries and surface layer, enabling an increase in the H_{cJ} value by 30% (to 23 kOe) without significant losses in B_r and $(BH)_{max}$ values due to the formation of a «core-shell» grain structure (Fig. 1). Control over the magnet's hysteresis characteristics was established.

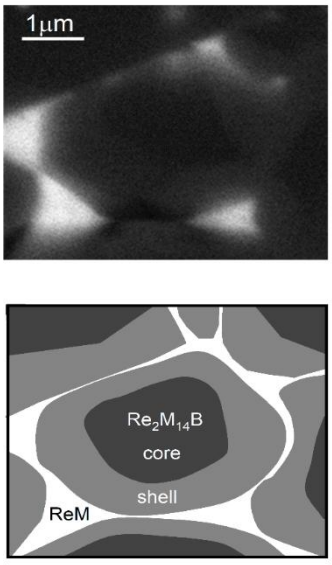

Fig. 1. «Core-shell» grain structure after diffusion annealing of a magnet with rapidly quenched Tb-Cu alloy ribbons.

This study was supported by the Russian Science Foundation, project no. 24-12-20025, https://rscf.ru/project/24-12-20025/ and the Government of the Sverdlovsk Region. The production of alloys was carried out according to the framework of the State Assignment of the Ministry of Education and Science and Higher Education of the Russian Federation (topic “Magnet,” no. 122021000034-9).

A RESONANT PHOTOEMISSION STUDY OF THE ERFE$_2$MN$_X$ (X = 0, 0.1) INTERMETALLIC COMPOUNDS

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The non-stoichiometric intermetallic RT_2Mn_x (R – rare earth element, T = Ni, Co, Fe) compounds with the cubic C15 Laves phase structure of the $MgCu_2$-type (space group $Fd\bar{3}m$) attract attention with their changing magnetic properties depending on transition metal amount and the choice of rare earth element [1-3]. In addition to the magnetic properties, the electronic structure also changes, which currently requires clarification, in particular, the contribution of the rare earth *f*-states to the valence band (VB) and an assessment of the *R*-*T*, *T*-Mn, *R*-Mn sublattices exchange interactions.

The electronic structure of $ErFe_2Mn_x$ (x = 0, 0.1) intermetallic compounds with Laves phase structure was studied by resonant photoemission spectroscopy using synchrotron radiation at the NanoPES beamline of the Kurchatov accelerator-storage complex of a specialized synchrotron radiation source (NRC Kurchatov Institute, Moscow). Using synchrotron radiation as a source of photons for recording photoemission allows for precise selection of the excitation energy (photon energy range 25-1500 eV), which in turn makes it possible to study the localization of 4*f*-electrons of erbium and 3*d*-electrons of iron and manganese in the VB.

Resonant photoemission spectroscopy makes it possible to study not only the ground state, but also the lifetime of the excited state (a core level-hole – VB electron), determine the energies of VB single-particle states and two-hole states on selected atoms see reactions to the sudden appearance of the core-level photo-hole. The presence of a second transition metal changes the intensity of the erbium spectra, indicating the presence of exchange interactions between their sublattices. Photoemission from iron atoms in the ternary compound does not undergo significant changes, indicating a negligible exchange interaction between iron and manganese.

Support by the Russian Science Foundation (project No 23-72-00067) is acknowledged.

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EXCHANGE BIAS EFFECT IN CHROMIUM- SUBSTITUTED Fe_3Se_4

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Exchange bias effect (EB) is a shift of the magnetic hysteresis loop along the magnetic field axis, observed in magnetically heterogeneous systems. This effect is typically associated with the formation of unidirectional anisotropy due to the exchange interaction at the interfaces between magnetic phases with different magnetic orderings, for instance, between ferromagnetic (FM) and antiferromagnetic (AF) phases, provided that there is sufficient magnetocrystalline anisotropy in the AF phase. Although this effect has been known for more than 60 years, it continues to attract considerable interest due to its practical applications in microelectronics and the ongoing search for new materials based on this effect [1].

Recently, we discovered the presence of a magnetization compensation point at $T_{comp} \approx 140$ K and a large exchange bias effect in the compound Fe_2CrSe_4, which has a monoclinic crystal structure consisting of regions described by space groups I2/m and B2, and exhibits ferrimagnetic ordering below 300 K [2]. The shift of the magnetic hysteresis loops, characterized by the exchange bias field H_{EB}, reaches a value of 6. 6 kOe at 2 K [2], which was attributed to the heterogeneous magnetic state of the sample due to the non-uniform distribution of iron and chromium atoms. Additional heat treatments have a strong influence on the magnitude of the EB effect in the Fe_2CrSe_4 sample. To elucidate the mechanism of the exchange bias in this compound and to determine the main factors affecting the magnitude of the effect, in the present work we have synthesized the $Fe_{3-x}Cr_xSe_4$ samples with deviations in the chromium atom concentration around x = 1.0, studied their structure and magnetic properties, and also performed neutron diffraction experiments on the Fe_2CrSe_4 sample to determine the distribution of chromium and iron atoms in the cation sublattice.

The $Fe_{3-x}Cr_xSe_4$ compounds with x = 0.9, 1.0 and 1.1 were synthesized by solid-state reaction in evacuated ampoules at 900°C followed by annealing. Crystal structure was characterized by Xray diffraction (Bruker D8 Advance) and powder neutron diffraction at the IBR-2M pulsed reactor (Dubna). Magnetization was measured from 2 K to 350 K in fields up to 90 kOe (PPMS DynaCool) and from 80 K to 400 K in fields up to 17 kOe (Lake Shore VSM 7407). The ferrimagnetic transition temperatures for $Fe_{3-x}Cr_xSe_4$ with x = 0.9, 1.0 and 1.1 were determined as 317 K, 300 K and 301 K, and compensation temperature $T_{comp} \approx$ 80 K, 140 K and 240 K, respectively. The spontaneous exchange bias decreased to 0.5 kOe for the sample with the Cr content x = 1.1 but remained nearly unchanged for x = 0.9 (H_{EB} = 6.5 kOe). Neutron diffraction of Fe_2CrSe_4 in the paramagnetic state (at T = 320 K) showed that Cr atoms are mainly located in a completely filled cation layer together with Fe atoms (in 2*a* positions). This non-random distribution of chromium atoms apparently leads to the formation of quasi-two-dimensional Cr clusters in cationic layers, which results in the occurrence of exchange bias in this layered system due to competing Fe-Fe, Fe-Cr and Cr-Cr exchange interactions.

Support by IMP UB RAS youth project № m 01-25.

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SYNTHESIS AND FERROMAGNETIC RESONANCE OF HEMATITE SINGLE CRYSTALS

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Hematite α-Fe_2O_3 is of interest for microwave and spintronic applications due to its antiferromagnetic ordering, the presence of a weak ferromagnetic moment above the Morin temperature, and the ability to excite magnetic resonance in the gigahertz range. Unlike traditional ferrite materials, the resonant properties of hematite are determined by strong exchange interactions and magnetic anisotropy, making it a promising candidate for creating tunable microwave structures [1].

This study investigated the synthesis of hematite single crystals using solution-melt crystallization. Bi_2O_3–Na_2CO_3 flux system was used, allowing for a lower effective crystallization temperature of Fe_2O_3 and eliminating the need for fluxes based on V_2O_5. The synthesis was conducted in a platinum crucible in a muffle furnace.

The phase composition of the obtained crystals was studied by X-ray diffraction using CuKα radiation. Analysis of the diffraction patterns revealed that the main reflections correspond to the α-Fe_2O_3 phase. The calculated unit cell parameters were $a = b = 5.0342(5)$ Å and $c = 13.7460(5)$ Å, which is consistent with the literature data for hematite.

The resonance properties of the samples were studied using broadband VNA spectroscopy on a coplanar waveguide. With varying external magnetic fields, a change in the transmission coefficient S_{21} was recorded, associated with the absorption of microwave power upon excitation of the quasi-ferromagnetic α-Fe_2O_3 mode. In the studied magnetic field range, a shift in the resonant frequency from approximately 12 to 19 GHz was observed. The ferromagnetic resonance line width was about 40 Oe.The experimental dependence of the resonant frequency on the external field agrees well with the calculation performed taking into account the contributions of the effective field, exchange interaction, and the Dzyaloshinskii–Moriya interaction.

The obtained results demonstrate that solution-melt crystallization using Bi_2O_3–Na_2CO_3 flux produces α-Fe_2O_3 single crystals suitable for microwave magnetic resonance studies. The combined X-ray diffraction and VNA spectroscopy data indicate that these crystals hold promise for the further development of tunable microwave resonant structures. Further optimization should focus on reducing defects, controlling residual flux content, and narrowing the resonance absorption linewidth.

The work was carried out within the framework of the state assignment of the Kotelnikov Institute of Radio Engineering and Electronics of the Russian Academy of Sciences.

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TEMPERATURE DYNAMICS OF THE PROPAGATION VELOCITY AND ATTENUATION OF ELASTIC VIBRATIONS IN MANGANESE-ZINC SPINEL FILMS IN THE VICINITY OF THE MAGNETIC PHASE TRANSITION

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The investigation of the acoustic properties of magnetoelastic materials near magnetic phase transitions (MPTs) is of considerable interest for the development of highly sensitive ultrasonic sensors and magnetoacoustic diagnostic devices [1]. In nonstoichiometric manganese–zinc spinel (MZS) crystals, the magnetic anisotropy constants K_1 and K_2 exhibit pronounced temperature dependence. At the spin-reorientation phase transition temperature T_p, the first anisotropy constant K_1 becomes zero [2]. Such behavior leads to a significant modification of the magnetoelastic coupling, which in turn strongly affects the effective elastic moduli, as well as the propagation velocity and attenuation of ultrasonic waves [3]. In the present work, numerical simulations of nonlinear magnetoelastic dynamics were performed for magnetic films with parameters corresponding to the nonstoichiometric spinel crystal $Mn_{0.64}Zn_{0.36}Fe_{2.1}O_4$ within a temperature range encompassing the transition temperature T_p. The equations of magnetoelastic dynamics were solved for three characteristic temperature regimes: the low-temperature region below T_p', the intermediate region of the magnetic phase transition T_p'–T_p'', and the high-temperature region above T_p'' [3]. Based on the solutions of the coupled equations of magnetic and elastic dynamics [1], time-dependent components of elastic displacement were obtained for each temperature regime. From these results, the temperature dependences of the propagation velocity and attenuation decrement of elastic vibrations were determined for the crystallographic directions [111] and [100]. It was shown that, near the magnetic phase transition, an anomalous decrease in the propagation velocity of elastic vibrations by 8–12% occurs, accompanied by a pronounced increase in attenuation exceeding 100% compared to the regions far from the magnetic phase transition. The obtained temperature dependences of the velocity and attenuation of elastic vibrations, derived from numerical solutions of the magnetoelastic dynamics equations, were compared with available experimental data on the propagation velocity and attenuation decrement of ultrasonic waves in manganese–zinc spinel crystals [2].

The simulation results demonstrated that the amplitude of the temperature-dependent maximum of the attenuation decrement in the MPT region under an applied static magnetic field first increases and then decreases. This strong sensitivity of the elastic characteristics to the external magnetic field near the phase transition indicates promising opportunities for the development of devices with magnetically tunable acoustic properties.

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THEORETICAL AND EXPERIMENTAL ANALYSIS OF THE ELECTRONIC BANDS AND MAGNETIC ORDERING PROPERTIES OF GADOLINIUM FERROBORATE

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In this study, the magnetic ordering regularities, electronic band structure, and crystal lattice dynamics of gadolinium ferroborate within the wide temperature interval of 293–1123 K were analyzed through the integration of theoretical and experimental methods. In this context, gadolinium ferroborate, which is considered an isostructural analogue of the natural huntite mineral ($CaMg_3(CO_3)_4$), possesses particular scientific and practical significance. This compound, belonging to the class of multiferroics, exhibits a unique synergy of magnetic, electrical, and magnetoelectric properties.

Experimental investigations carried out to determine the temperature dependence of the inverse magnetic susceptibility of gadolinium ferroborate demonstrated that, although this functional relationship generally exhibits a linear character, two anomalous inflection points are observed at T_1=853 K and T_2=943 K. Mathematical analysis of the experimental curves indicates that within the three principal intervals: a) 293 K<T<853 K; b) 853 K<T<943 K; and c) 943 K<T<1123 K, the magnetic susceptibility perfectly obeys the classical Curie–Weiss law. The singularities observed in the $\chi^{-1}(T)$\ dependence provide evidence that profound structural transformations, namely spatial structural phase transitions, occur within the crystal lattice of gadolinium ferroborate at these temperature points.

The experimental results confirm that, despite thermodynamic phase transformations, the effective magnetic moment of gadolinium remains nearly unchanged. This phenomenon indicates that the magnetically active ground state of the gadolinium ion exists in a strongly localized quantum state. In contrast, the energy of the paramagnetic exchange interaction plays a central role in the formation of the paramagnetic Curie temperature and in the energetic spectrum of the system.

The emergence of magnetic ordering nuclei within the system and the stabilization of local order are determined by the degree of hybridization between the following two principal electronic subsystems: 3d (Fe)–4f (Gd). As a result of decreasing temperature or local structural deformations, the indirect exchange integral between the electrons of the partially filled 3d shell of iron ions and the localized electrons of the inner 4f shell of gadolinium ions increases sharply. Consequently, this intensifies the spin-polarization phenomenon in the electronic band structure and fundamentally alters the macroscopic magnetic properties of the material.

In conclusion, the magnetic anomalies and phase transitions observed in gadolinium ferroborate crystals are intrinsically associated with their electronic band structure and with the trigonal chain anharmonicity of the crystal lattice. The obtained results provide the possibility for the targeted control of magnetic phase states in complex 3d–4f oxide systems.

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SINGLE DOMAIN WALL PROPAGATION IN CO-RICH MAGNETIC MICROWIRES WITH GRADED MAGNETIC ANISOTROPY

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Amorphous magnetic wires have attracted great interest owing to unusual magnetic properties, suitable for promising applications [1,2]. The so-called Taylor-Ulitovsky technique allows manufacturing amorphous magnetic wires of the widest diameters range (from 200 nm up to 100 μm) covered with an insulating and flexible glass-coating [1,2]. The domain wall, DW, velocities observed in amorphous microwires with magnetic bistability are generally an order of magnitude superior to that of planar nanowires [1]. The degree of the DW dynamics control is essentially relevant for proposed applications. The controllable DWs nucleation and propagation have been predicted in such magnetic materials with graded magnetic anisotropy [3]. Such graded magnetic anisotropy was obtained using rather complex techniques, such as a change in the chemical composition during the thin films deposition [3]. Recently, we proposed simple method to prepare Fe-rich glass-coated microwires with graded magnetic anisotropy by stressannealing at variable temperature [1]. On the other hand, hysteresis loops of Co-rich microwires can be substantially tunned by annealing conditions: annealing temperature and time [1].

We studied the effect annealing in temperature, T_{ann}, gradient on hysteresis loops and dependence of DW velocity, v, versus magnetic field, H, in $Co_{69.2}Fe_{3.6}Ni_1B_{12.5}Si_{11}Mo_{1.5}C_{1.2}$ microwire. The DW dynamics was studied using modified Sixtus-Tonks method using 3 pickup coils placed along the studied microwire. Such sample annealed in T_{ann} gradient exhibits spatial variation in local hysteresis loops: a gradual modification of the local hysteresis loops from almost linear (typical for as-prepared sample) to perfectly rectangular, i.e. graded magnetic anisotropy. As earlier predicted, in the region with graded anisotropy we observed unusual DW propagation where the DW velocity, v, is non-uniform along the microwire. While in the region annealed at constant T_{ann}, the DW propagates with constant velocity.

Resuming, have proposed rather simple method to design graded magnetic anisotropy in Corich magnetic microwire by annealing of microwires with a temperature gradient. Such graded anisotropy is suitable for engineering of DW dynamics.

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DFT INVESTIGATION OF CATION ORDERING AND MAGNETIC PROPERTIES IN NICRBO$_4$ WARWICKITE

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Warwickite-type borates (general formula MM′BO$_4$) have attracted significant attention as a versatile platform for designing multifunctional magnetic materials, yet the interplay between cation ordering and magnetic exchange in mixed transition-metal systems such as NiCrBO$_4$ remains largely unexplored, motivating the present DFT+U study. Warwickites offer a flexible crystallographic framework where two non-equivalent octahedral sites (M1 and M2) can accommodate different transition metal cations. In NiCrBO$_4$ M1 and M2 sites can be occupied by Ni^{2+} (d^8) and Cr^{3+} (d^3). Using DFT+U calculations, we systematically investigate different cation orderings over M1/M2, determine the ground state magnetic structure, evaluate exchange constants, and analyses the role of Jahn-Teller (JT) distortions. Spin polarized DFT+U calculations (PBE+U) are performed with the projector augmented wave method. Different ordering patterns were considered, including Ni on M1/Cr on M2, Cr on M1/Ni on M2, and mixed ordered configurations. The total energies of the ordered configurations show that the most stable ordering is the mixed ordering where Ni and Cr ions occupy as M1 as well as M2 sites with the alternation along the *a*-axis, which results in doubling of the cell in this direction. The ordering where Ni occupy M1 site and Cr occupy M2 site is slightly higher by energy indicating strong site selectivity driven by JT effects. NiO$_6$ octahedron on M1 and M2 sites exhibits a characteristic tetragonal elongation, whereas, the CrO$_6$ octahedron on M2 is nearly regular. To obtain the possible magnetic configurations for *Pnma* symmetry group, the representation analysis was performed and the total energy of different magnetic configurations was calculated and compared. The ground state is an antiferromagnetic with antiferromagnetic coupling within the *bc* plane and ferromagnetic alignment along the *a* axis. The calculated magnetic moments consistent with high spin configurations. Exchange coupling constants were extracted via four-state method within a Heisenberg model [1]. The overall magnetic ordering is determined by the competition between antiferromagnetic and ferromagnetic exchange constants.

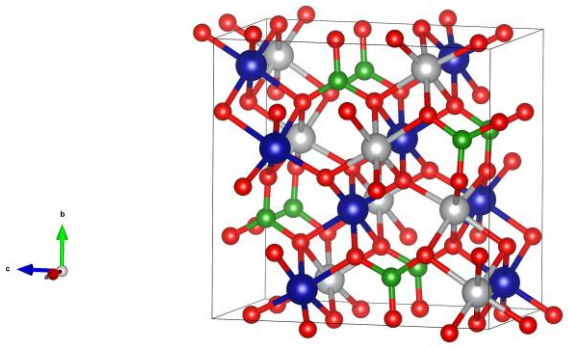

Fig.1. The lowest energy cation ordering structure in NiCrBO$_4$ warwickite. Blue and grey balls are Cr and Ni ion correspondingly, green ball is boron atoms, red balls are oxygen atoms.

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PHASE TRANSITIONS IN $GDFE_{3-X}MN_X(BO_3)_4$

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$GdFe_{3-x}Mn_x(BO_3)_4$ is a new member of rare-earth borates family with the huntite structure and common formula $ReM_3(BO_3)_4$ (Re being a rare-earth element or Y; *M* = Al, Cr, Fe, Ga, Sc) which represent a wide class of modern prospective multiferroic materials [1 - 2]. The studied sample with $x = 0.27$ has been synthesized by flux growth technique using Mo- and W-free solvent based on Bi_2O_3-B_2O_3-Na_2O [3].

Relative to the unsubstituted compound $GdFe_3(BO_3)_4$ the obtained $GdFe_{3-x}Mn_x(BO_3)_4$ demonstrates significant change in phase transitions cascade [2]. The analysis of the thermal and field magnetization dependences of the synthesized $GdFe_{3-x}Mn_x(BO_3)_4$ reveals a series of low-temperature features in the form of a shift of the temperatures T_N and T_{SR} as compared to those characteristic for unsubstituted $GdFe_3(BO_3)_4$ and a new feature is observed to appear at $T = 16$ K to a cascade of phase transitions due to the presence of manganese in the structure (Fig. 1).

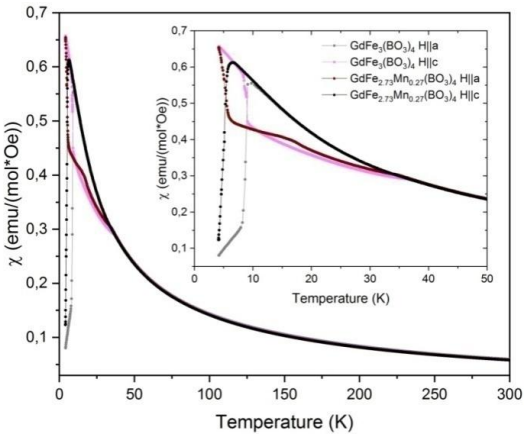

Fig. 1. Thermal dependences of the magnetic susceptibility of $GdFe_{2.73}Mn_{0.27}(BO_3)_4$ (wine – $H \parallel a$; black – $H \parallel c$), as compared to $GdFe_3(BO_3)_4$ (grey – $H \parallel a$; pink – $H \parallel c$).

Specific heat measurements reveal no features accounted for the structural phase transition $R32 \rightarrow P3_121$ typical for $GdFe_3(BO_3)_4$ at 150-170 K temperature range (depending on the impurities comes from the solvent). However, during the dielectric properties measurements it was found two peculiarities – at 16 K and at about 115 K. While the peculiarity at $T = 16$ K has magnetic origin (Fig. 1), the high temperature peculiarity at $T = 115$ K could be assigned to the structural phase transition in $GdFe_{3-x}Mn_x(BO_3)_4$. Raman spectroscopy study confirmed the presence of the phase transition at $T = 115$ K.

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THE INFLUENCE OF FLUX COMPOSITION ON THE MAGNETIC PROPERTIES OF $NDSC_3(BO_3)_4$ CRYSTALS

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Rare-earth borate crystals with a huntite structure have previously been studied as non-linear optical media, and more recently, as multiferroics [1]. The object of this study is $NdSc_3(BO_3)_4$ crystals, which exhibit a giant magnetoelectric effect [2]. The crystals were grown by spontaneous nucleation and mass growth on seeds from the following melt-solution [3]:

$88\%\ \text{wt.}\{Li_2WO_4 + 2B_2O_3 + 0.6Nd_2O_3\} + 12\%\ \text{wt.}\ NdSc_3(BO_3)_4.$

The magnetic properties of the grown crystals were measured using a PPMS (Physical Properties Measurement System) vibrating sample magnetometer in the temperature range of 4.2–300 K and in magnetic fields up to 9 T.

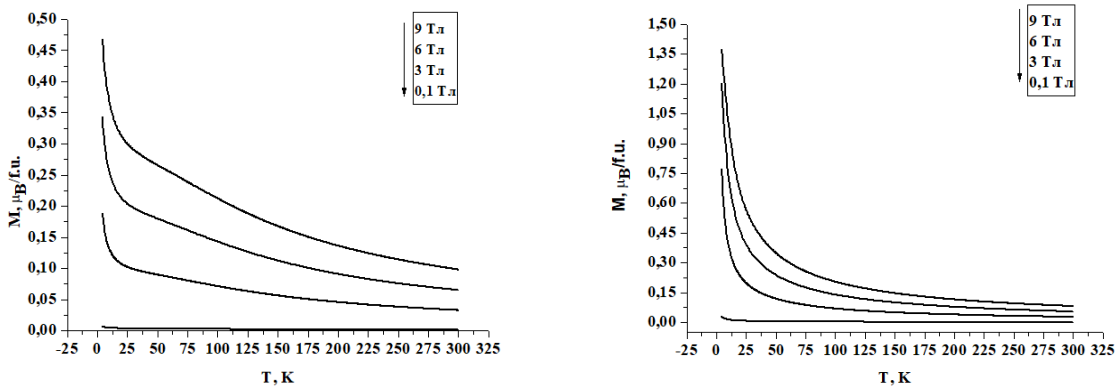

Fig. 1. Temperature dependences of the magnetization of a $NdSc_3(BO_3)_4$ crystal for a) H||c and b) H⊥c.

As seen from Fig. 1, the magnetization curves are typical for a paramagnet. However, when a magnetic field is applied parallel to the third-order axis, the magnetization exhibits a shape unusual for a classical paramagnet, which may result from the presence of impurities in the crystal matrix. The dependences demonstrate an anisotropy that enhances with the increasing magnetic field.

For the $NdSc_3(BO_3)_4$ crystal, the experimental data obtained using a lithium tungstate-based flux were compared with the data for a bismuth molybdate-based flux [2]. The comparison showed that the temperature dependences of both the magnetization and the inverse magnetic susceptibility are similar for both samples.

This work was supported in part by the RSF-KRSF grant No. 25-12-20011.

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INVESTIGATION OF THE ELECTRONIC AND MAGNETIC PROPERTIES OF FERRIMOLYBDENITE

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In this study, the electronic structure and magnetic properties of ferrimolybdenite $Fe_2[MoO_4]_3$ were investigated using the first-principles DFT+U computational method. Ferrimolybdenite belongs to the class of complex iron–molybdenum oxide compounds and is of significant scientific interest due to its specific electronic structure, magnetic ordering, and potential prospects as a functional magnetic material. The DFT+U approach was applied to more accurately describe the localized 3d electrons of iron atoms, as well as to determine the relationship between the crystal structure, electronic states, and magnetic behavior of the compound.

Crystal structure analysis shows that Fe, Mo, and O atoms in $Fe_2[MoO_4]_3$ form a stable oxide framework. In this structure, molybdenum atoms are coordinated with oxygen atoms, forming MoO_4 tetrahedral units, while iron atoms are mainly located in oxygen-coordinated polyhedral environments. Such a structural arrangement leads to the formation of strong ion-covalent Fe–O and Mo–O interactions. These bonds not only ensure the stability of the crystal lattice but also play an important role in determining the electronic and magnetic properties of the material.

The calculated total and partial densities of states show a noticeable asymmetry between spin-up and spin-down electronic states. This spin-dependent difference indicates the magnetic nature of ferrimolybdenite and the formation of spontaneous magnetic polarization. In the energy region near the valence band, the main contribution comes from Fe 3d states, while the lower part of the conduction band involves the d-states of both Fe and Mo atoms. The calculated electronic band structure along the high-symmetry directions of the Brillouin zone shows that the Fermi level is located close to the boundary between the valence and conduction bands. The presence of an energy gap between spin-dependent states confirms the semiconducting nature of $Fe_2[MoO_4]_3$.

The magnetic moment calculations show that iron atoms make the dominant contribution to the total magnetization. The average local magnetic moment of Fe atoms is about 3.42 μB. This value is lower than the ideal ionic value, which can be explained by Fe–O hybridization and partial delocalization of 3d electrons. In contrast, the magnetic moments of Mo atoms are very small, varying approximately in the range of 0.036–0.040 μB. This indicates that molybdenum atoms make only a weak direct contribution to magnetic ordering. Small induced magnetic moments are also observed in oxygen atoms, ranging from 0.018 to 0.045 μB. This suggests that oxygen atoms participate in magnetic coupling through Fe–O–Mo and Fe–O–Fe interaction pathways.

Overall, the obtained DFT+U results show that ferrimolybdenite $Fe_2[MoO_4]_3$ is a magnetic semiconducting oxide. Its magnetic properties are mainly formed by Fe 3d electrons and their interaction with surrounding oxygen atoms.

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SPIN ORBITAL INTERACTION IN THE INTERMETALLIC COMPOUNDS OF THE SYSTEM Er-In

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The rare-earth compounds have drawn attention due to their electronic properties which describe the presence of highly localised 4 f -electrons in them [1]. Among these, the binary compounds of the Er-In system (Er_2In, ErIn, and Er_3In_5) are of particular interest owing to the coexistence of highly localized 4f magnetic moments and itinerant conduction electrons. The Hall effect in magnetic materials, consist of two primary components: the normal Hall effect (R_0), and the anomalous Hall effect (R_s) originating from internal spin-dependent relativistic effects. The spin-orbit interaction plays a key role in generating the anomalous component through two main mechanisms: extrinsic scattering (comprising skew-scattering and side-jump mechanisms) and intrinsic Berry curvature contributions. While the structural and basic thermodynamic properties of Er-In phases have been mapped out to some extent, a systematic study of their high-temperature galvanomagnetic properties and the explicit role of spin-orbit coupling remains scarce.

In this work, we present a comprehensive experimental study on the temperature dependence of the Hall coefficient, magnetic susceptibility, and electrical resistivity of the Er_2In, ErIn and Er_3In_5 phases. By examining the relationship between R_H and χ, we extract the parameters of the spin-orbit interaction and elucidate the mechanisms governing charge transport in these compounds.

The samples were synthesized by arc-melting high-purity constituent elements (Er: 99.9%, In: 99.99%) under a purified argon atmosphere. To ensure high homogeneity the synthesized samples underwent a prolonged homogenization annealing process for a duration of 10 hours. The electrical resistivity (ρ) and the Hall coefficient (R_H) were measured using the standard four-probe DC method in a wide temperature range spanning from 77 K up to 1000 K. The magnetic susceptibility (χ) was determined using the Faraday balance method [2].

Our experimental results show, that both $R_H(T)$ and $\chi(T)$ decrease monotonically with increasing temperature, closely following a Curie-Weiss-like hyperbolic decay. This strong mirroring indicates that the temperature profile of the Hall coefficient is dominantly driven by the anomalous component R_s, which reflects the magnitude of the spin-orbit interaction between itinerant conduction electrons and the localized 4f electron shells. The anomalous Hall coefficient R_s reaches a maximum value of $2.48 * 10^{-7}$ m^3C^{-1} in the Er_2In compound, which correlates directly with its higher resistivity (ρ = 205 $\mu\Omega$ cm) and higher rare-earth concentration. In these systems, the physical origin of R_s is intrinsically tied to relativistic spin-orbit coupling. The mechanism can be interpreted via asymmetric scattering or the side-jump mechanism. Given that R_s scales progressively with the baseline resistivity (ρ) across the compounds (Er_2In > Er_3In_5 > ErIn), it points towards a scattering-induced extrinsic mechanism. The heavy 4f shell of Erbium induces a strong local potential gradient, causing spin-up and spin-down conduction electrons to scatter asymmetrically, creating the macroscopic anomalous Hall voltage observed experimentally.

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MAGNETIZATION REVERSAL OF IRON-BASED NANOCRYSTALLINE NANOELEMENTS WITH INCLUSIONS OF NON-MAGNETIC PHASE

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Using three-dimensional micromagnetic modeling, we studied the effect of non-magnetic phase inclusions in the volume concentration range p = 1 – 20% on the magnetization reversal processes of iron-based nanocrystalline nanoelements. The saturation magnetization of the magnetic phase is taken to be Ms = 1700 emu/cm^3, the exchange constant C = 2A = 2×10^{-6} erg/cm, the cubic magnetic anisotropy constant Kc = 4.8×10^5 erg/cm3. The size of the cubic numerical cells a = 5 nm does not exceed the exchange length in iron, $L_{ex} = \sqrt{C}/M_s$ ≈8.3 nm. The studied sample has the shape of an elongated parallelepiped with dimensions Lx >> Ly, Lz. The typical number of numerical cells is N ~ 10^4. Two alternative models for the distribution of the non-magnetic phase throughout the sample volume are considered. In the first model, the non-magnetic phase is represented by non-magnetic numerical cells randomly distributed throughout the sample volume with a given volume concentration p. The magnetic phase is nanocrystalline, so the orientation of the easy axes of cubic anisotropy of individual magnetic cells is random. In the second model, the non-magnetic phase is concentrated in thin layers separating single-crystal magnetic grains, the exchange coupling between which is characterized by a reduced value of the exchange constant $C_{ex0} = \eta C$, where the factor η = 0.1 – 0.9 is selected depending on the number of magnetic grains in the sample Ngr and the volume concentration of the non-magnetic phase p. As Fig. 1 shows, in both models considered, the coercivity of the element decreases with increasing concentration of the non-magnetic phase.

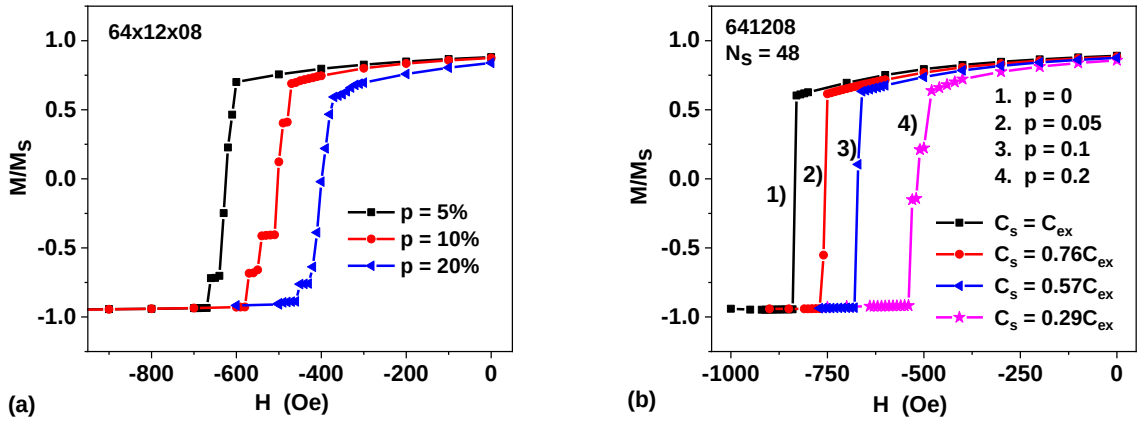

Fig.1 Descending branches of quasi-static hysteresis loops of an iron-based nanocrystalline element with dimensions of 64×12×08 cubic numerical cells for the first a) and second b) models considered, respectively

As Fig. 1 shows, by contrast to bulk materials in both models considered the coercivity of the nanoelement decreases with increasing concentration of the non-magnetic phase. Therefore, the parameters of hysteresis loop of nanoelements can be purposefully controlled by selecting the concentration of the non-magnetic phase and its distribution in the nanoelement.

EFFECT OF CALCIUM SUBSTITUTION ON THE MAGNETIC COMPENSATION TEMPERATURE IN IRON GARNETS

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Ferrimagnetic iron garnets with magnetic moment compensation exhibit a non-collinear magnetic phase in an external magnetic field. In such materials, unconventional spin dynamics and some other unique properties important for practical applications are observed experimentally. The compensation temperature T_C is determined by the cation composition of the garnet and depends on the degree of diamagnetic substitution of iron and the content of other magnetic cations.

This work presents the results of an experimental study of epitaxial (111) garnet films of composition $Bi_{0.7}Gd_{0.15}Y_{2.15-x}Ca_xFe_{3.42}Ga_{0.83}Al_{0.75}O_{12}$. Based on the temperature variation of magneto-optical hysteresis loops, the Néel temperature was determined to be 387±2 K, and the compensation temperature was found to depend on the calcium content: 200 K < T_C < 300 K for 0.06 < x < 0.12.

The substitution of trivalent cations by Ca^{2+} ions, due to charge compensation, leads to the appearance of Fe^{4+} ions. Tetravalent iron cations form an additional magnetic sublattice, which results in a change of T_C (Fig. 1).

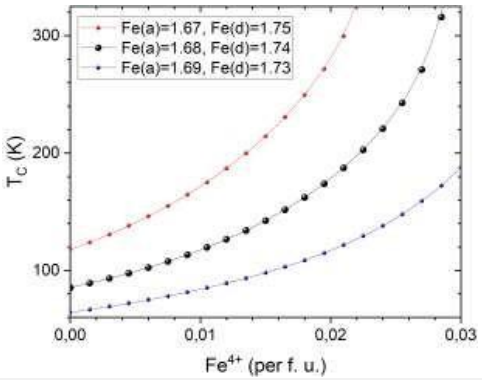

Fig. 1. Dependence of the compensation temperature T_C on the content of Fe^{4+} ions, calculated using molecular field theory.

The concentration of Fe^{4+} ions is lower than that of Ca^{2+} ions and decreases with increasing temperature due to thermal activation of $Fe^{4+} \rightarrow Fe^{3+}$ transitions. Furthermore, optical pumping can activate $Fe^{4+} \rightarrow Fe^{3+}$ transitions. Indeed, for the studied compounds, a photoinduced decrease in T_C by several degrees is experimentally observed when applying optical pumping with power up to 200 mW in the nearinfrared and optical ranges.

Fe^{4+} ions contribute additionally to the absorption spectra in the wavelength range 1 μm < λ < 1.6 μm. For the studied samples, a photoinduced increase in transmittance in the wavelength range 1 μm < λ < 1.6 μm was experimentally observed under optical pumping. The increase in transmittance is associated with the light-activated $Fe^{4+} \rightarrow Fe^{3+}$ transitions, providing additional confirmation of the proposed mechanism for the photoinduced modification of the compensation temperature.

This work was financially supported by the Ministry of Science and Higher Education of the Russian Federation, project № FZEG-2026-0011.

CORRELATED OPTICAL, VIBRATIONAL, AND SURFACE CHARACTERIZATION OF $Dy_3Fe_5O_{12}$ SINGLE CRYSTALS

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Rare-earth iron garnets $R_3Fe_5O_{12}$ are model ferrimagnetic oxides in which optical properties are governed by the interaction between Fe–O electronic states and localized rare-earth 4*f* states [1,2]. In this work, optical absorption, Raman spectroscopy, and atomic force microscopy (AFM) studies of $Dy_3Fe_5O_{12}$ single crystals were performed.

The optical absorption spectra measured in the range 200–1100 nm reveal a clear separation between high-energy and low-energy electronic excitations [3]. In the ultraviolet–visible region, intense absorption (10^4–10^5 cm^{-1}) is associated with electronic transitions within the Fe–O sublattice, including possible charge-transfer and correlation-driven intersite contributions. In the near-infrared region, weak absorption bands ($\lesssim 10^2$–10^3 cm^{-1}) attributed to Dy^{3+} intra-ionic 4*f*–4*f* transitions are observed.

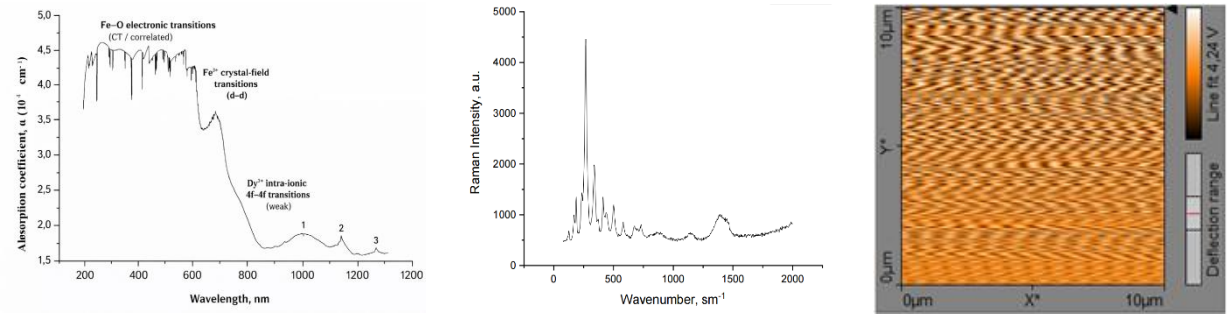

Fig. 1. Combined characterization of $Dy_3Fe_5O_{12}$ single crystals: (a) optical absorption spectrum α(λ); (b) room-temperature Raman spectrum; (c) AFM surface topography image.Put the name and description of figure here.

Raman spectroscopy reveals well-defined phonon modes characteristic of the garnet structure, indicating high crystalline quality and low structural disorder. AFM measurements demonstrate a morphologically homogeneous surface without periodic modulation or extended defects, confirming that scattering effects do not significantly influence the optical spectra.

The combined analysis shows that the optical response of $Dy_3Fe_5O_{12}$ is governed by weakly coupled Fe–O and Dy^{3+} electronic subsystems dominating different spectral regions. The obtained results provide a consistent framework for understanding excitation mechanisms in rare-earth iron garnets [4].

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METHOD FOR MEASURING MAGNETIZATION IN ALTERNATING MAGNETIC FIELDS

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Magnetocaloric materials continue to be in the focus of attention as working materials for promising magnetic cooling technology. Dozens of different materials with giant values of the magnetocaloric effect (MCE) are currently known. Recent studies in cyclic magnetic fields show that not all of them are promising in terms of the stability of magnetocaloric properties, as well as the dependence of these properties on the frequency of the magnetic field. Most of the materials studied in cyclic magnetic fields show a strong dependence on the frequency of the magnetic field, but it is difficult to establish the nature of this phenomenon only using the data on the adiabatic temperature change. Therefore, an important task is to study the parameters associated with the MCE, such as magnetization and magnetostriction (the latter in the case of the first-order phase transitions) in cyclic magnetic fields.

In this paper, a method for studying magnetization in alternating (AC) magnetic fields is proposed. The method is based on the law of electromagnetic induction, which states that for any closed circuit, the electromotive force (EMF) generated in it by a magnetic field is equal to the rate of change of the magnetic flux through this circuit, taken with a minus sign. As such a circuit, we used two oppositely wound coils. This is done in order to minimize the EMF induced in the coil without a sample. But due to the non-ideality of the coil geometry and its placement in an alternating magnetic field, some value of an EMF will be induced in the AC field. When placing a magnetic material in the center of the coil, the induced EMF will change due to the magnetic field created by the sample. The difference in EMF in the coil in an AC magnetic field with and without a sample will be proportional to the magnetization of the sample.

The reference magnetocaloric material gadolinium Gd was selected for testing and calibration the technique. Magnetization in alternating magnetic fields was also studied for other rare earth elements terbium Tb and dysprosium Dy. The studies were carried out both in a constant magnetic field using the vibration technique and in AC magnetic fields with a frequency of 0.3 Hz and a field change amplitude of up to 3 kOe. The measurements of the temperature dependences of magnetization for Gd, Tb and Dy at a low frequency of the field are in agreement with the results obtained by the vibration magnetometry method. In the future, the proposed method for studying magnetization will be used to study magnetization in alternating magnetic fields with an amplitude of up to 12 kOe and a frequency of up to 30 Hz.

The work was supported by the Russian Science Foundation, grant № 24-12-00362.

IRON-GALLIUM BORATES AS A MODEL OBJECT FOR STUDYING THERMAL EXPANSION OF THE MAGNETICALLY ORDERED MATERIALS

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Magnetoelastic interaction that determines a coupling between the elastic and magnetic subsystems in magnetically ordered materials [1], significantly affects the physical properties of many materials. Therefore, it is of high interest from both fundamental and applied science perspectives. This interaction is responsible for a number of properties discovered and studied in a prominent representative of such materials – iron borate, $FeBO_3$, – an easy-plane antiferromagnet with weak ferromagnetism [2]. In the present work, we have studied the influence of the magnetoelastic interaction on the thermal effects observed in diamagnetically diluted iron borate single crystals – iron-gallium borates, $Fe_xGa_{1-x}BO_3$. These crystals have been chosen as a model object for interpreting thermal changes in lattice parameters and for determining magnetoelastic constants based on X-ray diffraction data.

Temperature dependences of the crystal lattice parameters of $Fe_xGa_{1-x}BO_3$ single crystals have shown that the nature of the thermal expansion significantly changes upon passing through the Néel point. In the magnetically ordered state below the phase transition temperature, thermal changes in the crystal lattice parameters are additionally influenced by magnetostrictive deformations. The experimental results are interpreted within the framework of the developed theoretical model, based on the symmetry of the crystal and its domain structure. Temperature dependences of magnetoelastic constants for $Fe_xGa_{1-x}BO_3$ crystals have been obtained for the first time.

The results are useful, for instance, for assessing the influence of magnetostriction on X-ray rocking curves characterizing the perfection of the crystal structure. The latter is very important, in particular, for the practical application of $FeBO_3$-based single crystals as monochromators for synchrotron radiation [3].

The X-ray analysis studies have been out in the framework of a part of a state assignment for the National Research Center "Kurchatov Institute".

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THE EFFECT OF SURFACE TERMINATION ON THE MAGNETIC PROPERTIES OF RARE-EARTH MXENES ($RE_{1/3}TI_{2/3})_2X$ (RE = GD, HO, SM) WITH X= O, CL, F FUNCTIONALIZATION

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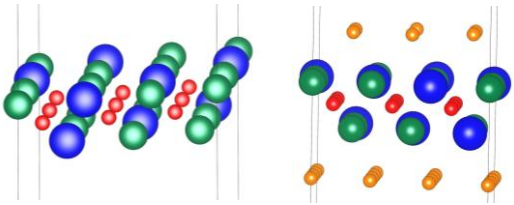
MXenes are a large family of two-dimensional materials with the general formula $M_{n+1}X_nT_x$ (M is a transition metal, X is carbon or nitrogen, T is a functional group (F, O, Cl, etc.), n = 1-3). MXenes have a unique combination of electronic, optical, mechanical, and other physical properties [1]. Due to their attractive properties leading to practical application, MXenes have come into the spotlight and have been actively studied for the past 20 years. Recent time two-dimensional MXenes incorporating rare-earth elements as M-element attract attention since offer a promising route toward atomically thin magnets with large magnetization. Here we focus on mixed compositions where one third of the metal sites are occupied by Gd, Ho, or Sm, and two thirds by Ti to study a realistic scenario that combines 4f magnetism with the structural stability of Ti-based MXenes. The stable ordered structure of MXenes is shown in Figure 1a. During the synthesis process, the termination of MXenes surfaces by the T = F, O, Cl, etc. functional groups is performed. The composition of these groups is determined by the chemistry of the medium during the etching and subsequent processing of MXenes. The magnetic behavior is highly sensitive to surface terminations (O, Cl, F) and cation ordering. To analyze the effect of surface functional groups on the structural and magnetic properties of the MXenes, the lowest energy atomic configurations and magnetic orderings were determined upon fluorine, chlorine and oxygen functionalization of the MXene surface. A systematic geometry optimization was performed to identify the most energetically favorable sites for O, Cl, and F on the MXene surface. The energy preferred configuration is shown in Fig. 1b. Our analysis shows that selecting the termination and controlling its spatial distribution is as important as the rare earth composition. Using DFT+U calculations, we obtained the magnetic ground states for bare and surface-functionalized $(RE_{1/3}Ti_{2/3})_2C$ MXenes. Oxygen termination suppresses local magnetic moments. In contrast, fluorine and chlorine rather stabilize the intrinsic magnetic order. Thus, our findings guide the rational design of rare earth MXenes for spintronic applications.



a) b)

Fig. 1. a) The stable ordered MXene structure; b) The lowest-energy site of functional groups on the surface. RE, Ti, C and X atoms are shown by blue, green, red and orange balls are shown correspondingly.

The study was supported by grant No. 26-22-20038 from the Russian Science Foundation, https://rscf.ru/project/26-22-20038/, and targeted funding (grant) from the Krasnoyarsk Regional Science Foundation.

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MAGNETOCALORIC EFFECT IN SINGLE CRYSTALS OF $GdCa_3Mn_3O_3(BO_3)_4$ GAUDEFROYITE

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The compounds of $ReCa_3(MnO)_3(BO_4)_3$ are artificial analogues of the mineral gaudefroyite $Ca_4(MnO)_3(BO_3)_3CO_3$ in which the carbon group $[CO_3]^{2-}$ and one of the Ca^{2+} cations are replaced by a borate group $[BO_3]^{3-}$ and a trivalent rare earth cation. Significant interest in these compounds is caused by the special hexagonal arrangement of structural elements in the crystal lattice with the formation of a kagome lattice. As a result, gaudefroyites are promising objects for research in the direction of geometrically frustrated magnetism. The greatest interest in these compounds is caused by the possibility of using these materials in for applications in the liquefaction and transportation of gases at low temperatures.

This paper presents studies of the magnetocaloric effect on a single crystal $GdCa_3Mn_3O_3(BO_3)_4$. The measurements were carried out in two directions of the magnetic field: along the *c* axis and the *a* axis. Figure 1 shows the results of the temperature dependence of the change in magnetic entropy in two directions and at different magnetic field strengths.

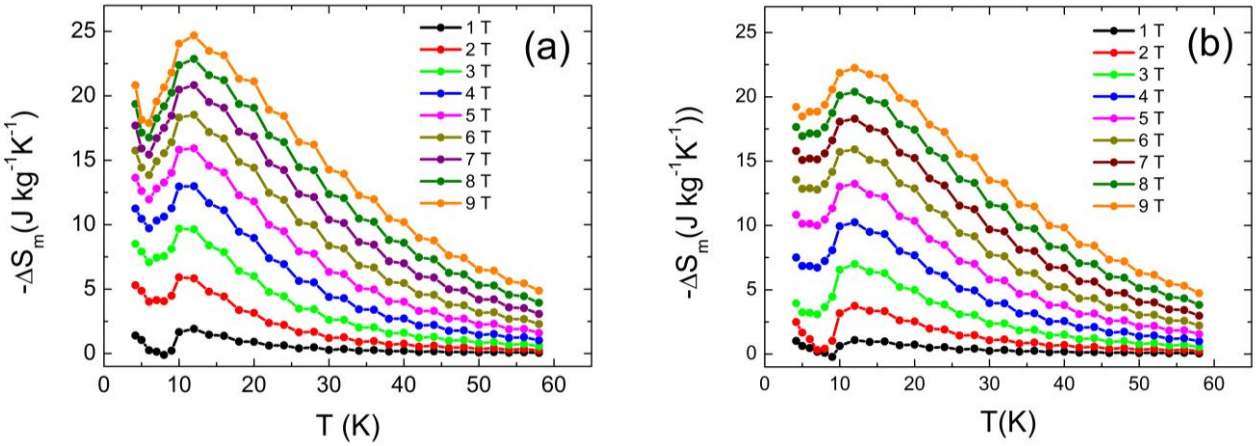

Figure 1. Temperature dependence of the magnetic entropy change in directions of magnetic fields H||a (a) and H||c (b).

It can be seen that the maximum change in entropy reaches the values $|\Delta S| = 22$ J kg^{-1}K^{-1} for the direction H||c and $|\Delta S| = 24$ J kg^{-1}K^{-1} for the direction H||a. According to generally accepted terminology, such changes $|\Delta S|$ are considered gigantic.

This research was funded by Russian Science Foundation, grant number № 25-12-20011 (https://rscf.ru/project/25-12-20011/), Krasnoyarsk Regional Science Foundation.

THE PROPERTIES OF THE $GD_{0,5}ND_{0,5}FE_3(BO_3)_4$ SINGLE CRYSTALS GROWN FROM DIFFERENT MELT-SOLUTIONS

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Multiferroic crystals with a structural formula similar to the natural material huntite have attracted attention in recent decades as a promising candidate for producing new elemental base materials. These crystals are also interesting because their properties are significantly determined by their production method. Most of these crystals are produced by the solution-melt method. The composition of the solvent significantly influences the composition of the growing crystal and, consequently, its properties. We used two types of solvent: one containing bismuth ions (1) [1] and one free of them (2) [2].

$$(100\text{-}n)\%\text{wt. } [Bi_2Mo_3O_{12} + pB_2O_3 + qGd_2O_3] + n\%\text{wt } Gd_{0,5}Nd_{0,5}Fe_3(BO_3)_4, \quad (1)$$

$$(100\text{-}n)\ \%\text{wt. } [Li_2WO_4 + pB_2O_3 + qGd_2O_3] + n\%\text{wt } Gd_{0,5}Nd_{0,5}Fe_3(BO_3)_4 \quad (2)$$

Sistems	n	p	q	$T_{sat,}{}^oC$
1	28	2,5	0,5	960
2	12	3	0,3	990

In this paper, we evaluate the influence of bismuth ions on the magnetic properties of crystals grown from a bismuth-containing solution/melt. Data obtained on crystals grown from a lithium tungstate system are presented for comparison.

Fig. 1. Field dependences of the magnetization of $Gd_{0,5}Nd_{0,5}Fe_3(BO_3)_4$ (solid curves) and $Gd_{0,5}Nd_{0,5}Fe_3(BO_3)_4$: Bi (dashed curves) measured at 4.2 K and in the B ∥ c (a) and B ⊥ c (b) geometry. The insets show the same data at a different scale.

Magnetic properties were studied using a PPMS QuantumDesign vibrating magnetometer (a shared-use facility at the Krasnoyarsk Science Center, Siberian Branch of the Russian Academy of Sciences) in a temperature range of 4.2–300 K and magnetic fields up to 9 T.

For magnetic field orientations H ⊥ c, a magnetic field-induced spin-reorientation transition is also observed, but at higher fields: $H_{SR2} \approx 40$ kOe for $Gd_{0,5}Nd_{0,5}Fe_3(BO_3)_4$ and $H_{SR2} \approx 35$ K for $Gd_{0,5}Nd_{0,5}Fe_3(BO_3)_4$:Bi, respectively. Here, a tendency toward a decrease in the transition temperature is again evident as Gd^{3+} ions are replaced by Bi^{3+} ions. Thus, magnetic studies show that in $Gd_{0,5}Nd_{0,5}Fe_3(BO_3)_4$ ferroborate crystals grown using a bismuth trimolybdate melt solution, Bi^{3+} ions replace Gd^{3+} ions in an amount of 6 at% and have a significant effect on the magnetic properties of the grown crystals.

This study was supported by grant No. 22-12-20019 provided by the Russian Science Foundation and the Krasnoyarsk Regional Science Foundation.

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MAGNETOSTRICTION AND THERMAL EXPANSION IN THE FERROMAGNETIC SEMIMETAL $MnZn_{1-X}Cr_XSb$

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The interaction of magnetic moments with lattice deformation in Weyl semimetals is unique due to their electronic structure. Lattice deformations can shift the position of Weyl nodes in impulse area, acting as an effective vector gauge field. Magnetoelastic effects are associated with strong spin-orbit interactions, which form the Weyl band structure. In magnetic Weyl semimetals, lattice deformation determines spin-orientation transitions and magnetostriction.

In the Weyl semimetal $MnZn_{1-x}Cr_xSb$, the lattice deformation with temperature was determined from the thermal expansion coefficient. Magnetostriction was studied in magnetic fields up to 12 kOe perpendicular to the plane of the sample and along the plane.

An increase in the linear dimensions of the samples in the temperature range of 120-130 K was found for samples x=0.1 and 0.2 upon heating, associated with a spin-reorientation transition in the plane and with the crystal lattice deformation as a result of rhombic distortion. The anomaly in the region of 170-180 K is caused by a spin-reorientation magnetic transition with a the spin rotation from the tetragonal axis into the plane, similar to $Mn_{1.15}Zn_{0.85}Sb$ [1]. The temperatures of the maxima at T=260 K of the magnetostriction coefficient are agrees with the temperatures of the extremes of dR/dT on AC and the reactive part of the impedance dX/dT, are associated with the topological transition. In the vicinity of the Curie temperature [2], a maximum thermal expansion coefficient is observed for concentrations x = 0.1 and 0.05.

The temperature dependence of the magnetostriction coefficient of $MnZn_{1-x}Cr_xSb$ changes sign twice and shows the compression of samples at magnetic transitions T=170 and 320 K. Below a temperature of 170 K, the sample is compressed in a magnetic field directed perpendicular to the plane of the sample, and in a field along the plane it increases. This may be caused by a field sign change of the magnetic anisotropy field [1].

The maximum magnetostriction in the vicinity of the Curie temperature is caused by a change of the exchange energy between spins, which leads to a sharp change of distance between nodes and a volume change, since the exchange energy depends from the distance between ions. In semimetals, high-mobility current carriers are associated with localized magnetic moments through *sd* exchange interactions. A change of magnetization causes a redistribution of the state density on the Fermi level and, accordingly, magnetostriction through the deformation potential.

The study was supported by grant 25-42-10003 from the Russian Science Foundation, https://rscf.ru/project/25-42-10003, and the Belarusian Republican Foundation for Basic Research No. T26RNF-038.

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THE IMPACT OF TORSIONAL DEFORMATION OF AMORPHOUS RIBBON ON THE CHIRALITY OF THE IMPEDANCE

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Amorphous metallic alloys possess a unique combination of physical properties that make them attractive for various practical applications [1]. For instance, Fe-based amorphous alloys exhibit higher corrosion resistance than crystalline stainless steel despite having a reduced chromium content. Their electrical resistivity is typically two to four times higher than that of crystalline counterparts, leading to lower eddy current losses [2]. Their exceptional soft magnetic properties, such as high permeability and low coercivity, allow for efficient energy conversion in transformers, motors, and electromagnetic shielding. Additionally, the amorphous structure provides a unique combination of high electrical resistivity and mechanical flexibility, making these alloys ideal for miniaturized, high-frequency devices and wearable electronics [2].

The geometric shape of the amorphous magnetic alloys dictates their widespread application. For instance, sensors based on the Giant Magnetoimpedance (GMI) effect commonly utilize amorphous microwires, which offer high sensitivity, low noise, and compact form factors. Meanwhile, amorphous ribbons are frequently used as cores in transformers.

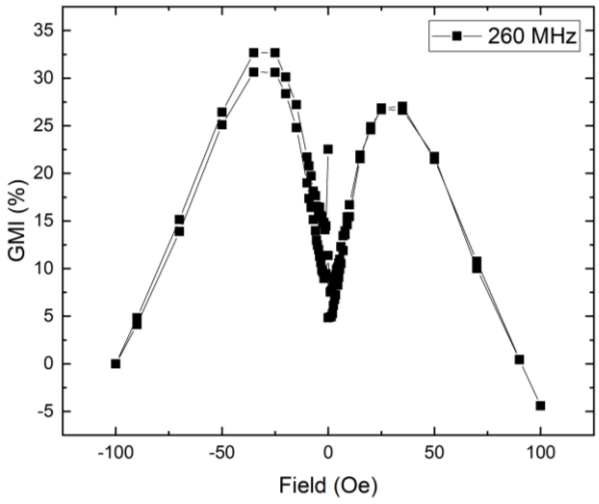

Fig. 1 Dependence of the GMI effect on the field in an amorphous magnetic tape twisted 360 degrees

The GMI effect is characterized by a change of the complex impedance of a sample carrying a high-frequency current which depends on the external magnetic field. Using magnetoimpedance measurements, we found that twisting stress leads to significant differences in GMI. Importantly, the asymmetry of the GMI curve with respect to the external magnetic field revealed the chirality of the ribbon — the handedness of the helical magnetic anisotropy induced by internal stresses. This asymmetry, manifested as a difference in the GMI response for positive and negative magnetic fields, directly reflects the presence of a helical magnetization structure and governs the sensitivity and linearity of GMI-based magnetic field sensors (see Fig.1). The effects achieved through the mechanical deformations of ribbons can serve as the basis for creating structures with modified properties. Previously we discovered that an amorphous wire coiled into a spring exhibits chirality (i.e., GMI dependency on the direction of the field) [3]. Given the potential of using amorphous ribbon, we decided to investigate whether a similar effect exists in ribbons subjected to torsion. As we are considering the possibility of using amorphous ribbons in sensors.

Thus, in this work we investigate the effect of torsional deformation on the impedance of amorphous ribbons.

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THE FILMS FeZrN AND FeTiB: THE PHASE-STRUCTURAL STATE AND THE SOFT MAGNETIC PROPERTIES DEPENDING ON THE PRODUCE CONDITIONS

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The continuous advancement of magnetic electronics and the consequently increasing demands on the properties of the soft magnetic materials pose the challenge of creating film ferromagnets characterized by a combination of high saturation magnetization, low coercive field, high permeability in microwave magnetic fields, and natural ferromagnetic resonance frequency exceeding the operating frequencies of the electronic device. Besides, the films should be characterized by high thermal stability of these properties. The physicochemical approach previously proposed and developed by the authors considers films of Fe – $Me_{III, IV}$ (Ti, Zr, Hf, Sc, Y, La) – X (B, C, N, O) alloy systems as promising soft magnetic materials. The film structure formed under the specific conditions of the deposition process followed by annealing is characterized by high thermal stability, which is due to the dispersion strengthening of the main high-induction αFe-based magnetic phase with the $Me_{IV}X$ phase. The detailed understanding and comprehensive data on the quantitative relationship between the specific fabrication conditions from one side and their phase-structural state and magnetic properties on the other side should be considered. We present last results on the relationship between the fabrication conditions of FeZrN and FeTiB films, belonging to above-mentioned class of promising materials, their phase-structural state and magnetic properties.

This work examines the FeZrN films produced using a unique ion-beam deposition method, which allows for the production of films of varying compositions in a single process, and the FeTiB films produced by magnetron deposition. X-ray diffraction data show that all films after deposition have a mixed structure, represented by a predominant nanocrystalline phase (a supersaturated bcc solid solution of Zr and N or Ti in αFe) and an amorphous phase. As Zr, N or Ti content in the films increases, the volume fraction of the amorphous phase increases in the as-deposited films, the grain size of the bcc phase decreases, and additional crystalline phases (ZrN, Fe_xN, or TiB_2) are formed, amounting no more than 10 vol%. All the films studied after annealing at 500ºC retain a mixed structure, which undergoes a number of changes: an increase in the volume fraction of nanocrystalline phases, depletion of the bcc Fe-based solid solution in Zr, N or Ti with a slight increase in the grain size of this phase.

The parameters of the stochastic magnetic structure (the relative size and the effective anisotropy field of stochastic domains and the local magnetic anisotropy field at the grain scale), saturation magnetization, coercive field, static permeability, and ferromagnetic resonance frequency of the films are quantitatively estimated and their interrelations are studied. The quantitative interrelation between static and dynamic magnetic properties of the studied films on one side and the phase composition and their magnetic microstructure parameters on the other side was presented. For the first time, three methods of determination of the magnetic anisotropy field were applied to the same material: correlation magnetometry (anisotropy field of stochastic domains), static hysteresis loop (coercive field), and frequency dependence of the permeability (anisotropy field from the Kittel equation).

RADIATION-INDUCED OXYGEN PARAMAGNETIC CENTERS IN FLUOROZIRCONATE GLASSES AND THEIR SPECTRAL-LUMINESCENT PROPERTIES

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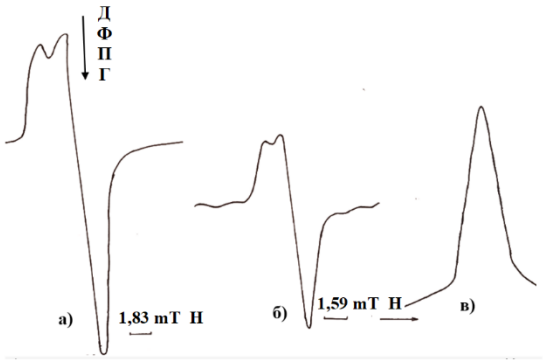
In this work, radiation-induced paramagnetic centers in fluorozirconate glasses were investigated using the method of Electron Paramagnetic Resonance (EPR). After γ-irradiation, signals with parameters $g_1 = 2.004$, $g_2 = 2.009$, and $g_3 = 2.027$ were detected, characteristic of oxygen-containing and peroxide radicals analogous to centers in silicate and oxide matrices. The EPR spectra of fluorozirconate glasses irradiated with a dose of 10^8 R are presented (Fig. 1).

It was shown that the shape and intensity of the EPR signals depend on the irradiation conditions and heat treatment; after annealing, the spectral resolution improves due to structural rearrangement of defects. The signal intensity in powdered samples is higher than in bulk glasses because of stronger interaction with oxygen from the surrounding environment.



The presence of oxygen in the glasses at concentrations of 10^{18}–10^{21} cm^{-3} was confirmed by the method of Rutherford Backscattering Spectrometry. It was established that impurities significantly affect the signal intensity: iron enhances the signals, whereas cerium and neodymium weaken them.

Spectral-luminescent studies revealed the appearance of an absorption band near 290 nm and a new luminescence band with a maximum at 520 nm after irradiation, which is associated with the formation of oxygen and peroxide radicals.

The obtained results confirm the key role of oxygen in the formation of radiation defects and luminescent properties of fluorozirconate glasses and are important for the development of radiation-resistant optical materials.

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CRYSTAL GROWTH, CHARACTERIZATION AND MAGNETOCRYSTALLINE ANISOTROPY OF NICR(BO_3)O

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Recently, novel oxyborate NiCr(BO_3)O has been reported, which demonstrates a record high magnetic transition temperature among isostructural analogues [1]. The compound presents a rare example of the combination of the cationic disordering and magnetic ordering. To study the magnetocrystalline anisotropy, the sizeable single crystals were grown by spontaneous nucleation using the flux [2]. The quasi-binary system corresponds to 98.9% $mass$ [$Bi_2Mo_3O_{12}$ + Na_2O + 3.7 · B_2O_3 + 0.1 · NiO] + 1.1% $mass$[$NiCr(BO_3)O$]. The viscosity of the melt solution was reduced by adding Na_2CO_3. Spontaneous nucleation was observed at T_{cr} = 960 °C. In the temperature range of at least 50 ºC, the target phase is the high-temperature crystallizing phase only. The single crystals present well-cut prisms elongated along the *c*-axis, with shiny, smooth facets, and a length up to 20 mm. The crystals are transparent in visible and green colour (Fig. 1). The high quality of the grown crystals was confirmed by an X-ray diffraction study. The principal crystallographic axes were determined using a Laue diffractometer.

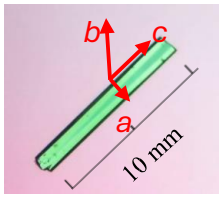

Fig. 1. Photo of the NiCr(BO3)O single crystal.

DC magnetization measurements were carried out for the external magnetic field directed along principal crystallographic axes, and magnetocrystalline anisotropy was found (Fig. 2). The compound demonstrates magnetic phase transition at 45 K and a series of magnetic anomalies at 25 and 10 K. The low-temperature magnetic moment along the *b* axis is one order of magnitude higher than that along the *a* and *c* axes. The magnetization isotherm measurements in a magnetic field up to 90 kOe show that magnetic moments of Ni^{2+} and Cr^{3+} lie in the *ab*-plane. The compound undergoes spin-orientation transition along the *a*-axis. The symmetry group analysis was performed for the space group *Pbmn* (62). The experimental and theoretical studies revealed that magnetic structure is antiferromagnetic with a small uncompensated magnetic moment arising from the peculiarity of the cation distribution over two nonequivalent crystallographic sites.

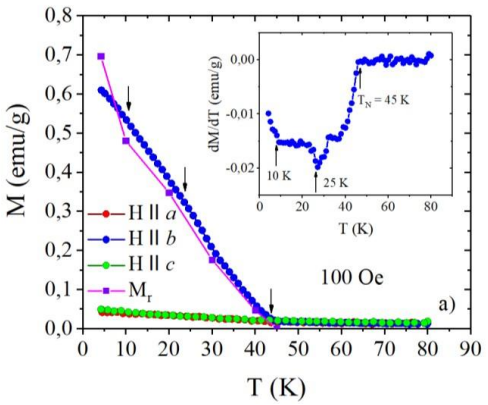

Fig. 2. Temperature dependence of the magnetization of NiCr(BO_3)O. Inset: first derivative *dM/dT* (*b*-axis) as a function of the temperature. Arrows indicate the temperatures of the magnetic anomalies.

This research was supported by the Russian Science Foundation and Krasnoyarsk Regional Fund of Science and Technology Support, Grant No.24-12-20012, https://rscf.ru/project/24-12 https://rscf.ru/project/24-12-20012/20012/.

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INFLUENCE OF THE INFILTRATING ADDITIVES OF R-CU-CO TYPE ON MAGNETIC HYSTERESIS PROPERTIES AND INTERGRAIN EXCHANGE INTERACTION OF THE ND-FE-B ALLOYS

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The disadvantages of Nd2Fe14B phase are the low Curie temperature of 312 ℃ and high temperature coefficients of remanence and coercivity, leading to a significant decrease in the performance of neodymium magnets as the operating temperature increases. This fact makes it difficult to use neodymium magnets in strong demagnetizing fields at high operating temperature. This problem is solved by alloying the initial alloy with heavy rare-earth metals such as Dy and Tb, which leads to an increase Hc at room temperature and allows to keep its value acceptable at elevated operating temperatures, but significantly increases the cost and leads to a decrease in the value of residual magnetization. One of the ways of obtaining highly coercive permanent magnets with a relatively low content of REM is the process of intergrain infiltration, in which, on the one hand, there is a thickening of the grain-boundary phase, and on the other hand, heavy elements partially penetrate deep into the grains of the main phase, forming a core-shell structure.

In this work the influence of the composition of low-melting additives of REM-Cu-Co type (where REM = La, Ce, Nd, Gd and Tb) on magnetic hysteresis properties and inter-grain exchange interaction of rapidly quenched nanocrystalline hard magnetic alloy based on Nd2Fe14B compound is investigated. According to the results of experimental studies of magnetic susceptibility and magnetization-temperature dependences, it was found that the intergranular exchange interaction constant decreased, but the exchange interaction of ferromagnetic type between grains is preserved. It was found that the use of any REM in the composition of a fusible additive leads to an increase in the coercivity. The obtained values of Hc show that using cheaper REMs (La, Ce and Gd) it is possible to increase the coercivity by 55 % compared to the initial one. Using Nd and Tb as additives it was possible to increase the coercivity up to 22 kOe and 33 kOe, respectively.

The work was financially supported by Ministry of Science and Higher Education of the Russian Federation (Ural Federal University project within the Priority 2030 Program).

HIGH-TEMPERATURE FERRIMAGNET $CuFe_4(BO_4)_2O_2$ WITH CHONDRODITE STRUCTURE

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A search for a new magnet in the ternary system Fe_2O_3-CuO-B_2O_3 resulted in obtaining the novel oxyborate $CuFe_4(BO_4)_2O_2$ with a chondrodite structure. Until now, only $CoAl_4(BO_4)_2O_2$ had been reported as a synthetic magnetic analogue [1], but its magnetic properties had not yet been studied. Single crystals were grown by the flux method in the spontaneous nucleation regime. The complex solvent based on bismuth trimolybdate can be presented as a quasi-binary system *68wt%[$Bi_2Mo_3O_{12}$+$Na_2B_4O_7$+CuO]+32wt%[CuO+$2Fe_2O_3$+B_2O_3]*.

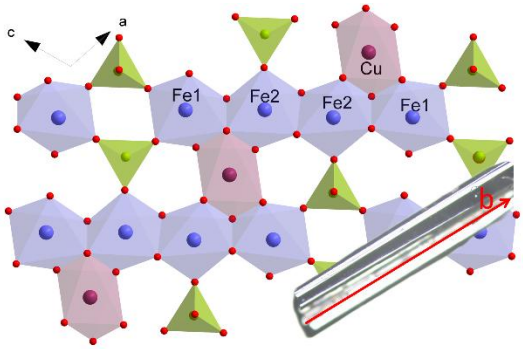

Fig. 1. Crystal structure projected onto the *ac*-plane (one layer is shown). Inset: a photo of a single crystal.

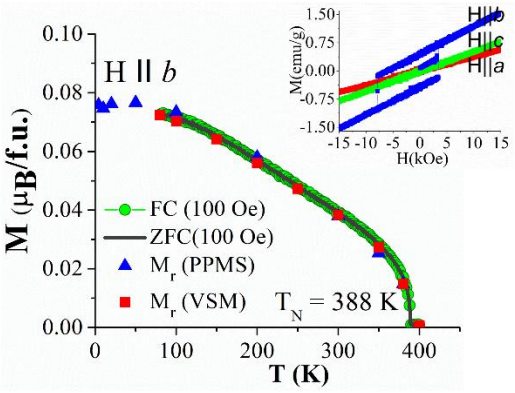

Fig. 2. Temperature dependence of the magnetization along *b*-axis. Inset: magnetization isotherms at 300 K

The crystals are black prisms elongated along the *b*-axis with a shiny surface (Fig. 1). X-ray fluorescence spectroscopy and X-ray diffractometry revealed the chemical formula to be $CuFe_4(BO_4)_2O_2$. The compound crystallizes in a monoclinic symmetry, space group $P2_1/c$ (14), the lattice parameters are a = 7.5326(4) Å, b = 4.4778(2) Å, c = 10.0336(6) Å, β = 109.0496(14)°, and V = 319.89(16) Å^3. The metal atoms have octahedral oxygen coordination, while boron has tetrahedral coordination. The iron ions occupy two positions Fe1 (4e) and Fe2 (4e), and the copper ions occupy one position Cu (2a) (Fig. 1). There are five nonequivalent oxygen positions. The edge-shared octahedra form a 3D framework consisting of rows of Fe1-Fe2-Fe2-Fe1 connected via Cu and boron atoms.

DC magnetization measurements revealed that the novel compound is a ferrimagnet with a transition temperature of T_N = 388 K (Fig. 2-Magnetic crystallographic anisotropy was found with the *b*-axis as the easy magnetization direction (Fig. 2, inset).

This study was supported by the Russian Science Foundation and Krasnoyarsk Regional Fund of Science and Technology Support, Grant № 24-12-20012, https://rscf.ru/project/24-12-20012/.

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ELECTRICAL AND MAGNETIC PROPERTIES OF FE-V-AL HEUSLER ALLOYS

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The search for new magnetic and thermoelectric materials for the creation of thermoelectric devices controlled by an external magnetic field is relevant task. Recently, Heusler compounds have attracted considerable attention as thermoelectric materials. For a long time, intermetallic compounds were considered unsuitable for thermoelectric devices due to their conductive properties. However, recent studies [1–5] have shown that the creation of defects can lead to increased phonon scattering, which contributes to a significant reduction in lattice thermal conductivity and an increase in the Seebeck coefficient. In addition, properties of Heusler alloys are sensitive to small variations in composition near the stoichiometric one.

Thus, the aim of the work is to study the electrical and magnetic properties of Fe-V-Al-based Heusler alloys with small variations in elements near the stoichiometric composition, as well as to establish behavioral patterns of these characteristics.

Fe-V-Al Heusler alloys were synthesized in an induction furnace in a purified argon atmosphere followed by annealing. Structural certification and elemental analysis of the alloys were performed at the Collective Access Center for Nanotechnologies and Advanced Materials of the Institute of Metal Physics, UB RAS. The surface microstructure and elemental analysis of the alloys were studied using a Tescan Mira scanning electron microscope equipped with EDS and EBSD analyzers for structural, textural, and elemental analysis. Elemental analysis showed that deviations from the nominal composition for all alloys are insignificant. Measurements of the temperature dependences of electrical resistivity were carried out using standard four-probe technique on direct current in the temperature range from 4.2 to 300 K with a change in the direction of the electric current flowing through the sample. The magnetization and Hall effect were measured at T = 4.2 K and in magnetic fields of up to 70 kOe.

Since the alloys studied are ferromagnetic, an anomalous Hall effect is observed in addition to the normal one. Heusler alloys, close in stoichiometric composition to Fe_2VAl, exhibit semiconductor-type conductivity. These anomalies may be due to a very narrow band gap and the strong influence of charge carrier scattering by local magnetic moments. It is expected that electronic properties can be significantly improved since the Fermi level and band gap can be easily "tuned" in Fe-V-Al Heusler compounds by varying the concentrations of iron, vanadium, and aluminum. This provides the opportunity to optimize the material for a specific application.

The research was supported by RSF (project No. 26-72-10138).

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ELECTRONIC STRUCTURE AND MAGNETIC PROPERTIES OF Co- AND Fe-DOPED Ni-Mn-Ga HEUSLER ALLOYS: A DFT STUDY

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Heusler alloys, particularly the Ni-Mn-Ga system, are among the most promising multifunctional materials due to their unique combination of magnetic shape memory effect, large magnetocaloric response, and high-temperature stability. However, for practical applications, controlled doping with transition metals such as Co and Fe allows tuning of the electronic structure, magnetic ordering, and phase stability. Despite considerable experimental efforts, a systematic first-principles understanding of how Co and Fe substitution affects the density of states, magnetic moments, and relative phase stability in Ni-Mn-Ga across different concentrations remains essential for guiding further materials design.

In this work, the electronic and magnetic properties of Co- and Fe-doped Ni-Mn-Ga alloys were investigated using two complementary first-principles approaches: the Projector Augmented-Wave (PAW) method as implemented in the VASP code [1, 2], and the Korringa-Kohn-Rostoker (KKR) method as implemented in the SPR-KKR package [3]. The Perdew-Burke-Ernzerhof (PBE) exchange-correlation functional [4] was used in both codes. Special Quasi-random Structures (SQS) based on 128-atom supercells were generated using the ATAT toolkit [5] to model disordered alloys. Structural relaxation was performed in VASP with a plane-wave cutoff of 450 eV, energy convergence of 10^{-5} eV/atom, and force tolerance of 10^{-2} eV/Å. Brillouin-zone integration employed a 4×4×4 k-point mesh. The coherent potential approximation (CPA) was used to treat substitutional disorder.

Partial density of states analysis shows that near the Fermi level, the electronic structure is dominated by Mn and Ni d-states, with Ga contributing negligibly. Upon Co doping, the metallic character is preserved, but a systematic redistribution of states occurs between -2 eV and E_F. Difference DOS (ΔDOS) for Co 0.09 vs. 0.03 at.% reveals electron density transfer from lower energies (negative peak near -1 eV) to states closer to E_F (positive peaks near 0.1 eV), mainly due to NiMn and Co d-d hybridization. Total magnetic moment increases with Co content: from 3.370 μ_B/f.u. (Co 0.03) to 3.538 μ_B/f.u. (Co 0.09) in the $L2_1$ phase, with B2-FM always slightly higher. Energetically, $L2_1$-FM is the most stable configuration across all studied Co concentrations, followed closely by B2-FM, while AFM and PM states are higher in energy. The Curie temperature for $Ni_{2.062}Mn_{0.844}Co_{0.094}Ga$ increases linearly with Mn occupation of the 4*b* site, extrapolating to 293.5 K for fully ordered $L2_1$. For Fe doping, a threshold behavior is observed: at low Fe content (0.05 at.%) Fe states near E_F are negligible, but at ≥0.12 at.% a pronounced Fe *d*-peak appears (up to 0.399 states/eV/f.u.), attributed to the decreasing *e*/*a* ratio upon Ni replacement by Fe. Thus, Co and Fe doping provide distinct pathways for manipulating the electronic structure and magnetism in Ni-Mn-Ga-based Heusler systems.

The study was financially supported by the Ministry of Science and Higher Education of the Russian Federation as part of the state assignment № 075-00188-26-00.

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EXPERIMENTAL AND DFT STUDY OF MAGNETIC PROPERTIES OF THE HEXAFERRITE BARIUM CERAMICS EXPOSED TO GAMMA-IRRADIATION

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Interest in barium hexaferrites with the composition $BaFe_{12}O_{19}$ remains consistently high due to their unique crystal structure and pronounced magnetic properties. These materials are characterized by high magnetic anisotropy, resistance to corrosion and chemical effect, an elevated Curie temperature (about 450 °C), as well as a high saturation magnetization (approximately 64 emu/g). The combination of functional properties of barium hexaferrites determines their wide application in the development of magnetic and magneto-optical devices, as well as components for microwave electronics, including ferrite absorbers of electromagnetic emission, antennas, magnetic cores, and memory elements. Additional interest in M-type hexaferrite ceramics is associated with the manifestation of multiferroic properties — the coexistence of strong magnetism and ferroelectricity under various types of irradiation, which opens prospects for their application in devices with magnetoelectric coupling.

The aim of this work is to investigate the influence of gamma-ray fluxes on the electronic structure and magnetic properties of barium hexaferrite $BaFe_{12}O_{19}$.

Changes in the structure and properties under the action of hard radiation are mainly caused by radiation-induced defects. High-energy γ-radiation (1.17 and 1.33 MeV) from the radioisotope ^{60}Co interacts with both the electronic and nuclear subsystems of the crystal lattice, inducing primary processes of electron–positron pair production (threshold energy 1.022 MeV) and complete ionization of all electron shells (up to 100 keV). They are followed first by the formation of paired point defects (vacancy–interstitial atom) in the anionic and cationic sublattices, and subsequently by the formation of separated aggregates consisting of vacancies and interstitial atoms on the nanoscale. As a result of oxygen vacancy generation, the local electron density surrounding the iron ions changes, which can be experimentally detected using spectroscopic techniques (in particular, Mössbauer spectroscopy on ^{57}Fe nuclei) or theoretically investigated using the density functional theory method with Hubbard correction (DFT+U). This approach makes it possible to account for Coulomb repulsion between localized 3d electrons and to correctly describe the band gap. The crystallographic parameters of $BaFe_{12}O_{19}$ required for the DFT+U calculations were obtained from the Materials Project database [1]. Rearrangements of the electronic structure arising under irradiation affect the exchange interactions between Fe^{3+} ions occupying different crystallographic positions (12k, 2a, $4f_1$, $4f_2$, 2b). This, in turn, may lead to a decrease in saturation magnetization and changes in coercive force. DFT+U calculations for the ferrimagnetic (FiM) phase were performed using the Quantum ESPRESSO software package. The following Hubbard parameters were used in the calculations: U(Fe) = 4 eV, while for oxygen and barium atoms U = 0 eV was assumed. To account for spin polarization, the parameter `*nspin = 2*` was set; the initial magnetic moments for Fe ions in tetrahedral and octahedral positions were assigned as +0.2 and −0.2, respectively, which is necessary for modeling the ferrimagnetic spin ordering in $BaFe_{12}O_{19}$.

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A MAXWELL-BASED THERMODYNAMIC CRITERION FOR THE POINT OF MAGNETIC PHASE TRANSFORMATION IN EXTERNAL FIELDS: BEYOND THE LANDAU-BELOV-ARROT APPROXIMATION

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The Curie temperature of the second-order ferromagnetic transition is strictly defined only in zero magnetic field. Under these conditions, magnetic, thermal, elastic, and magnetothermal properties exhibit extremes at different temperatures, causing a field-induced spread of thermodynamic markers. In this paper, the behavior of high-purity gadolinium is analyzed within the framework of Maxwell's equations. It is demonstrated that the experimentally observed separation of the anomaly locations in the field lies in the range of 4–16 K. .

Analysis of previously obtained heat capacity experimental data revealed a characteristic temperature region corresponding to Maxwell's equations, where the magnetic contribution to the heat capacity approximately satisfies the condition $(\partial C_m/\partial H)_T \approx 0$. Within the studied field range, this condition corresponds to an approximately field-independent magnetic contribution to the heat capacity. In this paper, we demonstrate that this point can serve as a physically justified point of the thermodynamic transition associated with the maximum entropy response rate of the magnetic subsystem. The proposed approach provides a unified thermodynamic interpretation of magnetic, calorimetric, elastic, and magnetocaloric anomalies near the ferromagnetism-paramagnetism transition in ferromagnets. A literature review confirms such behavior in Gd, Tb, and Dy. Since the estimated elastic contribution does not exceed ~0.1 K, introducing the criterion $C_m(H)\approx$const seems justified primarily for describing the interaction between the magnetic and thermal subsystems.

This approach, based on Maxwell's equations and focusing directly on the thermodynamic behavior of the magnetic contribution to heat capacity, offers a number of advantages for determining both the Curie temperature of ferromagnets in zero magnetic fields and the magnetic phase transformation point in a magnetic field using magnetization measurements in the vicinity of the $\partial^2 M/\partial T^2 = 0$. The advantages of this approach include:

[1] Experimental simplicity and accuracy (no need for thermodynamic models or expansions).
[2] A clear thermodynamic interpretation related to the maximum entropy response rate of a magnet.
[3] No influence of sample geometry compared to traditional methods.
[4] Experimental applicability over a wide field range (demonstrated from zero to ~2.5 T in Gd. The possibility of extending this to higher fields, where the $\partial^2 M/\partial T^2=0$) point disappears, requires further experimental verification).
[5] Logically understandable unification of physically distinguishable states of a ferromagnet, both in zero field and in an external magnetic field.

This work was supported by the Russian Science Foundation (project no. 24-19-00782, https://rscf.ru/en/project/24-19-00782/).

POSTER SESSION

Magnetic Soft Matter + Magnetism in Biology and Medicine + Neutrons

Tuesday, 18 August, 18:00 - 20:00

MOLECULAR DYNAMICS SIMULATION OF MAGNETIC PROPERTIES OF MAGNETIC ELASTOMERS FILLED WITH MAGNETIC PARTICLES WITH INTERNAL MAGNETIC ANISOTROPY

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Magnetic elastomers are so called “smart” materials consisting of magnetic particles embedded in a non-magnetic elastic matrix. Magnetic elastomers have a wide range of practical applications in industry and medicine. Their practical application lies in the ability to alter their magnetic and mechanical properties by varying numerous factors, such as the external magnetic field, the type of matrix material, the distribution of magnetic particles, their size, the polydispersity of the particles, and their intrinsic magnetic properties [1 – 3].

This research examines two basic models of magnetic elastomers with uniformly sized magnetic particles exhibiting internal magnetic anisotropy. The non-magnetic elastic matrix is modelled using a classical harmonic potential, which can be visually represented as harmonic springs of varying rigidities. Within these models, either translational motion or both translational and rotational motion of the particles can be constrained. In the first model, which constrains only the translational motion of magnetic particles, each magnetic particle is held by a single spring, one end attached to the particle's centre and the other to a point in space that characterizes the particle's equilibrium position. The second model also imposes a constraint on the rotation of magnetic particles by considering two harmonic springs. Since magnetic particles exhibit internal magnetic anisotropy, the spring attachment to the particle is related to the direction of the easy (magnetisation) axis: these points lie on the axis. The other ends of the springs are attached to two points in space, also lying on the easy axis, at a distance of five particle diameters from each other on opposite sides of the particle.

In the computer simulation, magnetic particles interact via a magnetic dipole-dipole potential, and short-range repulsion is described by the “soft sphere” potential (the Weeks-Chandler-Andersen potential). The Zeeman energy is used to account for the interaction of magnetic particles with an applied external magnetic field. Computer simulation using the molecular dynamics method is implemented in the ESPResSo software package [4] and is aimed at obtaining a dynamic magnetic response, as well as the distribution of reversal first-order (magnetisation) curves (FORCs).

Support by RSF (project 25-22-00270) is acknowledged.

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INFLUENCE OF PARTICLE MOBILITY IN MAGNETIC ELASTOMER ON THE MAGNETOELECTRIC PROPERTIES OF LAYERED COMPOSITES

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Magnetoelectric composites, namely two-layer structures based on piezoelectric polymers (PEP, for example, polyvinilindenfluoride (PVDF)) and magnetoactive elastomers (MAE), are of broad interest for the development of sensors and energy harvesting devices. Their relevance is driven by the possibility of combining the high sensitivity of the magnetic phase with efficient piezoelectric conversion. A promising approach for fine-tuning the properties of such materials involves varying the microstructure of MAE.

This study aims to investigate the magnetoelectric effect (MEE) in PEP-MAE structures, depending on the particle distribution in MAE layer and viscoelastic properties of MAE layer. Particular attention is paid to elucidating the interplay between the mechanical viscosity of the matrix, the magnetic response of the filler, and the resulting electromechanical coupling under different field geometries.

Spherical iron microparticles were distributed inside electrically neutral polymer matrix isotropically or anisotropically. MAE with anisotropic distribution of particles (chain like distribution) were prepared under external uniform magnetic field. Varying oil concentration in MAE sample (0, 25, 40, 60 %), elastic modulus of MAE polymer was changed. Concentration of iron microparticles remained the same in all MAE. Magnetic properties of MAE were studied with VSM LakeShore 7404 at room temperature in the field range up to 16 kOe. Magnetic properties of isotropic and anisotropic MAE show the influence of particle distribution on hysteresis loop, suggesting the presence of so-called “easy axis” in anisotropic MAE along the direction of polymerization field and, correspondingly, particles chains.

Two-layer composites, comprising of glued PEP layer and different MAE layers, were investigated in the magnetoelectric mode. Namely, inductive voltage was measured from PEP layer (which was covered by conductive plates, voltage was measured in transverse configuration, “T”) under treatment the structure by external magnetic fields. Both AC magnetic field (amplitude was 4-7 Oe and frequency range was up to 400 Hz) and DC magnetic field (from 0 to 3.1 kOe) were applied 1) longitudinally to the composite plane (L-T), and 2) transversally to the composite plane (T-T).

Mechanisms of MEE in different measuring configurations (L-T, T-T) differ from each other, that leads to different values of resonance frequency, resonance voltage and their dependences on DC magnetic field (bias field). In the L-T case the mechanism is associated with magnetodeformational effect in MAE layer. It allowed to tune the resonance frequency up to 143%. In the second T-T case the mechanical instability of MAE layer leads to sufficient increase of inductive voltage. The influence of particle distribution and viscoelastic properties of MAE layer on both mechanisms of MEE is discussed.

This work was supported by Russian Science Foundation, grant № 22-72-10137-П.

THE EFFECT OF MATRIX VISCOSITY ON MAGNETIC PROPERTIES OF AN ELASTOMER

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Magnetic elastomers consisting of magnetoactive particles distributed in an elastic polymer matrix are of broad interest for practical applications. Their relevance is particularly driven by the rapid development of robotics and medicine, where such composites are already employed as "smart" probes and materials for artificial muscles. One promising approach for fine-tuning the properties of such materials is the use of hybrid fillers, where particles of two different magnetic materials are simultaneously incorporated into a single matrix, which allows expanding the range of controllable characteristics through synergistic phase interactions. Furthermore, the viscosity of the polymer matrix during the fabrication stage has a critical influence on the final microstructure and material response: varying the viscosity determines particle mobility and the kinetics of chain-like structure formation under an external magnetic field, thereby opening additional opportunities for programming the properties of the final product.

This study aims to investigate the dependence of the magnetic and magnetoelectric properties of a series of composites with hybrid fillers on the viscosity of the diamagnetic matrix. Understanding the interaction between particles of two different materials and sizes as the viscosity varies can facilitate the precise tailoring of the samples for specific applications during the fabrication stage.

For the fabrication of silicone matrices of specific dimensions, a two-component silicone compound ELASTOSIL RT 604 A/B was used, mixed in varying proportions with silicone oil. As fillers, pure Fe and ZnCFO particles were used at a weight fraction of 10%, as well as their mixture in equal proportions at total weight fractions of 10% and 20%. The particles were dispersed throughout the volume using an ultrasonic bath, after which the resulting prepolymer was cast into a mold.

The magnetization loop parameters of the samples were measured using a LakeShore 7400 vibrating sample magnetometer. To measure the magnetoelectric characteristics, a sample coated with a PVDF piezopolymer layer was placed in an alternating gradient magnetic field, which induced an alternating voltage of the same frequency across the output contacts connected to the PVDF [1].

This study expands the capabilities for developing magnetoelectric materials with tunable properties that can be predefined as early as the sample fabrication stage.

This work is supported by RSF grant 22-72-10137-П

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STUDY OF CONCENTRATED FERROFLUIDS BASED ON STRONTIUM HEXAFERRITE NANOPARTICLES IN A MAGNETIC FIELD

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The structural composition of a concentrated aqueous solution of 50 × 5-nm plate-shaped ferrimagnetic nanoparticles of strontium hexaferrite ($SrFe_{12}O_{19}$) in a magnetic field has been studied using synchrotron small-angle scattering. A characteristic feature of these magnetic fluids is the formation of randomly oriented periodic structures even in the absence of a magnetic field. Two-dimensional maps of the synchrotron smallangle scattering intensity show isotropic scattering in zero field and growth of a series of diffraction reflections along the direction of the applied magnetic field at $Q = nq_b$, where $q_b \approx 0.226$ nm^{-1} (period ~27.8 nm), which is due to the formation and orientation of nanoplate chains along the field. The analysis of the broadening of diffraction reflections has shown that the coherence of the chains even in extremely high magnetic fields, is 8–10 periods. However, this does not limit the length of the chain, but is due to disorientation and the dispersion of particle sizes. The degree of orientation of the segments is determined by the azimuthal width and intensity of the Bragg peaks. The chains of nanoplates are rotated toward the field direction with the field increase in the range $H < 70$ Oe (isotropic fluid–one-dimensional nematic transition); they form an intermediate state in the range 70 Oe $< H <$ 300 Oe and a smectic (three-dimensional) phase at $H > 300$ Oe. The intermediate state is characterized by a logarithmic dependence of the intensity and width of the Bragg peak on the magnetic field, which presumably indicates a self-organized criticality state of the magnetic colloid.

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MEASURING MAGNETIZATION IN A ULTRA-HIGH MAGNETIC FIELD: SENSOR DESIGN AND EXPERIMENTS RESULTS

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A new type of induction compensation sensor for measuring magnetization of materials in ultra-high magnetic fields is proposed (Fig. 1). The sensor design determines its low sensitivity to both axial and radial inhomogeneities of the magnetic field. At the same time, the sensor has high electrical strength. Laboratory studies of the signal of the new sensor design in a non-uniform magnetic field were carried out, and a technique for determining the decompensation area was established. Magnetization measurements of various materials in the ultra-high magnetic field of the MK-1 generator [1] were performed at liquid helium temperature. A comparison of experimental data obtained using the new type of sensor and sensors of old designs is performed. Signals from empty sensors of the old and new designs are compared. Signals from different sensors filled with the same material are also compared. The obtained magnetization curves for the compound Gd_2BaNiO_5 [2] containing Haldane chains, as well as for nabokoite $KCu_7TeO_4(SO_4)_5Cl$ [3], are discussed.

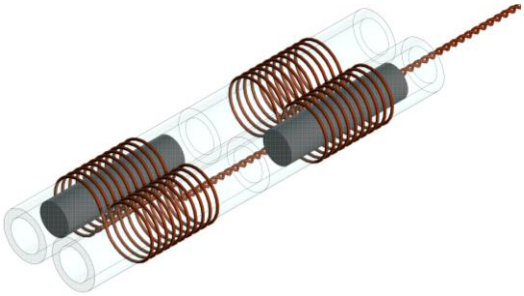

Fig. 1. Sketch of a new compensation sensor

The work was carried out within the framework of the scientific program of the National Center of Physics and Mathematics, direction No. 7 "Research in high and ultra-high magnetic fields".

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MAGNETIC STRUCTURE OF CO1.2MN1.8BO5, CO2.19MN0.81BO5 AND CU2FEBO5 VIA NEUTRON DIFFRACTION AND MAGNETIZATION MEASUREMENTS

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Oxyborates M23+M2+BO5, where M3+ and M2+ are tri- and divalent transition metals, most often crystallize in the ludwigite structure, but vonsenites, chalsites, and orthopinakiolites also occur. All these structures are characterized by a large number of nonequivalent crystallographic sites; the lattice vectors a and b are much larger than the c vector, which is about 3 angstroms.

Due to the presence of nonequivalent transition-metal sites and multiple oxidation states, oxyborates exhibit a variety of magnetic ground states. Another intriguing feature is the uneven distribution of dopant ions among the crystallographic sites. To investigate the site occupancies and determine the magnetic structures, samples of $Co_{1.2}Mn_{1.8}BO_5$, $Co_{2.19}Mn_{0.81}BO_5$ and Cu_2FeBO_5 were synthesized using the ^{11}B isotope, enabling neutron diffraction studies in addition to conventional magnetic susceptibility and magnetization measurements.

Neutron diffraction revealed that $Co_{1.2}Mn_{1.8}BO_5$ adopts the orthopinakiolite structure (Figure 1), contrary to the prevailing assumption that the entire $Co_{3-x}Mn_xBO_5$ series crystallizes in the ludwigite structure. The orthopinakiolite structure contains seven nonequivalent transition-metal sites (Figure 1). Below 60 K, additional magnetic Bragg peaks appear in the neutron diffraction patterns, indicating the onset of long-range magnetic order.

$Co_{2.19}Mn_{0.81}BO_5$ crystallizes in the classical ludwigite structure, and neutron diffraction measurements indicate the presence of short-range magnetic order at low temperatures. Cu_2FeBO_5 crystallizes in the $P2_1/c$ space group, and neutron diffraction experiments reveal that its magnetic unit cell is doubled along the short crystallographic axis.

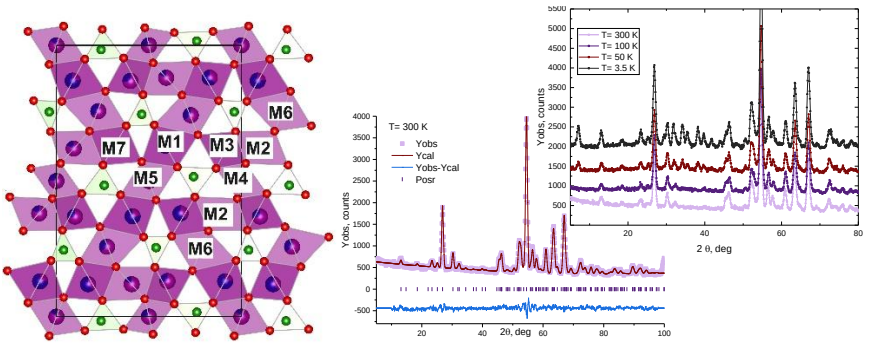

Fig. 1. Left: Crystal structure of Co1.2Mn1.8BO5. Right: Experimental neutron scattering data and theoretical approximation

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MAGNETO-CONTROLLABLE OPTICAL LIGHT TRANSMISSION IN MAGNETIC NANOFLUIDS

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Magnetic fluids represent a unique and versatile class of fluids with remarkable properties that have captivated the interest of researchers and engineers across diverse disciplines. These materials are special intelligent materials with many applications in biosensors, magneto – optical devices, medicine and photonics [1, 2]. In turn, these applications depend on the magnetic and magneto-optical properties of magnetic fluids. Remarkable magneto-optic response to external magnetic field is fundamental requirement for magneto-optic sensors or magneto-optic smart devices.

Magnetically regulated optical transmission in ferrofluids represents a promising approach for smart light-transparency applications. We investigated magnetic nanofluid materials for the development of magneto-controllable optical transparency systems.

Figure 1 illustrates the dependence of normalized light transmission on the duration of magnetic field application. An external magnetic field of 800 mT was applied longitudinally relative to the propagation direction of the 633 nm polarized light passing through the magnetic fluid samples.

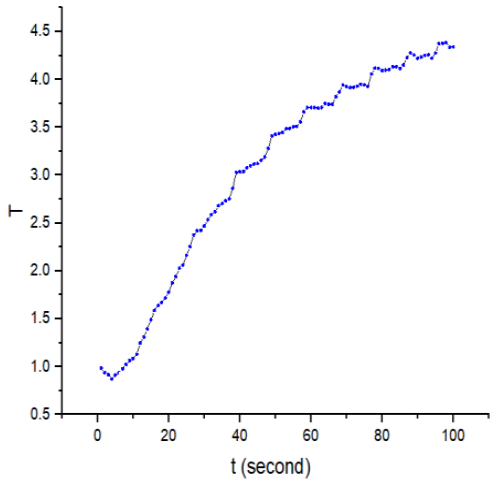

Fig. 1. Time dependence of the normalized transmitted intensity.

Upon exposure to the external magnetic field, the optical transparency of the magnetic fluid samples exhibited an initial decrease, followed by a pronounced increase as the magnetic field application time increased. This behavior may be associated with the field-induced rearrangement and alignment of magnetic nanoparticles within the fluid, resulting in changes in the optical transmission characteristics.

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EXPERIMENTAL STUDY OF MAGNETIC FLUID FILM FLOW IN ULTRASONIC FLAW DETECTION PROBLEMS

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Ultrasonic flaw detection (UFD) is a method for detecting defects on various surfaces using echo probing. To ensure more effective signal transmission, a contact fluid is used to fill the gap between the sensor and the surface of the item being tested. It is crucial to maintain this acoustic contact in order to avoid malfunction or inaccurate scan results. Conventional liquids, such as water, oils or glycerin, have a number of drawbacks; for example, they spread under the influence of gravity, thereby disrupting the device's operation. Magnetic fluid offers an excellent alternative to such liquids [1]. The sensor is equipped with a magnetic system that will hold the magnetic fluid in the gap and prevent it from spreading. To use magnetic fluid effectively as a contact medium, it is necessary to select a suitable magnetic system and study the properties of the film flows that arise during dynamic surface scanning. The paper [2] examines a hydrodynamic problem, the solution of which yielded relationships determining the dependence of flow rate on the boundary velocity, gap height and magnetic field configuration. The aim of this study is to experimentally determine the properties of magnetic fluid film flows in ultrasonic flaw detection applications and to compare these with the theory developed in [2]. A set of experimental setups was constructed to study the characteristics of magnetic fluid film flow. The creation of the film flow and the measurement of its thickness were carried out using a model simulating surface scanning. A 3D printer was used as the structural basis, supplemented by a glass plate onto which a thin layer of magnetic fluid was applied, a sensor equipped with a magnetic system, and a magnetic fluid supply system. In addition to the housing, an optical system was assembled to direct the laser beam onto the layer of magnetic fluid. As the beam passes through the layer of magnetic fluid, part of the light is absorbed or scattered, which affects the photodiode signal. The drop in signal level was measured using a La-i24USB ADC. A cylindrical magnet was used as the magnetic system, allowing the magnetic fluid to be held in the gap without the formation of bubbles. The experiment utilised three samples of a magnetite-kerosene-oleic acid magnetic fluid with different volume fractions of the solid magnetic phase. The thickness of the magnetic fluid film was measured at a fixed gap height and at different boundary movement speeds. As it was shown in measurements, thickness of the ferrofluid film is defined by the parameters of ferrofluid (viscosity, saturation magnetization, disperse composition) and by the speed of sensor. Dependence of film thickness d on the surface scanning speed v is quadratic $d \sim v^2$.

The work was carried out as part of a major scientific project funded by the Ministry of Science and Higher Education of the Russian Federation (Agreement No. 075-15-2024-535 dated 23 April 2024).

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POSTER SESSION

Magnetic Nanostructures and Low Dimensional Magnetism I

Tuesday, 18 August, 18:00 - 20:00

COUPLING OF MAGNETISM AND STRUCTURAL PHASE TRANSITION IN V_2O_3/NI HETEROSTRUCTURES

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Vanadium sesquioxide (V_2O_3) is a prototypical strongly correlated oxide that exhibits a coupled first-order metal to insulator, structural, and magnetic phase transition from a paramagnetic rhombohedral metal to an antiferromagnetic monoclinic insulator [1]. In epitaxial thin films, this transition occurs over an extended temperature range between approximately 110 K and 155 K, with a midpoint near 131 K, and proceeds via phase coexistence with nanoscale domain formation. These transitions typically occur simultaneously but can be modified or suppressed through techniques such as doping and applying stress. In this work, we investigate V_2O_3-based magnetic structures grown on sapphire Al_2O_3 substrates with different crystallographic orientations to elucidate how local structural distortions, strain, and defects in govern magnetic coupling across the antiferromagnetic/ferromagnetic interface. Previous macroscopic magnetic measurements revealed a peak in coercivity within the 110 – 155 K temperature window, coinciding with the phase coexistence region of V_2O_3, as well as the onset of exchange bias near the transition temperature [2] – [4]. These effects indicate strong magnetostructural coupling associated with the phase transition in V_2O_3, leading to pronounced changes in coercivity and the emergence of exchange bias within the phase-coexistence region.

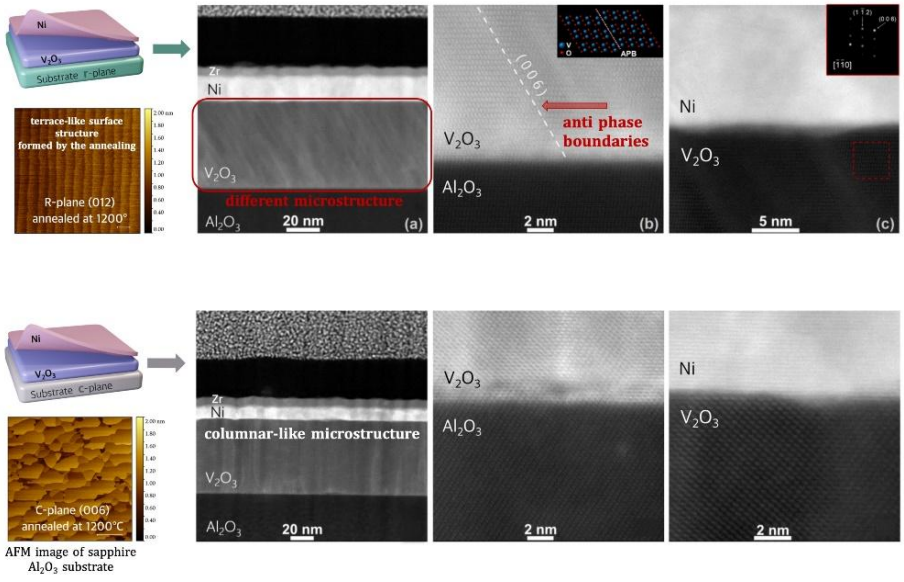

Fig. 1. HAADF-STEM images of (a) the cross-section of the V_2O_3/Ni/Zr thin film on Al_2O_3 *r*- and *c*plane substrates, (b) the Al_2O_3/V_2O_3 interface, and (c) the V_2O_3/Ni interface. STEM measurements were conducted on a double aberration-corrected Thermo Fisher Scientific X-Ant-EM operated at 120 kV at the EMAT institute in Antwerp, Belgium.

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SPIN HALL MAGNETORESISTANCE IN $W_{75}TA_{25}/CO_{90}FE_{10}/RU$ NANOSTRUCTURES

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A major trend in recent spintronics research is the search and investigation of novel materials for the generation and detection of spin currents. One of the key mechanisms for generating spin currents is the spin Hall effect (SHE), which is most pronounced in non-magnetic metals (NM) with strong spin-orbit coupling. In this context, the $W_{75}Ta_{25}$ alloy is of particular interest due to its large spin Hall angle values – a parameter characterizing the efficiency of charge-to-spin current conversion. A direct consequence of the SHE in FM/NM nanostructures is spin Hall magnetoresistance (SMR), which arises from the absorption/reflection processes of spin currents at the FM/NM interface. Consequently, the resistance of the nanostructure is determined by the mutual orientation of the magnetization **M** in FM and the spin polarization **s** in NM. The low-resistance and high-resistance states are observed when **M** ∥ **s** and **M** ⊥ **s**, respectively.

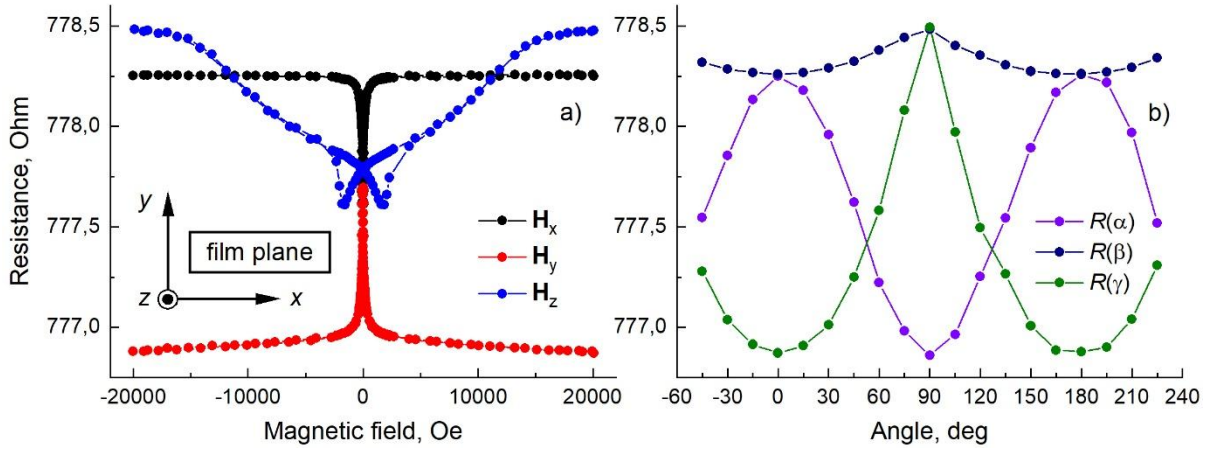

Fig. 1. Field (a) and angular (b) dependences of resistance for $W_{75}Ta_{25}$(3nm)/$Co_{90}Fe_{10}$(2nm)/Ru(2nm) nanostructure at room temperature. $\mathbf{H}_x$, $\mathbf{H}_y$ and $\mathbf{H}_z$ denote the magnetic field applied along the *x*, *y* and *z* axes. Angular dependences *R*(α), *R*(β) and *R*(γ) correspond to the resistance measured at *H* = 20 kOe during sample rotation in the *xy*, *xz* and *yz* planes. The current flows along the *x*-axis. The spin polarization vector **s** is collinear with the *y*-axis.

In this work, we investigate the microstructure and magnetoresistive properties of $W_{75}Ta_{25}$(2-5nm)/$Co_{90}Fe_{10}$(2nm)/Ru(2nm) structures deposited by magnetron sputtering on glass substrates.

Increasing the $W_{75}Ta_{25}$ thickness promotes the sequential formation of the low-resistivity α-phase on top of the initial high-resistivity β-phase, accompanied by a weakening of the $Co_{90}Fe_{10}$ textural order. The field and angular dependences of resistance (Fig. 1) indicate a dominant contribution of SMR to the total magnetoresistance of $W_{75}Ta_{25}/Co_{90}Fe_{10}$/Ru nanostructures. The maximum SMR magnitude reaches 0.18% for a 3-nm-thick $W_{75}Ta_{25}$ layer, exceeding typical values reported for most metallic FM/NM systems and indicating a large spin Hall angle in the $W_{75}Ta_{25}$ alloy.

The current research is supported by Russian Science Foundation (project No. 24-12-20022).

THE ROLE OF CU BUFFER LAYER THICKNESS IN CREEP DOMAIN WALL DYNAMICS OF CU/PD/CO/PD HETEROSTRUCTURE

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Investigation of dynamics of magnetic domain walls (DWs) is important since it determines performance of memory, magnetic logic devices and magnetic sensors based on DWs propagation [1]. In our previous work, we studied how the dynamics of DWs in out-of-plane (OoP) and in-plane (InP) magnetic fields changes with an increase in the Pd bottom layer thickness in Cu(2)/Pd(3-10 nm)/Co(0.7 nm)/Pd(3 nm) system [2]. As a result, as the Pd layer thickness increases, its roughness increases, which leads to an increase in the asymmetry of DWs velocity in the same in-plane (InP) fields. The open question remains, what influences this asymmetry: the interface roughness or thickness of the Pd layer itself. To find out whether roughness is the origin of the asymmetry in this work, we change the thickness of the Cu layer, thereby changing the roughness of the Pd/Co interface without changing the thickness of the bottom Pd layer.

The samples were evaporated by a molecular beam epitaxy on Si(111) substrate. The deposition rates were monitored by a quartz crystal microbalance. The thickness of the Cu layer d_{Cu} was varied from 2 to 12 nm. The roughness of the Cu layer was evaluated using scanning tunnelling microscopy. The magnetic structure was investigated by a magnetooptical Kerr effect microscope.

When applying only out-of-plane (OoP) field H_z, an increase in the DW depinning field is observed in samples with varying Cu thicknesses, which coincides with an increase in the coercive force in the hysteresis loops measured by vibrating sample magnetometer. A sharp increase in both the coercive force and the depinning field is also observed upon changing of film growth from Frank-van der Merwe (layer-by-layer) to Stranski-Krastanov (layered-island), which is accompanied by an increase in the surface roughness.

When applying an additional InP field H_x as the Cu layer thickness increases, the DWs velocity asymmetry increases with increasing roughness, as observed with variations in Pd thickness [2]. However, at thicknesses above 7 nm, a sharp decrease in the asymmetry occurs, as seen in Figure 1. This behavior is presumably related to a change in the pinning potential caused by the change in island shape at this copper layer thickness.

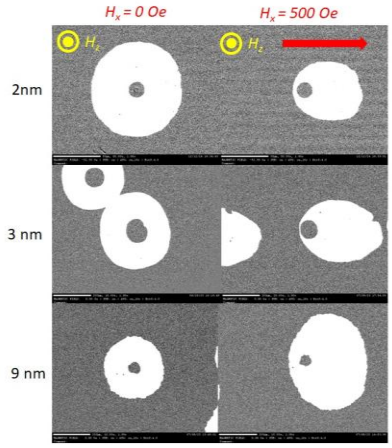

Fig. 1. Binarized magneto-optical differential contrast images for different OoP and InP fields for d_{Cu} 2,3 and 9 nm. For H_x = 0 Oe, there is no velocity asymmetry. For H_x = 500 Oe, the mobility of the right DW is greater than that of the left DW at all H_z values.

Support by the Russian Scientific Foundation (grant no. 25-22-20079, https://rscf.ru/project/25-22-20079/) and the Primorsky Kray Government (grant no. 25-810-62470-2-0214-000004) is acknowledged.

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MAGNETIZATION REVERSAL AND RESPONSE IN BISEGMENTED Co/Ni JELLYFISH NANOWIRES

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In recent decades, increased research interest has been focused on low-dimensional structures, particularly one-dimensional objects, where quantum-size effects and the contribution of surface states significantly alter the physicochemical properties of the material. Magnetic nanostructures occupy a special place among such systems, allowing for targeted modulation of magnetic parameters by varying their geometric shape and elemental composition. Significant interest in the study of one-dimensional magnetic nanostructures is due to their wide range of potential applications. Nanowires with a specified architecture are in demand in the creation of electronic devices, sensors, catalysts, and drug delivery systems [1]. Due to the unusual physicochemical properties of nanoscale objects, the synthesis of segmented nanowires opens opportunities for obtaining materials with controlled characteristics. One-dimensional structures (nanowires, nanosprings) are applicable in biomedicine for diagnostics and therapy, including interaction with cells at the molecular level, which is relevant for regenerative medicine [1]. Magnetic nanowires can destroy cancer cells using hyperthermia: they rotate around their axis under the influence of a low-frequency circularly polarized field, and friction with a liquid generates heat [2]. «Jellyfish» nanowires also hold promise for high-performance magnetic memory [3]. In this study, bisegmented «jellyfish» like nanowires were obtained using electrochemical deposition using two-layer porous anodic aluminium oxide matrices (synthesized by soft anodization in various acids): Co in the «heads» and Ni in the «legs», as well as Ni in the «heads» and Co in the «legs». The deposition process was interrupted to change the electrolyte and potentials when moving to the next segment. Elemental analysis revealed a change in composition from head to foot, confirming the formation of binary Co/Ni and Ni/Co structures. The magnetic properties of nanowire arrays in matrices were studied using a LakeShore VSM 7400 vibrating-coil magnetometer: when the external field was oriented along the long axis of the nanowires, the coercivity decreased from 540 Oe (Co-head) to 465 Oe (Ni-head), and the saturation field decreased from 9050 Oe to 4350 Oe. Thus, as a result of the work, two-layer porous matrices were synthesized, two-segment ferromagnetic Co/Ni and Ni/Co «jellyfish» nanowires were electrochemically deposited, the morphology was studied using a scanning electron microscope, the elemental composition was confirmed by energy-dispersive X-ray spectroscopy, and the magnetic characteristics were confirmed by vibrational magnetometry.

The study was carried out with the support of the Russian Science Foundation (project No. 24-72-10088).

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MAGNETIC PROPERTIES AND DOMAIN STRUCTURE OF Pt/Co/CoOx/Gd/Pt MULTILAYER THIN FILMS

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Multilayer structures based on magnetic and nonmagnetic materials are of great interest for spintronics due to the possibility of realizing perpendicular magnetic anisotropy (PMA), the Dzyaloshinskii–Moriya interaction (DMI), and spin–orbit torque (SOT) effects.

In this work, Pt/Co/CoO_x/Gd/Pt multilayer structures were fabricated by magnetron sputtering. The magnetic properties were investigated using vibrating sample magnetometry, while the domain structure was studied by magnetic force microscopy (MFM) and magneto-optical Kerr effect measurements.

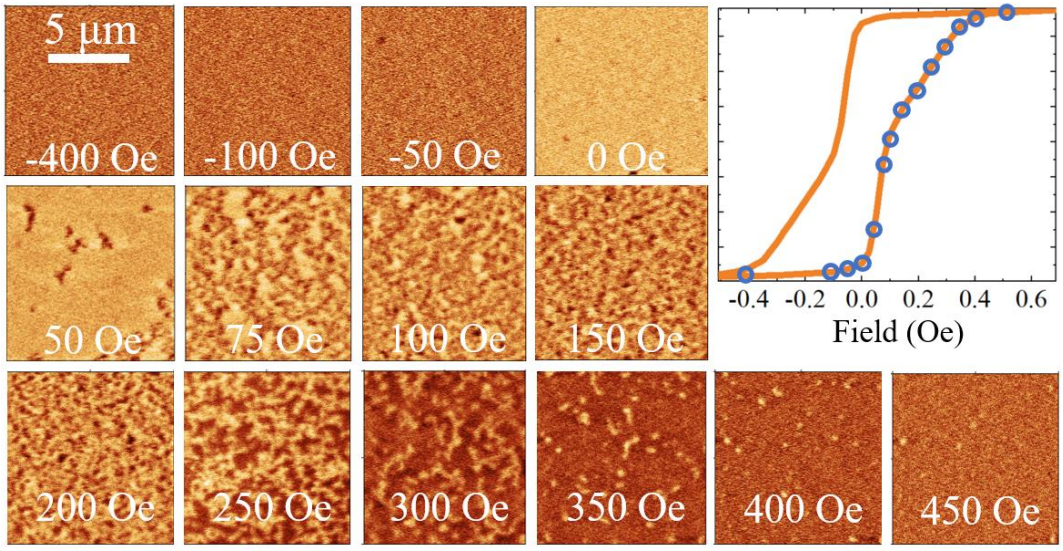

Fig. 1. Domain structure images obtained by MFM.

The experimental results showed that increasing the thickness of the bottom Pt layer (40–100 Å) in the Pt/Co/CoO_x/Gd/Pt structure leads to an increase in the magnetic moment of the system from 75 to 109 μemu·G^{-1}·cm^{-2} and to a growth of the effective PMA field from 1400 to 2400 Oe.

Due to the increase in the thickness of the bottom Pt layer, it was found that the magnetic hysteresis loops measured in the out-of-plane geometry acquire a shape characteristic of superlattices with a labyrinth domain structure. For the sample with a 100 Å thick bottom Pt layer, MFM revealed a labyrinth domain structure from which individual skyrmions can be formed by applying magnetic fields and stabilized in the remanent state fig. 1.

Further studies will focus on investigating the SOT effect and DMI in this system by measuring shifts in magnetic hysteresis loops under the application of electric current through microstructures [1].

The work of Turpak A.A., Chernousov N.N., and Davydenko A.V. was supported by the Russian Science Foundation (grant № 25-42-00083, https://rscf.ru/project/25-42-00083/).

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EFFECT OF THE DIRECTION OF STRAIN-DEPENDENT DZYALOSHINSKII MORIYA VECTOR ON GROUND STATE SPIN CONFIGURATIONS

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Classical studies show that skyrmions arise when Dzyaloshinskii-Moriya interaction (DMI) D is strong enough to compete with exchange J and effective anisotropy K_{eff}, but not so strong that the system transitions directly to a spiral/labyrinth domain state. In magnetic thin films this typically means being within a narrow parameter window of J, K_{eff}, D, saturation magnetization, thickness, and field. Modern research shows that strain shifts this stability window by modifying K_{eff} and often D [1, 2, 3]. This is experimentally confirmed in multiferroic heterostructures, where electric field modifies perpendicular anisotropy and interfacial DMI via strain, allowing the creation, deformation, and annihilation of skyrmions [4]. A sufficiently strong magnetoelastic coupling can itself drive a uniform ferromagnet into a periodic chiral structure even without an intrinsic DMI.

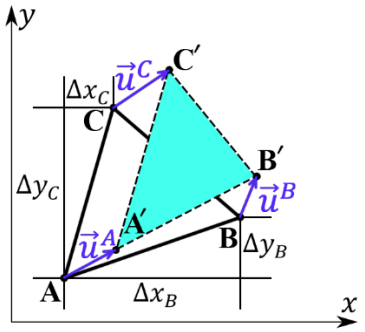

Fig. 1. Deformation of a discrete triangular simplex.

We study an elastic ferromagnetic monolayer with triangular symmetry and strain-dependent DMI and investigate the influence of DMI vector $\vec{D}^{\varepsilon}$ directed at different axes relative to the film's plane on the formation and stability of magnetic skyrmions in ground states at different deformations of the film and magnitudes external magnetic field perpendicular to the film. A discrete model is developed that incorporates elastic energy, Heisenberg exchange, and a strain-dependent antisymmetric DMI term. The strain tensor is computed locally for each triangular lattice element, and a scalar strain parameter is introduced to modify the magnitude of DMI between nearest neighbors in the following form:

$$d_i^{\varepsilon} = \frac{1}{C_i} \sum_{j=nn(i)}^{C_i} \sqrt{\sum_{k,l=x,y} \left|\varepsilon_{kl}^{i,j,j+1}\right|^2}$$

Using numerical simulations, phase diagrams of the ground states of the system such as ferromagnet, domains, skyrmions and skyrmion lattice are mapped out against D_x^{ε}, D_y^{ε} and D_z^{ε}.

This research was funded by state assignment, agreement No. 075-03-2024-123/1 dated 02/15/2024.

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COBALT- CARBON-BASED NANOPARTICLES: PHASE COMPOSITION, MAGNETIC PROPERTIES, ADSORPTION OF ORGANIC DYES

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Carbon is a remarkable polymorphic material. As an element, it is a constituent of all organic molecules, offering an inexpensive, biocompatible material with different functional properties. This explains the widespread use of both carbon and its compounds in the synthesis of various nanostructures. Usually, carbon does not form compounds with the main metallic components (Co, Fe, Ni, etc.), but crystallizes or assembles into amorphous layers of its own phase. Special conditions are required for incorporation carbon into the structure. This paper presents the results of a study of cobalt-carbon-based nanoparticles (NPs) synthesized under conditions that ensure the incorporation of carbon atoms into the metal structure, the formation of a carbide phase and, simultaneously, the formation of a carbon shell around the NPs. The synthesis was carried out from oleic acid ($C_{17}H_{33}COOH$), oleylamine ($C_{18}H_{37}N$) and $Co(CH_3COO)_2$ during the process of thermal decomposition and holding at temperatures from 320 °C to 380 °C for several hours in an argon atmosphere. Varying the reaction conditions, we obtained the next phases: (Co+CoO)@C, Co@C, (Co+Co_2C)@C, and Co_2C@C. Changes in the synthesis conditions lead to a change not only the NPs phase composition but also some changes in their morphology. Thus, the NPs of the sample subjected to minimal thermal exposure are rounded crystalline formations with a wide size distribution. Increasing the holding time to 2 hours leads to the formation of smaller NPs of metallic cobalt. In the case of two-stage heating a mixture of Co and Co_2C crystals is observed. Co_2C NPs are stable dense conglomerates of particles with sizes of ~200 nm. The common feature of all NP samples is the presence of an amorphous carbon shell enveloping the particles.

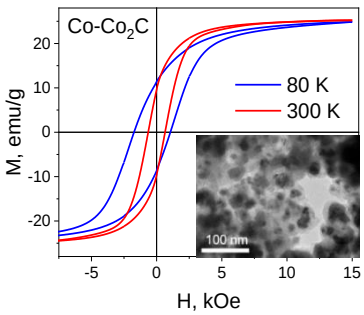

Fig. 1. Field dependences of NP samples with complex compositions at 300 and 80 K. Insets: TEM images of NPs.

Since CoO oxide and Co_2C carbide are paramagnetic at room temperature, the magnetic behavior of the NPs is due to the presence of metallic cobalt in all samples. As the temperature decreases from 300 to 80 K, the magnetization value remains virtually unchanged, which is typical of metallic Co. In the case of two-component phase compositions, a shift in the hysteresis loops along the field axis is observed, indicating the occurrence of unidirectional anisotropy (exchange anisotropy), which is stronger in the case of Co-Co_2C (Fig. 1). If the exchange shift of the hysteresis loop in the Co/CoO structure, exchange anisotropy occurs during the antiferromagnetic transition of CoO near 290 K. In the Co_2C structure, the exchange shift of the hysteresis loop is apparently due to the soft ferromagnet–hard ferromagnet interaction. Selective adsorption of various types of organic dyes by the studied NPs was revealed.

Support by Russian Science Foundation (project no. 26-22-20055, https://rscf.ru/project/26-22-20055/, and by the Krasnoyarsk Regional Fund of Science and Technology Support is acknowledged.

COLLOIDAL CUINS2 QUANTUM DOTS AS ECO-FRIENDLY FLUOROPHORES FOR NEXT-GENERATION SOLAR ENERGY CONVERSION

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Copper indium disulfide (CuInS2, CIS) quantum dots (QDs) constitute a promising class of heavy-metal-free ternary semiconductor nanocrystals, since their direct band gap of approximately 1.5 eV, high absorption coefficient, and compositionally tunable emission make them attractive, environmentally benign alternatives to Cd- and Pb-based QDs for photovoltaic, light-emitting, and luminescent solar concentrator (LSC) applications [1]. In this work, CIS QDs were synthesized by a colloidal route from copper(I) iodide and indium(III) acetate precursors in a 1-dodecanethiol/oleylamine solvent system, with nanocrystal nucleation and growth promoted by heating to 230 °C under an inert atmosphere.

The UV-Vis absorption spectrum (Fig. 1, left) exhibited a broad, monotonically decaying edge extending to approximately 450–500 nm without a well-resolved excitonic feature, consistent with the size polydispersity and defect-related electronic structure typical of CIS nanocrystals obtained from a CuI/In(OAc)3/DDT/OLA precursor system [2]. The corresponding photoluminescence spectrum (Fig. 1, right) displayed a single broad emission band centered at approximately 700 nm with a full width at half maximum on the order of 100 nm; this red-shifted, strongly Stokes-shifted emission is attributable predominantly to donor–acceptor pair recombination involving copper-related defect states rather than direct band-edge recombination, in agreement with reports of similarly broad emission from CIS QDs prepared under comparable Cu:In:S stoichiometries [2]. The large apparent gap between the absorption onset and the emission maximum is a recognized hallmark of I–III–VI2 QDs. It is of particular interest for luminescent solar concentrators, where it substantially suppresses reabsorption losses [3].

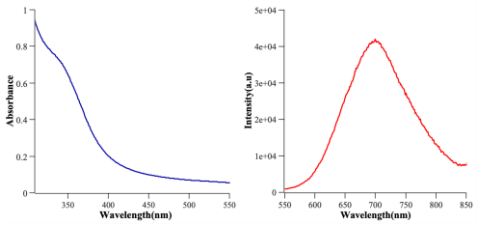

Fig. 1. UV-Vis absorbance (left) and photoluminescence emission (right) spectra of the as-synthesized CuInS2 QDs.

Taken together, these results confirm that CIS QDs with red-to-near-infrared, defect-mediated emission are obtained reproducibly from a CuI/In(OAc)3/DDT/OLA precursor system, representing a promising, heavy-metal-free candidate for luminescent solar concentrators and other green photovoltaic applications.

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POSTER SESSION

Theory + Superconductivity

Tuesday, 18 August, 18:00 - 20:00

JOSEPHSON-LIKE MAGNETIC TUNNEL JUNCTION: TRANSITION FROM CLASSICAL TO QUANTUM REGIME

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The pursuit of quantum computing solutions capable of addressing problems beyond the capabilities of classical systems has become increasingly urgent. Superconducting circuits based on Josephson junctions currently form the backbone of quantum logic in many platforms where nonlinearity introduced by the junction allows for the formation of discrete energy levels —enabling two-level quantum systems, or qubits. Despite their success, Josephson-based qubits are constrained by their requirement for ultra-low temperatures, typically in the millikelvin range. This limitation has driven the search for alternative platforms. One particularly promising candidate is spintronics, where magnetic structures exhibit quantum dynamics analogous to those of Josephson junctions [1]. We theoretically propose and analyze a Josephson-like magnetic tunnel junction (MTJ) structure that exhibits quantum spin dynamics analogous to those in superconducting Josephson junctions. By exploiting the isomorphism between the equations of motion for low-dissipation MTJs with easy-plane anisotropy (see in Fig1 (a) and (b)) and the Josephson phase dynamics, we construct a theoretical framework for realizing spintronic qubits. Within this framework, we identify the physical parameters—such as anisotropy constants, Gilbert damping, spin current amplitude, and geometric factors—that govern the transition from classical to quantum behavior. We show that different types of spintronic qubits, including analogs of charge, flux, and transmon superconducting qubits, can be implemented depending on the hierarchy of energy scales. A Hamiltonian formalism is developed for each regime, enabling an analytical treatment of the two-level quantum dynamics and estimation of coherence times. In particular, we demonstrate that the spin current can be used not only to excite but also to stabilize the qubit states through dissipation control. These findings provide a route toward integrating spintronic qubits into CMOS-compatible architectures and lay the groundwork for a fully spintronic platform for quantum computation.

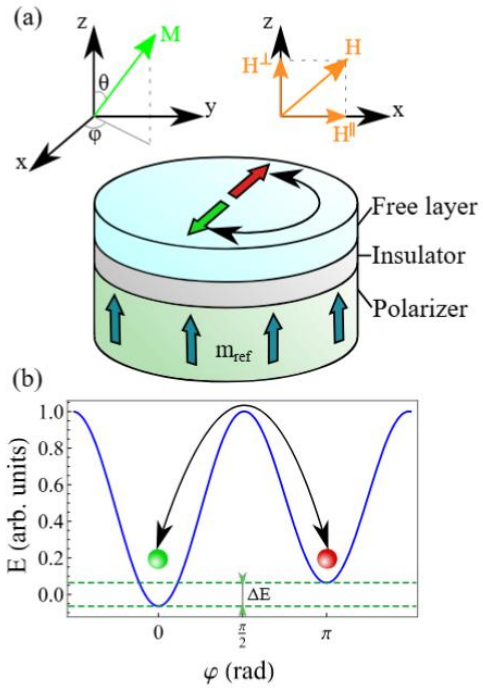

Fig. 1. (a) Schematic representation of the MTJ structure. (b) Potential energy of the magnetic layer as a function of the azimuthal angle at a fixed external magnetic field.

This work was supported by the RSF grant No. 25-12-00302.

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INVESTIGATION OF THE CRITICAL BEHAVIOR OF THE DILUTED QUATERNARY POTTS MODEL ON A HEXAGONAL LATTICE

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The study of critical behavior in a dilute 4-state Potts model on a hexagonal lattice is of particular interest, since phase transitions in superstructures with layers of adsorbed hydrogen (2x2)-2H/Ni(111) belong to the universal class of pure Potts models with q =4 [1].

In this regard, the main purpose of this work is to study the critical behavior of a weakly diluted Potts model with a spin state of q = 4 on a hexagonal lattice [2]. Using the method of Binder cumulants of the fourth order [3] and the theory of finite dimensional scaling for all studied systems at spin concentrations p = 1.00; 0.95; 0.90; 0.80, it was shown that a phase transition of the second order is observed in both pure and dilute modes [4], and critical magnetization parameters β, susceptibility γ, heat capacity α, and correlation radius ν were calculated using the theory of finite dimensional scaling.

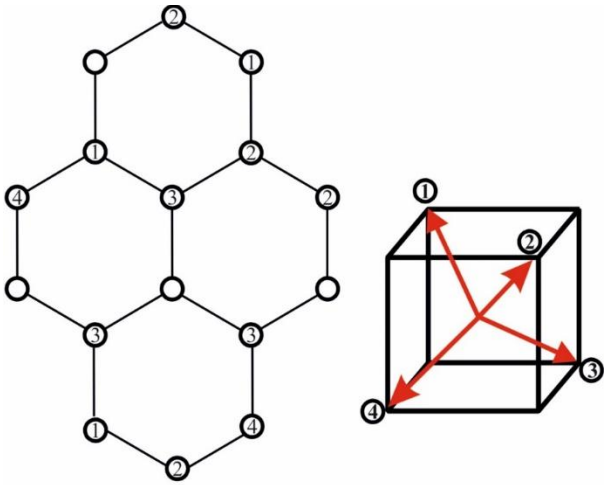

Fig. 1. Simulated structure.

The introduction of non-magnetic impurities into the spin system describing the four-state Potts model on a hexagonal lattice leads to a noticeable change in the critical parameters according to the Harris criterion [5], especially for spin concentrations of p = 0.90 and p = 0.80. Moreover, an intersection region was found between the pure system (p = 1.0) and a weakly dilute regime (p > 0.90), which includes the critical exponent values obtained at p = 0.95, whereas for the range $0.80 \le p \le 0.90$, the universality class of the model is determined by a different set of critical indices, differing from the case of the pure system.

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EFFECT OF EXCHANGE-CORRELATION POTENTIAL ON THE Mn_3Al MAGNETIC GROUND STATE: FIRST-PRINCIPLES CALCULATIONS

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During the synthesis of alloys with rigorously defined properties, the formation of metastable or accompanying undesirable phases is frequently observed. In the Mn_3Al alloy—a promising spintronic material due to its potential ferrimagnetic properties—this issue manifests as a competing β-Mn phase ($P4_132$ and $P4_332$). The formation of the target cubic Heusler structure ($L2_1$ or $D0_3$ type) is challenging due to the high stability of this phase [1].

This study, based on density functional theory (using the VASP package [2, 3] with the GGA-PBE [4] and meta-GGA-SCAN [5] approximations), investigates and compares the energetic stability of various magnetic states of the Mn_3Al Heusler alloy ($D0_3$ structure, $Fm\text{-}3m$ space group) and the β-Mn structure ($A13$ type, $P4_132$ space group). The results of collinear calculations demonstrate competition between magnetic order and crystalline symmetry.

It is established that when using the GGA-PBE approximation, certain configurations in the β-Mn phase are energetically more favorable than the ordered $D0_3$ phase. In contrast, the meta-GGA-SCAN functional exhibits the opposite trend. Presumably, this discrepancy can be attributed to a more comprehensive description of the electronic subsystem in the meta-GGA approach. The inclusion of the local kinetic energy density τ and the Laplacian of the electron density $\nabla^2 n$ provides a more accurate description of systems with complex magnetic ordering. The β-Mn structure possesses a complex threefold rotational symmetry at the 8*c* and 12*d* Wyckoff positions, which necessitates the use of non-collinear calculations to achieve more precise results [6]. In turn, accounting for these quantities in collinear calculations allows for a more detailed description of the atomic distribution and the formation of the complex antiferromagnetic order characteristic of this alloy, which contributes to reducing magnetic frustration in the manganese sublattices.

The small difference in the total energies of the phases and the crossing of their energy curves indicate a high sensitivity of phase stability to variations in interatomic distances. Such competition explains the likelihood of phase coexistence and opens up possibilities for the controlled tuning of the alloy composition via external pressure or thermal treatment.

The study was financially supported by the Ministry of Science and Higher Education of the Russian Federation as part of the state assignment № 075-00188-26-00.

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HISTOGRAM ANALYSIS OF DATA FOR A FIVE-COMPONENT POTTS MODEL ON A TRIANGULAR LATTICE UNDER VARIOUS DILUTION MODES

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The Potts model is one of the key and fundamental models of statistical physics and the phase transition theory, which demonstrates rich critical behaviour depending on the lattice dimension and the number of spin states q. The interest shown in this model is related to the possibility of analyzing the influence of defects, in particular non-magnetic impurities, which violate the translational invariance of the system. In this study, a histogram analysis of data derived from the Monte Carlo method [1] is conducted to examine numerical results obtained for a five-component Potts model on a triangular lattice, with respect to the concentration of non-magnetic impurities. The Hamiltonian of this model can be expressed as follows [2]:

$$H = -\frac{1}{2} J \sum_{i,j} \rho_i \rho_j \delta(S_i, S_j), \quad S_i = P_1, P_2, P_3, P_4, P_5 \tag{1}$$

In histogram analysis, the probability of detecting a system with the energy value U and the order parameter m is determined by the expression [3]

$$\overline{P(U,m)} = \frac{1}{Z(K)} W(U,m)\, exp[-KU] \tag{2}$$

Figure 1 presents a histogram analysis of data for a five-component Potts model at a spin concentration of p =0.85 for spin systems with linear sizes ranging from L =20 to L =100. Notably, no bimodality in the energy distribution was identified for any of the examined lattice sizes. In this case, the relationship between the probability P and the system energy E reveals a single, well-defined peak across all systems studied. This observation supports the notion of a second-order phase transition [3].

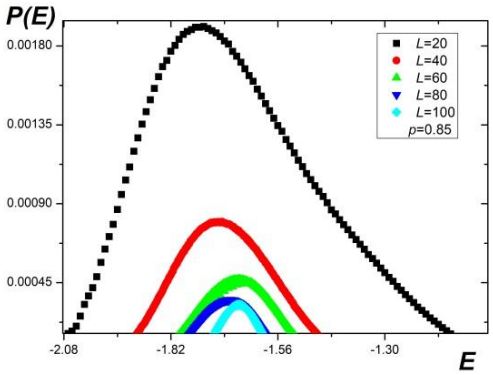

Fig.1. Energy distribution histogram for a five-component Potts model on a triangular lattice at p=0.85.

The results of the simulation performed utilizing data from the Monte Carlo histogram analysis demonstrate that in the pure Potts model with q=5, a first-order phase transition occurs, what is consistent with predictions from analytical theories [2]. The introduction of a weak non-magnetic disorder into the system suppresses the discontinuous behavior and modifies the first-order phase transition into a second-order phase transition.

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BENCHMARKING FIRST-PRINCIPLES APPROACHES FOR EXTRACTING MAGNETIC EXCHANGE INTERACTIONS

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Magnetic exchange interactions govern the macroscopic magnetic behavior of solids and underpin both fundamental spin phenomena and emerging technologies. The accurate and efficient determination of these interactions is therefore critical for predictive modeling of magnetic materials. Here we present a systematic first-principles comparison of three widely used approaches-the Least-Squares Total Energy (LSTE), the Four-State Total Energy (FSTE), and the Green's function-based Liechtenstein *et al.* (LKAG) methods-applied to thirteen antiferromagnetic compounds. We introduce an framework for identifying the minimal supercells required for an accurate exchange parameter extraction in the FSTE method, significantly reducing computational cost while preserving precision. Our results show that LSTE and FSTE yield nearly identical exchange parameters, whereas the LKAG method reproduces the dominant exchange interactions but exhibits quantitative deviations. A detailed analysis of computational efficiency versus accuracy reveals that the LSTE scheme offers the most favorable balance, establishing a general, reproducible, and scalable workflow for Heisenberg mapping, while the FSTE approach remains the most straightforward for extracting specific exchange interactions.

DIFFUSION MONTE CARLO BENCHMARK OF MAGNETIC TRANSITION METAL OXIDES

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Magnetic exchange interactions, often characterized by exchange constants, J_{ij}, are responsible for macroscopic properties of magnetic materials. One possible approach to determine J_{ij} relies on an inelastic neutron scattering experiment (INS). However, the INS experiment is expensive and highly sensitive to the purity of crystal. Another option is based on calculating energies of different magnetic configurations using density functional theory (DFT). Recent research [1] has shown that meta-GGA and GGA+U DFT functionals provide conflicting results, indicating the need for a more robust electronic structure method. Diffusion Monte Carlo (DMC) is a promising approach due to its attractive scaling with system size and ability to capture electronic correlations. Due to fixed node approximation, DMC method provides an exact solution when the nodal surface of the trial wave function is exact, so accurate trial wave function is required.

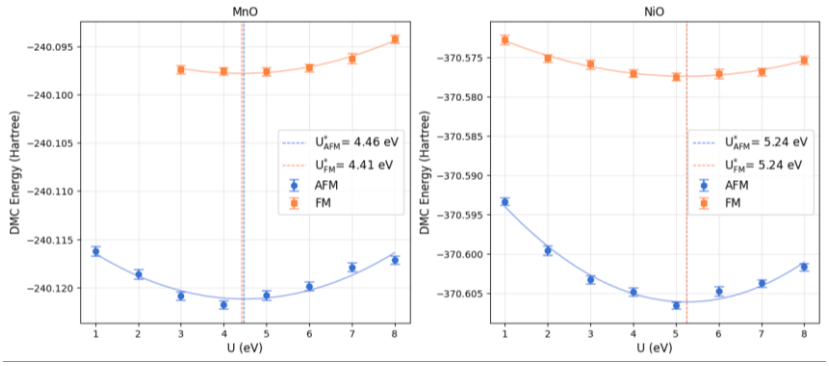

Fig. 1. DMC energies vs Hubbard U of AFM and FM MnO and NiO crystals

This research focuses on the DMC calculations of energy differences, $\Delta E^{DMC} = E_{FM} - E_{AFM}$, between ferromagnetic (FM) and antiferromagnetic (AFM) configurations of magnetic transition metal oxides. All calculations were carried out using QMCPACK code [2]. To improve the nodal surface of the wave function, the technique based on varying Hubbard U parameters to find the minimum of the DMC energy was employed, and the results of this procedure for FM and AFM phases of NiO and MnO are presented on Fig. 1.

In addition, extrapolation on thermodynamic limit ($1/N \rightarrow 0$) was carried out to mitigate the 2-body finite size effect by using different supercells. All energies were calculated using twist-averaged boundary conditions. The DMC energy differences were compared against various DFT approaches, namely, GGA, GGA+U, metaGGA, and hybrid DFT. It was found that, within statistical uncertainties, the DMC method provides values of ΔE^{DMC} closest to those obtained from the INS experiment and resolves the discrepancy observed in the DFT calculations. Therefore, we suggest that the DMC method can be a benchmarking tool for magnetic materials.

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THEORETICAL PREDICTION OF THE MAX PHASES $(Sc_{1-x}Cr_x)_2AlC$ STABILITY AND ELECTRONIC PROPERTIES

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MAX phases are ternary compounds with the general formula $M_{n+1}AX_n$, where *M* is a transition metal, *A* is a *p*-block element (e.g., *Si, Ge, Al, S,* or *Sn*), and *X* is carbon or nitrogen. These materials possess a range of properties, including electrical and thermal conductivity, oxidation resistance, and wear resistance due to their unique combination of metals and ceramic properties[1].

In this study, we examined the impact of substituting scandium ions with chromium (Cr) ions on the stability as well as the electronic and magnetic properties of the MAX phase Sc_2AlC and $(Sc_{1-x}Cr_x)_2AlC$. A comparison was then made of the electronic and magnetic properties of the obtained compounds. The atomic and electronic structure of $(Sc_{1-x}Cr_x)_2AlC$ was found using the DFT level of the theory by the CRYSTAL program[2]. The analysis of the change in the optimized geometry parameters $(Sc_{1-x}Cr_x)_2AlC$ in crystal cell and the atomic spins and charges of Sc and Cr were carried out depending on the used functional. According to calculations the B3LYP functional give a satisfactory result and are in good agreement with the literature data[3,4]. To simulate the possible magnetic properties, structures with different spins were calculated. All MAX phases showed high spin on metal atoms.

The research was supported by the grant of the Russian Science Foundation № 25-12-20012, https://rscf.ru/project/25-12-20012/, grant of the Krasnoyarsk Regional Science Foundation.

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STRUCTURAL PHASE TRANSITION IN VS_2: A FIRST-PRINCIPLES INVESTIGATION

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Two-dimensional vanadium disulfide (VS_2) is a promising magnetic transition metal dichalcogenide that exhibits intrinsic ferromagnetism at room temperature and therefore attracts considerable attention for spintronic applications [1]. Its electronic properties strongly depend on crystal structure and dimensionality, with the trigonal-prismatic H phase predicted to possess semiconducting characteristics, whereas the octahedral T phase is typically metallic. Previous theoretical and experimental studies indicate that bulk VS_2 is thermodynamically stable in the T phase, while in the monolayer limit the H phase becomes energetically favorable and remains structurally stable up to temperatures of about 500 K [2]. However, the evolution of phase stability between these two limits has not yet been systematically investigated. In particular, the relative thermodynamic stability of the H and T polymorphs in VS_2 and its dependence on temperature remain unclear, making this problem highly relevant for understanding phase transitions in two-dimensional magnetic materials.

In this work, the structural phase stability of VS_2 is investigated using first-principles calculations within density functional theory. The H and T polymorphs are considered for different thicknesses. Equilibrium crystal structures, total energies, electronic properties, and magnetic moments are calculated. The effect of temperature on phase stability is evaluated through calculations of vibrational contributions to the free energy, enabling a comparison of the thermodynamic stability of the competing phases at room temperature.

Particular attention is paid to the evolution of the free-energy difference between the H and T structures with increasing thickness. The influence of interlayer interactions on the structural and magnetic properties of VS_2 is analyzed, and the dynamical stability of the investigated phases is assessed through phonon calculations.

The obtained results provide insight into the interplay between dimensionality, lattice dynamics, and magnetism in VS_2 and establish stability trends for competing structural phases in two-dimensional vanadium dichalcogenides. The findings contribute to a deeper understanding of phase transitions in low-dimensional magnetic materials and may facilitate the development of future spintronic technologies.

The study was supported by the Russian Science Foundation grant No. 25-79-30019, https://rscf.ru/project/25-79-30019/.

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THE THREE-STATE POTTS MODEL ON THE BCC LATTICE IN AN EXTERNAL MAGNETIC FIELD

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Antiferromagnetic (AF) versions of the Potts model exhibit a complex and diverse picture, as they are critically dependent on the lattice topology and can exhibit frustration, residual entropy, and nontrivial ordered states even in the absence of obvious disorder. The presence of competing next-nearest-neighbor interactions in the AF Potts model significantly complicates the phase diagram [1]. An external magnetic field introduces an additional source of competition, which also affects the phase diagram, potentially stabilizing intermediate ordered states, changing the order of the phase transition, or completely suppressing ordering.

In this work, the influence of an external magnetic field on phase transitions and thermodynamic properties of the AF 3-state Potts model on a body-centered cubic (bcc) lattice is investigated using the Monte Carlo method. The system is described by the Hamiltonian:

$$H = -J_1 \sum_{\langle i,j\rangle, i\neq j} S_i S_j - h \sum_{\langle i\rangle} S_i = -J_1 \sum_{\langle i,j\rangle, i\neq j} cos(\theta_{ij}) - h \sum_{\langle i\rangle} S_i \quad (1)$$

where the spin $S_i = \{S_1, S_2, \ldots, S_q\}$ can be in different q states, and h is the external magnetic field. The spin states are represented as two-dimensional unit vectors: $S_1 = \{0, 1\}$, $S_2 = \{0.866, -0.5\}$, $S_3 = \{-0.866, -0.5\}$. The nearest-neighbor interaction is negative ($J_1 = -1$). Figure 1 presents the phase diagrams in the (h, T_N) plane for different values of J_2. At $J_2 = -0.2$ and -1, a significant complication of the phase diagram is observed compared to the case of $J_2 = 0$: additional phase transition branches appear, indicating the implementation of several types of magnetic ordering.

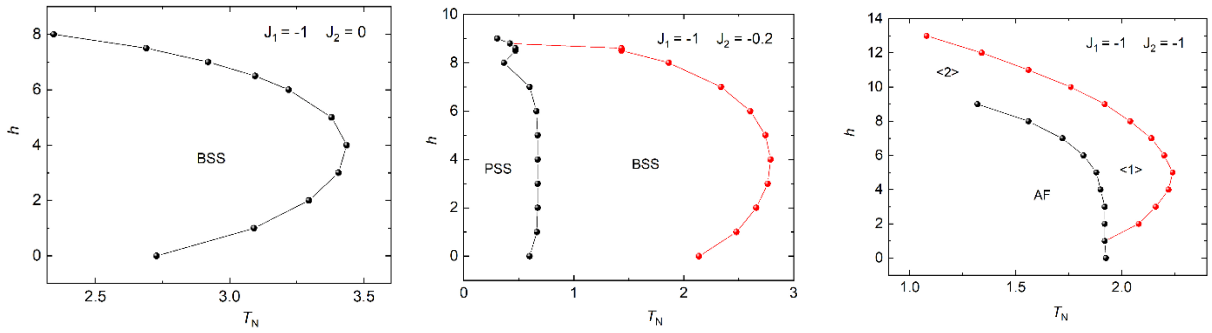

Fig. 1. Phase diagrams of the AF 3-state Potts model on a bcc lattice for different values of the next-nearest-neighbor interaction J_2.

The study was supported by a grant from the Russian Science Foundation, Russia No. 25-12-20029, https://rscf.ru/project/25-12-20029/»

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FIRST-PRINCIPLES MODELING OF SPIN-CURRENT GENERATION IN FERROMAGNET/TRANSITION-METAL DICHALCOGENIDE TERAHERTZ SPINTRONIC EMITTERS

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Spintronic terahertz emitters convert ultrafast laser-induced spin currents into sub-picosecond charge-current bursts and broadband THz radiation. Metallic ferromagnet/heavy-metal stacks provide an established benchmark [1], whereas ferromagnet/transition-metal dichalcogenide (FM/TMD) heterostructures offer strong interfacial spin-orbit coupling, broken inversion symmetry, and hybridization-driven electronic reconstruction. Giant spin injection has been reported in Co/MoS_2 [2], and THz spin-to-charge conversion in ferromagnet/$NbSe_2$ stacks [3]. Recent analysis of MoS_2/Co further indicates that the pump-energy-dependent THz response may arise from a hybrid metallic interface acting as an energy transducer rather than from direct semiconductor-controlled spin injection [4].

We propose a first-principles framework for studying ultrafast spin-current generation in FM/TMD emitters from their interfacial electronic structure. Density-functional calculations will determine spin-resolved density of states, band alignment, hybridization-induced metallic states, interfacial spin polarization, and magnetic moments induced in the TMD. These quantities will be coupled to a thermodynamic description of laser-driven spin transport, where nonequilibrium chemical potentials and transport coefficients define the spin-current response and permit estimation of absolute spin-current densities in A/cm^2 [5]. The workflow will enable quantitative comparison of TMD compositions, interface terminations, layer registries, interlayer distances, and related structural configurations.

A central objective is to establish whether interfacial hybridization is sufficient to explain experimental trends or whether bulk spin-to-charge conversion within the TMD must also be considered. Where appropriate, spin Hall conductivity will be calculated as a complementary descriptor of conversion efficiency. Comparing hybridized electronic states, thermodynamic spin-current generation, and spin Hall response should separate the roles of ferromagnetic heating, hybrid-layer-mediated energy transfer, and interfacial versus bulk conversion channels. The calculated trends will also be examined in relation to the common microscopic driving force proposed for ultrafast demagnetization and laser-induced THz spin transport [6].

The expected outcome is a predictive screening strategy that identifies FM/TMD combinations and stack geometries with enhanced spin-current generation and THz emission, providing practical design rules for compact next-generation terahertz spintronic sources.

This work was supported by the Ministry of Science and Higher Education (Contract No. FSFZ-2025-0002).

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HALDANE CHAINS S = 1 IN A ULTRA-HIGH MAGNETIC FIELD

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The magnetization of one-dimensional magnets was measured in magnetic fields up to 500 T. The study of Gd_2BaNiO_5 and $(Y_{1-x}Nd_x)BaNiO_5$ compounds containing Haldane spin chains of Ni^{2+} (S=1) will be presented. Substitution of rare-earth ions allows changing the intensity of interchain interactions. The source of the ultra-high magnetic field was a magnetocumulative generator MK-1 [1]. The measurements were carried out at a temperature of 4.2 K. Magnetization curves of the compounds were obtained. A transition of the initially antiferromagnetic subsystem of gadolinium ions to a ferromagnetic state, as well as ferromagnetic ordering of nickel chains are observed.

Samples were provided by the Physics Department of Moscow State University and the Chemistry Department of the Higher School of Economics.

The work was carried out within the framework of the scientific program of the National Center for Physics and Mathematics.

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THEORETICAL ANALYSIS OF PHASE NOISE IN A YIG SPIN-WAVE DELAY LINE OSCILLATOR

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This paper presents an analysis of deterministic and fluctuation processes in a delayedfeedback oscillator incorporating a dispersive delay line, a configuration characteristic of spinwave delay lines. The resonant system of such an oscillator constitutes a distributed-parameter network loaded by the reactive admittance of its active device (broadband amplifier) (Fig. 1).

Given that the delay-line yttrium iron garnet (YIG) resonator under consideration is nearly conservative and exhibits a non-equidistant spectrum of natural frequencies, the dynamic processes within the system can be effectively analyzed using the method of shortened equations, specifically in the formulation proposed by S. I. Evtyanov [1]. This analytical framework has previously been developed for oscillators employing non-dispersive delay lines [1, 2], as well as for surface acoustic wave (SAW) delay lines [2]. However, it has not yet been extended to dispersive delay lines, such as spin-wave delay lines.

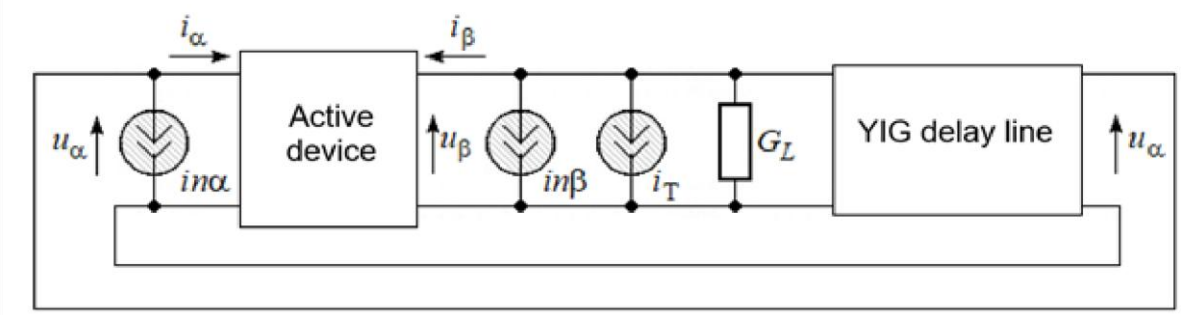

Fig. 1. Block diagram of the oscillator with noise sources

The objective of this work is to derive analytical expressions for calculating both the steady-state operating conditions and the fluctuation characteristics — specifically, the power spectral densities of amplitude and phase noise of an oscillator based on a dispersive delay-line YIG resonator.

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HOLSTEIN AND SSH POLARON CHANNELS AS COMPETING MECHANISMS IN THE RENORMALIZATION OF EXCHANGE INTERACTION

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The exchange interaction in strongly correlated systems is governed by virtual hopping processes and can be affected by different electron–phonon interaction (EPI) channels [1-5]. The local Holstein-type interaction is usually associated with suppression of superexchange [2], whereas the nonlocal SSH-type (or Peierls-type) interaction can both suppress and enhance superexchange. Thus, these two EPI channels may act as competing or cooperative mechanisms in the renormalization of magnetic exchange. The key problem addressed here is to understand the competition and cooperation between two different channels of interaction in strongly correlated systems.

To analyze this problem, we consider an extended correlated pd-model relevant to cuprate systems: $H = H_{pd} + H_{\mathrm{Hol}} + H_{\mathrm{SSH}}$, where H_{pd} describes the electronic Emery pd-model, H_{Hol} corresponds to the Holstein-type contribution, and H_{SSH} describes the SSH-type contribution.

The model is treated within the polaronic version of the generalized tight-binding method [6], where intracell electronic correlations and cluster electron-phonon contributions are treated exactly. In this approach, the Hamiltonian is rewritten in the Hubbard-operator representation. This makes it possible to project the extended Emery pd-model onto an effective low-energy extended Hubbard model with renormalized parameters. This representation provides a convenient basis for deriving a Heisenberg-type magnetic superexchange Hamiltonian that includes polaronic effects, using the projection-operator technique [7,8]. This method excludes high-energy virtual hopping processes and effectively keeps their contribution in exchange terms. The resulting exchange parameter does not reduce to a sum of separate electronic and EPI parts; instead, it exhibits a non-additive character arising from the cooperation and competition between the two interactions. We also analyze the renormalizations of the superexchange parameter caused by inter-cluster EPI contributions within the first coordination sphere and identify the main contribution due to the SSH term.

Moreover, we construct a phase diagram of superexchange interaction as a function of dimensionless EPI coupling constants. The diagram demonstrates a non-uniform variation of the exchange interaction, including regions of both suppression and enhancement. In particular, we find a region with strong suppression of superexchange parameter caused by polaron self-trapping. Our results provide a route for controlling magnetic properties of strongly correlated systems through interference of different Holstein and SSH channels of electron-phonon interaction.

Support by the Russian Science Foundation, project No. 24-12-00044 is acknowledged.

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KINETICS OF STRUCTURAL PHASE TRANSITIONS IN THE FeGa ALLOYS

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Fe-Ga-based alloys are of interest of scientists all over the world because of a series of properties of practical concerns. In particular, these alloys are used for manufacture of sensors and pressure transducers [1, 2]. Note, that among the iron-based alloys record-breaking values of magnetostriction are observed in Fe-Ga alloys. The most interesting properties are observed for the alloys with Gallium content from 19 to 27 at.%, since within that range of concentration the alloys have the best functional properties. The temperature of order-disorder transformation and phase stability of the alloys $Fe_{77}Ga_{23}$ was assessed by using MC simulation. The analysis used Hamiltonian operator of the Blume–Emery–Griffiths model and the Metropolis algorithm. Cooling process was considered, i.e. the initial configuration was the disorder phase, which is observed experimentally in that alloy at high temperatures. At the first stage we formed the initial configuration of the atoms location in the lattice, then we chose arbitrary sites in the lattice and derived energies for the initial and new configurations subject to repositioning of the atoms. In case of the energetic benefits of a new configuration we preserved such a beneficial configuration. This procedure was being performed until a number of configurations is generated to be equal to the number of all sites in the lattice. This process makes one step of the MC simulation. Moreover, the simulation was done depending on the MC steps number, which allowed studying the process of orderdisorder transformations to the time. MC step was taken as the time unit. The process of changing in the $L1_2$ volume fraction at T = 800 °C depending on the MC steps is shown in Fig. 1. It is seen that the $L1_2$ phase is developed mainly by small localized clusters with their subsequent growth in the lattice. The $L1_2$ clusters are formed in the matrix of the $D0_3$+A2+B2 phase's mixture.

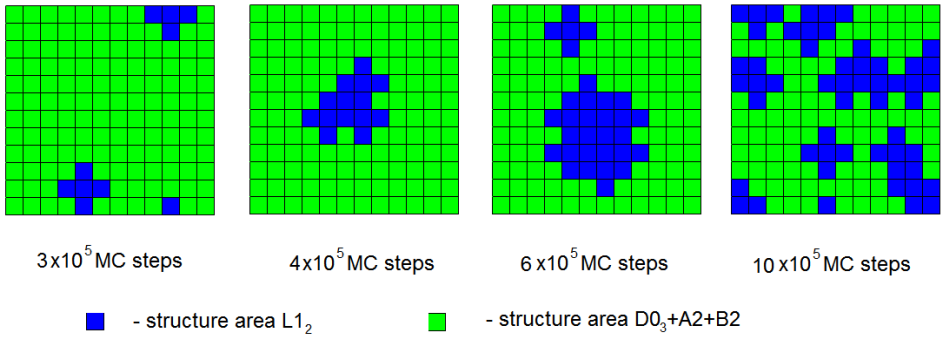

Fig. 1. Dependence of the $L1_2$ fraction in the model lattice volume on the MC steps (time) at 800 °C.

This study was supported by Russian Science Foundation No. 26-12-20023.

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FIRST-PRINCIPLES MECHANICAL MAPPING OF OFF-STOICHIOMETRIC NI-MN-GA HEUSLER ALLOYS

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Although Ni–Mn–Ga Heusler alloys are well known for their magnetic shape memory and magnetocaloric response, the mechanical properties of off-stoichiometric compositions have received little attention, unlike their stoichiometric Ni_2MnGa counterpart. Reliable data on elastic moduli, Poisson's ratio, and Debye temperature are essential for device-oriented applications involving mechanical actuation, energy dissipation, and phase transformation under load. This work extends previous DFT study [1] by systematically computing mechanical characteristics of compositionally stable austenitic (cubic) and martensitic (tetragonal/orthorhombic) phases across the full ternary Ni-Mn-Ga diagram.

Using DFT within the PAW formalism and the PBE-GGA exchange-correlation functional in VASP, we constructed 105 distinct 16-atom supercells covering the full compositional range. Structural and magnetic reference states were obtained via complete relaxation of atomic positions and lattice parameters. Thermodynamic stability against decomposition into elemental or binary phases was assessed through convex hull construction. For each stable or metastable composition, elastic constants were computed and subsequently converted into polycrystalline averages (B, G, E, ν) via Voigt–Reuss–Hill averaging, together with Debye temperatures derived from sound velocities. As an example, among 105 compounds only 48 compositions retained cubic symmetry, whereas 15 compositions revealed the mechanical instability due to negative sing of C' modulus (Fig. 1).

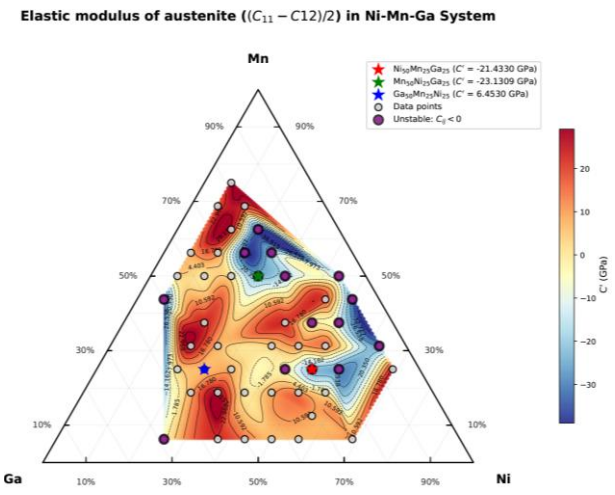

Fig. 1. Contour map of the tetragonal shear modulus $C'=(C_{11}-C_{12})/2$ for Ni-Mn-Ga in a cubic structure.

In general, for austenite, contour plots illustrate the spatial distribution of bulk and shear moduli, offering an intuitive guide to stiffness and shear resistance across the ternary diagram. For martensite, we present maps of the Young's modulus anisotropy ratio (E_c/E_a) and the average Debye temperature. Additionally, Pugh's criterion (G/B) is mapped to distinguish ductile from brittle regions. This mapping strategy enables rapid localization of composition domains where high stiffness, moderate anisotropy, and favorable ductility coexist. Such regions are particularly promising for the development of machinable and durable Ni-Mn-Ga alloys tailored for magnetic shape memory actuators and damping systems.

Supported by the Ministry of Science and Higher Education of the Russian Federation (contract № 075-00188-26-00).

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DFT+U STUDY OF THE MAGNETIC PROPERTIES OF MAGNETITE (Fe_3O_4)

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In this study, the magnetic properties of the magnetite (Fe_3O_4) crystal were theoretically investigated using the DFT+U computational approach. Magnetite plays a significant role in the fields of quantum materials physics and spintronics due to its complex electronic structure and ferrimagnetic ordering [1]. In this work, the atomic-scale magnetic moments of Fe^{2+} and Fe^{3+} ions were analyzed separately (Table 1).

According to the calculated results, the magnetic moments of Fe^{2+} ions vary in the range of 3.5654–3.5690 μB, and in all cases the spin orientation is directed downward (↓). This indicates that Fe^{2+} ions are located in a relatively uniform magnetic environment within the crystal lattice and possess a stable local electronic structure.

For Fe^{3+} ions, the magnetic moments range from 3.6185 to 3.6209 μB, and they exhibit two different spin orientations: some are aligned downward (↓), while others are aligned upward (↑). This confirms the presence of oppositely oriented spin sublattices in the magnetite crystal and the formation of ferrimagnetic ordering. Such an antiparallel spin configuration forms the basis of the net magnetization of the material.

In addition, the slight difference in magnetic moments between Fe^{2+} and Fe^{3+} ions indicates a strong exchange interaction and is associated with the degree of localization of 3d electrons. The DFT+U approach is particularly suitable for accurately describing such strongly correlated electron systems.

Overall, the obtained results confirm the ferrimagnetic nature of magnetite at the atomic level and provide a deeper understanding of the spin ordering mechanism between Fe^{2+} and Fe^{3+} ions. These findings may serve as a theoretical basis for the future development of spintronic devices based on magnetic materials.

Table 1. Magnetic Moments of Magnetite Atoms

Atom №	Type	Magnetic moment(μB)	Direction
Fe2+ atoms (1–8)			
1	Fe2	3.5684	↓
2	Fe2	3.5690	↓
3	Fe2	3.5684	↓
4	Fe2	3.5690	↓
5	Fe2	3.5654	↓
6	Fe2	3.5690	↓
7	Fe2	3.5684	↓
8	Fe2	3.5690	↓
Fe^{3+} atoms (9–24)			
9	Fe3	3.6185	↓
10	Fe3	3.6185	↓
11	Fe3	3.6185	↓
12	Fe3	3.6209	↓
13	Fe3	3.6185	↓
14	Fe3	3.6185	↓
15	Fe3	3.6185	↓
16	Fe3	3.6185	↓
17	Fe3	3.6185	↑
18	Fe3	3.6209	↑
19	Fe3	3.6185	↑
20	Fe3	3.6185	↑
21	Fe3	3.6209	↑
22	Fe3	3.6185	↑
23	Fe3	3.6209	↑
24	Fe3	3.6185	↑

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EFFECT OF 10 MEV ELECTRON IRRADIATION ON ELECTRONIC TRANSPORT OF Bi_2Se_3 SINGLE CRYSTALS

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The development of new thermoelectric materials and the control of their electronic and thermal properties are the key challenges in modern science at the intersection of condensed matter physics, physical materials science, engineering, and technology. Despite their unique advantages—direct conversion of thermal energy into electrical one, compactness, and reliability—the widespread use of thermoelectric devices is hampered by their relatively low efficiency, which is related to the thermoelectric figure of merit ($ZT \leq 1$) of the materials used.

Among the most promising and practical thermoelectrics are bismuth chalcogenides, such as Bi_2Te_3 [1], Bi_2Se_3 [2, 3] and others. Despite significant progress in researching the physical properties of these materials, finding optimal ways to control their thermoelectric characteristics remains a pressing issue. One effective modification method is creation of point defects in thermoelectrics, for example, via doping and irradiation with high-energy particles. In this work, we study the effect of 10 MeV electron irradiation on electron transport properties of thermoelectric Bi_2Se_3.

The Bi_2Se_3 single crystal was grown by the Bridgman-Stockbarger method as described in [4, 5]. Irradiation was carried out on a linear electron accelerator with an energy of 10 MeV and fluences of up to 16 mC/cm^2. Electrical resistance, thermoelectric power and Hall effect were measured at temperatures from 4.2 to 80 K and in magnetic fields up to 5 T using the Physical Property Measurement System (PPMS-9, Quantum Design).

The experiments demonstrated that irradiating Bi_2Se_3 single crystals with high-energy electrons leads to significant changes in electron transport, which can be used to modify and control the electronic and especially thermoelectric characteristics of topological materials. The results are discussed in terms of existing theoretical concepts.

The study was supported by the Russian Science Foundation, project No. 26-79-10314.

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Plenary

Wednesday, 19 August, 09:00 - 10:30

NONCOLLINEAR ANTIFERROMAGNETS FOR SPINTRONICS

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Recently, antiferromagnets have emerged as promising materials for spintronics due to their robustness against magnetic perturbations, absence of stray fields, and ultrafast spin dynamics. Among them, noncollinear antiferromagnets are particularly attractive because broken PT symmetry lifts spin degeneracy even in the absence of net magnetization and spin–orbit coupling. This produces momentum-dependent spin polarization and nonvanishing Berry curvature, allowing these materials to function similarly to ferromagnets in spintronic devices. Noncollinear antiferromagnets exhibit a range of useful functionalities, including anomalous Hall and spin Hall effects, efficient spin-current generation, and electrically switchable magnetic domains controlled by spin-transfer or spin–orbit torques. Their spin polarization also makes them promising for antiferromagnetic tunnel junctions, which can exhibit large tunneling magnetoresistance (TMR). Combining electrical writing through spin torques with TMR readout could enable ultrafast, high-density antiferromagnetic random-access memories (AFM-RAMs). This talk will review the key spintronic properties of noncollinear antiferromagnets and the underlying physical mechanisms governing them.

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RATIONAL DESIGN OF MAGNETIC NANOARCHITECTURES: FROM COMPOSITES TO HYBRID MATERIALS

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This communication explores the rational design of hybrid (bi)-magnetic nano-architecture with complex structures, (e.g. core/shell, bi-magnetic nanocomposites[1], [2] hollow nanostructures[3] , ….), in intimate contact with various functional components (e.g., polymers[4], [5], mesoporous structures, zeolites[6], biological molecules like enzymes[7], [8], or organic ligands[9]). In particular, a novel classification of magnetic nanocomposite is proposed, categorizing them into four types based on their structural and functional integration (Figure)[10].

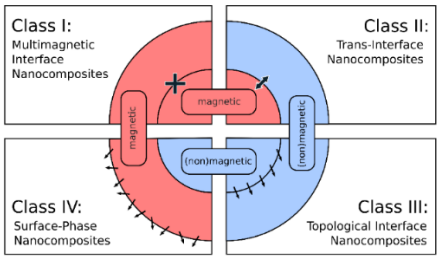

Figure 1. Novel Classification Framework for Magnetic Nanocomposites

This classification allows for a better definition of the transition from "*composite*" materials, which combine multiple phases with additive or averaged properties and hybrid magnetic nanocomposites, exhibiting emergent, synergistic functionalities arising from intimate nanoscale interactions. By more sharply defining the boundary between composites and hybrids, this approach opens new conceptual horizons and provides a roadmap for the strategic design of next-generation magnetic nanomaterials, where interfacial control is not incidental, but foundational.

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ORAL SESSION

Spintronics and Magnetotransport

Wednesday, 19 August, 11:00 - 13:00

2D VAN DER WAALS MATERIALS: A PLATFORM FOR POST-MOORE ELECTRONICS

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The exponential growth of data traffic and energy consumption in modern computing architectures signals the end of Moore's law era, demanding novel paradigms for information processing and storage. Two-dimensional (2D) van der Waals (vdW) materials have emerged as a transformative platform for post-CMOS electronics, offering atomically flat interfaces, exceptional electrostatic control, and unprecedented opportunities for creating heterostructures with tailored properties [1,2].

This talk presents recent advances in spin-orbitronics based on 2D magnetic materials and their heterostructures for next-generation non-volatile memory and probabilistic computing. The key challenge addressed is the elimination of external magnetic fields for deterministic spin-orbit torque (SOT) switching – a critical bottleneck hindering commercial SOT-MRAM adoption [3]. We demonstrate that low-symmetry 2D materials (WTe_2, $PtTe_2$, $MoTe_2$ etc.) inherently generate out-of-plane spin polarizations due to their crystal symmetry, enabling field-free magnetization switching in adjacent 3d ferromagnets and 2D magnetic materials [4,5].

Our comprehensive approach combines ab-initio calculations (VASP), micromagnetic simulations (MuMax3), and experimental validation across a unique infrastructure spanning CVD synthesis, molecular beam epitaxy, e-beam evaporation and nanolithography, and advanced magnetotransport measurements (ST-FMR, harmonic Hall, pulsed switching). We report a SOT-MTJ device achieving tunnel magnetoresistance up to 175%, deterministic field-free switching with 50 ns pulses, and controlled stochastic operation for probabilistic bits (p-bits) with sigmoidal current-probability characteristics [6].

The scientific novelty includes: (i) establishing correlations between crystal symmetry, interface quality, and SOT efficiency in hybrid and all-2D heterostructures; (ii) demonstrating energy-efficient switching (<10 fJ per operation) with endurance $>10^8$ cycles; (iii) implementing p-bit elements for neuromorphic and true random number generation (TRNG) applications.

These results, obtained within the State task of the Ministry of Science and Higher Education of Russia (FZNS-2026-0013), lay the foundation for technological sovereignty in post-silicon electronics, addressing critical needs for energy-efficient AI hardware and data center infrastructure.

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SPIN PUMPING IN EPITAXIAL FE/RH BILAYERS

Wiemeler J.[1], Ali H.[2], Kovacs A.[2], Tarasov I.[1], Wilhelm F.[3], Rogalev A.[3], Dunin-Borkowski R.[2], Farle M.[1], Semisalova A.[1]

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Spin-to-charge conversion in metallic heterostructures with strong spin-orbit coupling (SOC), such as Pt and Pd, is well established in spintronics. Rh, a 4d transition metal with SOC comparable to Pd and high orbital Hall conductivity, remains underexplored despite its potential [1,2]. Here, we investigate epitaxial Fe(5–10 nm)/Rh(0–15 nm) bilayers grown on GaAs(001) and GaAs(110) at room temperature via molecular beam epitaxy (ultrahigh vacuum, 5×10^{-10} mbar), with in situ characterization by low energy electron diffraction (LEED) and Auger Electron Spectroscopy (AES). Rh exhibits Stranski-Krastanov growth, forming continuous layers at ~1 nm thickness.

Broadband ferromagnetic resonance reveals a large spin mixing conductance, $g^{\uparrow\downarrow}_{mix}$ = (2.9 ± 0.2)×10¹⁹ m⁻²—comparable to Pt—alongside a spin diffusion length λ_{sd} = 9.0 ± 1.3 nm, similar to Pd (Fig. 1). High-resolution transmission electron microscopy (HR-TEM), scanning TEM, and X-ray diffraction confirm high crystallinity and a sharp, intermixing-free Fe/Rh interface. Despite a ~6% lattice mismatch between bcc-Fe and fcc-Rh, periodic misfit dislocations at the interface enable smooth epitaxial growth. Fe exhibits tetragonal distortion ($c/a \approx 1.026$) due to ~1.4% lattice mismatch with GaAs, while Rh remains cubic and strain-free.

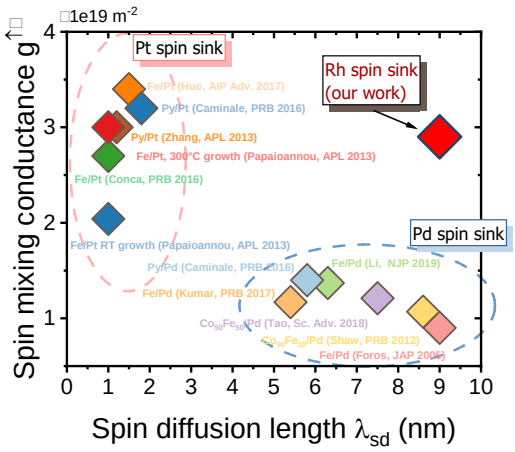

Fig. 1. Spin mixing conductance and spin diffusion length of Pt, Pd interfaced with different ferromagnetic layers, compared with Fe/Rh epitaxial heterostructure.

XMCD measurements at the Rh $L_{2,3}$ edge show negligible intrinsic Rh polarization in Fe/Rh bilayers on GaAs(001), though interface polarization can be tuned by growth mode (layer-by-layer for GaAs(001) vs. island growth observed for GaAs(110) substrate), highlighting the role of structure and interface in spin transport.

This work was supported by the Deutsche Forschungsgemeinschaft (DFG) within CRC/TRR270 (Project ID 405553726) and SE 2853/1.

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MICROSCOPIC ORIGIN AND ENGINEERING OF TOPOLOGICAL MAGNONS IN LAYERED VDW MAGNETS

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The discovery of two-dimensional van der Waals (vdW) magnetic materials has opened new avenues in spintronics and condensed matter physics, enabling the exploration of novel quantum phenomena. Recent experiments suggest that magnons in some of these systems may exhibit nontrivial topology; however, their microscopic origin remains unclear.

In this work, we propose a combined theoretical framework based on both direct measurements of magnon dispersion and magnon transport signatures to identify the underlying mechanisms responsible for topological magnons. In particular, we show that applying an external magnetic field and performing angular-dependent measurements, thereby tuning the direction of the magnetic ground state, provides a powerful tool to distinguish whether an observed magnon gap is topological. Furthermore, this approach allows one to determine whether the gap originates from Kitaev-type interactions or chiral Dzyaloshinskii–Moriya interactions [1-3].

We also demonstrate that the same strategy can be extended to probe the microscopic origin of magnon–phonon coupling in these materials [4].

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THZ SPINTRONIC EMITTERS WITH MAGNETIC FIELD-TUNABLE PARAMETERS

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Spintronic THz emitters with a ferromagnetic metal (FM)/non-magnetic (heavy metal) structure have been actively studied in recent years, as they represent a new type of emitter that differs from others in both its physical operating principles and functional characteristics. They are distinguished by their high efficiency, comparable to that of inorganic nonlinear optical emitters and exceeding that of semiconductor emitters, and a broad emission spectrum, as well as the ability to control the emission characteristics directly in the source at room temperature. In such emitters, the amplitude, polarization, and phase of the THz wave can be modulated using a magnetic field.

The physical mechanism for generating THz radiation in bilayer structures involves four main steps: excitation of spin-polarized electrons by femtosecond laser pulses in the FM layer, superdiffusion of these electrons into the NM layer, conversion of the transverse spin current to a longitudinal charge current via the inverse spin Hall effect, and the actual emission of THz waves by the charge current. The THz field amplitude is proportional to the magnetization modulus, and the polarization direction is perpendicular to the magnetization vector.

To modulate the polarization, the FM layer must have uniaxial magnetic anisotropy in the layer plane. In such a layer, within the anisotropy field applied along the hard axis, the magnetization rotates 180 degrees, saturating beyond the anisotropy field. Thus, changing the external magnetic field within the anisotropy field ensures rotation of the THz wave's polarization plane by 180 degrees without changing the amplitude. Opposite points along the magnetic field correspond to a phase shift of also 180 degrees (by π). In THz spintronic structures with uniaxial magnetic anisotropy and high magnetostriction deposited on a piezoelectric material, magnetization rotation can be achieved by an electric field. The maximum achieved polarization plane rotation in this case is 120 degrees and is currently limited by the mechanical strength of the piezoelectric material.

Spin valves are used to modulate the THz amplitude. Spin valves are a multilayer structure consisting of two FM layers separated by a NM metal interlayer (FM/NM/FM). A key feature of the spin valve architecture is that one ferromagnetic layer must be magnetically hard and the other magnetically soft. In this case, changing the magnetic field in the structure creates not only two magnetization states (saturation), which determine the phase of the THz wave, but also multiple states, allowing for modulation of its amplitude. The magnetic hardness of the ferromagnetic layer in the valve can be varied by changing the materials used and their thickness when forming the ferromagnetic layers; however, this typically leads to a decrease in generation efficiency. A more effective method is to fix the magnetization direction in one of the layers through exchange interaction with the antiferromagnetic layer.

Support by the Russian Science Foundation (grant No. 23-19-00849) is acknowledged.

ORAL SESSION

Magnetophotonics

Wednesday, 19 August, 11:00 - 13:00

SPIN CURRENTS AND TEXTURES INDUCED BY TWISTED LIGHT IN 2D DIRAC MATERIALS

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Optical beams with tailored spatial structure of electromagnetic field, such as vector beams or twisted beams that carrying orbital angular momentum, provide a new paradigm to manipulate electrons in condensed matter.

Here, we discuss optical injection of charge and spin currents and the emerging spin textures by structured light in two-dimensional (2D) Dirac materials. The currents and textures are entirely controlled by the structure of the optical beams, including the profiles of intensity, polarization, and phase, offering a versatile tool for all-optical injection and manipulation of charge and spin without restrictions imposed by material symmetry.

We present a phenomenological description of charge and spin currents induced by structured light and systematically explore the mechanisms of current injection for a class of 2D Dirac materials, such as monolayers of transition metal dichalcogenides, narrow-gap quantum wells, etc. It is shown that both charge and spin currents can be caused by the gradient of the light intensity as well as the gradients of the Stokes polarization parameters and the phase of the electromagnetic field. Microscopic mechanisms of the current generation include the optical orientation of electron spins by circularly polarized light, the optical alignment of electron momenta by linearly polarized light, and the class of charge and spin photon drag effects. Additionally, the charge and spin currents are coupled and interconverted to each other due to the spin Hall and inverse spin Hall effects.

Applying this formalism to twisted optical beams, we show that the induced currents possess both radial and azimuthal (vortex) components. These components can be tuned by adjusting the beam polarization profile, topological charge, and radial index, enabling the creation of complex spin density and spin current patterns including spin vortices. The results establish structured light as a powerful, contactless technique to create charge and spin current distributions, with potential implications for spin-orbitronics and ultrafast optoelectronics.

Support by the Russian Science Foundation (Project No. 22-12-00211-П) is acknowledged.

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ULTRAFAST TERAHERTZ MAGNETISM IN RARE EARTH IRON GARNETS (NONLINEARITY, NON-COLIINIARITY, CAVITIES, AND CRYSTAL FILED EXCITATIONS)

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Iron garnets ($A_3Fe_5O_{12}$) are a broad family of ferrimagnets with antiferromagnetic exchange interactions. Their magnetic structure comprises two iron sublattices and one rare-earth magnetic sublattice. Unlike collinear antiferromagnets, their magnetic state can be controlled by relatively weak magnetic fields while retaining terahertz (THz) eigenfrequencies. This provides unique access to the study of ultrafast magnetic dynamics, several distinct features of which are revealed here using THz-pump/infrared-probe spectroscopy.

First, iron garnets can exhibit magnetic compensation points where the net magnetization vanishes. Interestingly, this compensation may occur either between iron sublattices, as in gallium-substituted yttrium iron garnet [1], or between the iron and rare-earth sublattices, as in thulium iron garnet [2]. In both cases, THz pulses resonantly excite the exchange mode even near the compensation point. Furthermore, intense THz fields can additionally induce nonlinear off-resonant excitation of the quasi-ferromagnetic mode (typically in the GHz range) via the inverse Cotton-Mouton effect, demonstrated in thulium iron garnet [3].

Second, the strong temperature dependence of sublattice magnetization allows the exchange mode frequency to span an entire octave or more. This exceptional tunability enables precise frequency matching in cavities to realize the recurrent magnon-pumping effect. For instance, a twofold enhancement of the exchange mode amplitude and a fivefold decrease in effective damping have been demonstrated in gadolinium iron garnet (GdIG) [4].

Third, the non-collinear (canted) magnetic phase is a unique feature of ferrimagnets that emerges near the net magnetic moment compensation point. By using a 10 T superconducting magnet, we accessed this canted phase in GdIG and showed that magnetization dynamics are highly sensitive to the net magnetic moment orientation and exhibit a pronounced dependence on both the external magnetic field and temperature.

Fourth, experiments on holmium iron garnet reveal crystal-field excitations of Ho^{3+} ions in the THz-pump/infrared-probe spectrum [5]. The pronounced temperature dependence of the response suggests that non-collinear spin alignment is essential for observing these excitations.

The data shows excellent agreement with phenomenological modeling [6]. Ultimately, THz-pump/infrared-probe spectroscopy proves to be a versatile tool for studying ultrafast magnetization dynamics in these complex systems.

Support by Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project Number 548126838 is acknowledged.

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FEMTOSECOND MAGNETO-OPTICS IN MAGNETOPHOTONIC METASURFACES AND MAGNETOPLASMONIC CRYSTALS

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Dynamic light polarization control is crucial for technologies ranging from liquid-crystal displays and fiber-optic telecommunications to quantum-state preparation and ultrafast polarimetry. Meanwhile, magneto-optical (MO) cells demonstrate fast operation, but their dimensions are not suitable for compact applications such as integrated photonic circuits. This gap calls for the development of a tiny ultrafast polarization control device. We report ultrafast Faraday rotation dynamics inside a single femtosecond pulse transmitted through a Mie-resonant semiconductor metasurface covered with a thin ferromagnetic film. Time-resolved cross-correlation measurements reveal intrapulse polarization rotation with a relative modulation of 55% over 500 fs at the wavelength of the merged magnetic and electric dipole Mie resonances. These results may be applicable to subpicosecond polarization state control in integrated optical nonreciprocal isolators, ultrafast modulators, sensors, and optical signal processing units.

We also discuss ultrafast Faraday rotation dynamics in magnetophotonic crystals (MPCs) caused by femtosecond laser-pulse self-interference in the structured media. The magnitude of the time derivative of the effect depends crucially on the spectral position of the pulse central wavelength with respect to the microcavity mode, due to the artificial light dispersion. The derivative is always positive and is larger when the pulse central wavelength is at the center of the microcavity mode; the farther from the microcavity mode center, the smaller the increase of the Faraday rotation. For the reference film, the time derivative of the Faraday rotation turns from positive to negative via spectral tuning of the incident pulse. For compact magneto-optical devices in data processing, MPCs are more suitable, as the normalized effects are higher than in thin films. The results might be useful for femtosecond polarization pulse shaping with the advantage of magnetic-field control in next-generation photonic devices.

MAGNETOOPTICAL MEMORY AND SENSOR ELEMENTS ON THE BASIS OF ARTIFICIAL RELIEF FOR DOMAIN WALL

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Recent years numerous efforts were made in order to overcome difficulties in promotion of next magnetic memory generation. Harnessing of manipulations with domain wall (DW) in various media is considered including DW in antiferromagnets and ferrimagnets [1].

Numerical modelling and experimental investigation of stable states and magnetization reversal of two-domain structures in uniaxial Bi-substituted garnet film elements were made. Garnet films possessed almost compensated magnetization values of two iron sublattices so that summary magnetization doesn't exceed ~ 50 Gauss. Meanwhile, garnets retain high specific Faraday rotation and low coercive force of domain wall (1 – 3 Oe) despite low magnetization.

Isolated rectangular strip and strip-like bridge between two opposite normally magnetized infinite half-planes are found to exhibit different behaviour. Domain wall (DW) inside strip (bridge) suffers increasing repulsion (attraction) from nearest edge when shifted from centre. DW position centre position is strictly stable in isolated strip but bridge is magnetized spontaneously to one of two saturated states in zero external magnetic field. Isolated strip magnetization process occurs reversibly while bridge magnetization occurs by coercive manner. So bridge can be used as non-volatile memory unit. Coercive force is defined by magnetostatic barrier created by garnet film boundary and doesn't depend on DW internal structure.

Hybrid strip-bridge element (Fig. 1a) is shown to possess an indefinite DW equilibrium position which is highly sensitive to external field. DW motion without barriers can be used for high space resolution magnetic sensing with distant optical signal registration.

Natural dependence of domain wall full energy upon it DW length was used to form neuromorphic memory using jagged line as a boundary of elements. The writing external magnetic field threshold is proportional then to the gradient of element width (Fig. 1b).

Experimental methods were developed for magnetic parameters measurement of diluted garnets as well as variants of several DWs usage.

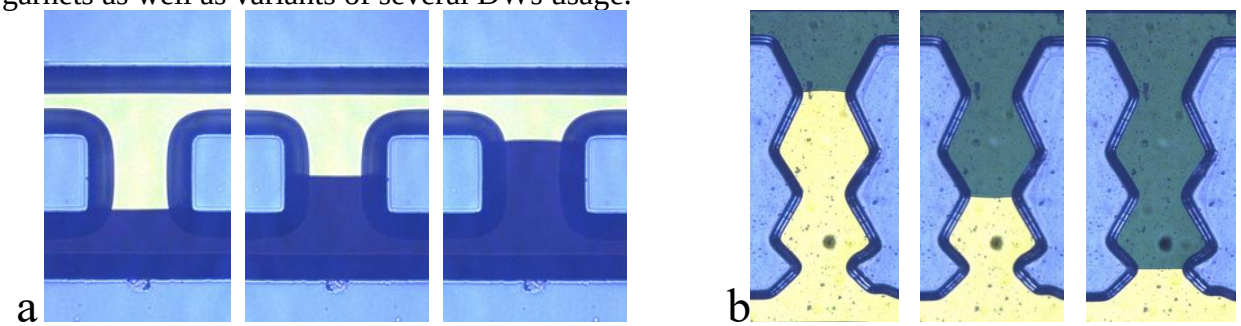

Fig.1. Stable positions of DW in zero external magnetic field:
a – in hybrid strip-bridge element with indefinite DW equilibrium for fine magnetic sensing,
b – in synapse element with rewritable weight coefficients based on DW energy relief for neuromorphic processing of optical information.

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MAGNETO-OPTICAL SENSING OF NANOSTRUCTURED MAGNETIC MATERIALS

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Nanostructured magnetic materials include granular nanocomposites, multilayer systems, amorphous and nanocrystalline alloys, and hybrid structures combining magnetic and non-magnetic phases. Their magnetic properties are governed by size effects, interfacial interactions, local anisotropy, internal stresses, and structural transformations occurring on the nanoscale.

The characterization of such systems requires methods sensitive not only to the bulk magnetic response but also to local and near-surface magnetic states. Magneto-optical techniques based on the Kerr effect provide an effective approach for studying magnetic nanostructures [1,2]. Depending on the experimental configuration, magneto-optical spectroscopy, Kerr magnetometry, and Kerr microscopy make it possible to investigate magnetic anisotropy, magnetization reversal, phase transitions, and the evolution of domain structures.

In this work, a comprehensive magneto-optical approach is applied to different classes of nanostructured magnetic materials, including granular composites, multilayer structures, and amorphous/nanocrystalline systems. Particular attention is paid to the relationship between morphology, magnetic ordering, and magneto-optical response. For nanocomposite systems, magneto-optical Kerr spectroscopy is especially sensitive to the distribution of the magnetic phase and to changes in magnetic ordering associated with percolation and interfacial interactions [3].

The obtained results demonstrate that magneto-optical methods allow detection of subtle changes in the magnetic state, visualization of domain structures, and analysis of magnetization reversal processes. In comparison with conventional magnetic measurements, which provide volume-averaged information, magneto-optical techniques reveal near-surface and locally inhomogeneous magnetic states associated with interfaces, grain boundaries, and structurally modified regions.

The combination of magneto-optical spectroscopy, Kerr microscopy, and magnetic measurements provides a non-destructive tool for the characterization of functional magnetic materials. This approach expands the possibilities for studying magnetic nanostructures and can be useful for the development of materials for sensing, information storage, spintronic, and high-frequency applications.

This work was supported by the Russian Science Foundation (project no. 25–72–00031). The study was conducted under the state assignment of Lomonosov Moscow State University. The work was supported in part of lab equipments by M.V.Lomonosov Moscow State University Program of Development (MSU, Russia).

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ORAL SESSION

Magnetism and Super- Conductivity

Wednesday, 19 August, 11:00 - 13:00

EFFECT OF SHORT-RANGE MAGNETIC ORDER ON PSEUDOGAP FORMATION IN CUPRATES

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To clarify the pseudogap origin in cuprates we have calculate the electronic structure of the 2D hubbard model within cluster perturbation theory. Square lattice is divided by a set periodic 4x4 clusters. After exact diagonalization of a cluster we construct Hubbard operators withib a set of cluster eigenstates. Inside each cluster we have calculated spin correlation functions up to the 9^{th} neighbours. Intercluster hoppings are treated within the Hubbard 1 approximation.

We have obtained the doping and temperature dependence of the electronic structure and short- range magnetic order. At low temperature and small doping there is the insulator gap at the Fermi level. In undoped antiferromagnetic below Neel temperature T_N cuprates a pseudogap state appears above T_N with a smooth crossover to a metallic Fermi liquid state at $T>2T_N$.. With increasing doping we have found two different pseudogap states, a weak pseudopap below T* (x) and strong one below T** (x). These two temperature both tend to zero above x>0.24 with the Fermi liquid formation. Antiferromagnetic short range correlation functions changes correspondingly

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FEATURES OF DISSIPATIVE SPIN-POLARIZED TRANSPORT IN TOPOLOGICAL SUPERCONDUCTING WIRE

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To date, much attention is devoted to dissipative engineering of quantum systems. One of its goals is the creation of nonequilibrium steady states with specified characteristics, sometimes unique and unattainable under equilibrium conditions [1].

In this talk, we will present the results of a study on the effect of dissipation on the transport properties of the Kitaev wire [2,3]. It is known that this spinless model describes hybrid semiconductor/superconductor nanowires with spin-orbit interaction in a strong magnetic field, which are actively investigated in experiments aimed at detecting Majorana bound states [4].

It is assumed that, in addition to local particle exchange with Fermi reservoirs (leads), the wire also interacts nonlocally with its environment (bath). The latter is taken into account within the framework of the Gorini–Kossakowski–Sudarshan–Lindblad equation for the density matrix of the system (wire + leads). Here, the dissipative term responsible for the nonunitary component of the density matrix evolution is given by linear jump operators (Lindblad operators). Within a quantum-field description, contributions to the differential conductance of the normal lead are obtained from local and nonlocal Andreev reflection, elastic cotunneling, as well as from processes of particle exchange with the bath (Markovian-type reservoir).

In the single-lead case, it is shown that the widely known effect of conductance quantization at zero bias voltage [5], induced by resonant local Andreev reflection on the Majorana bound state, is suppressed by dissipation. An analytical description of this phenomenon is carried out to the lowest order in perturbation theory. It is found that conductance quantization in the presence of dissipation is restored when the Lindblad operator is Hermitian. It is shown that in such a situation a dissipationless state emerges, which can be either spatially local or nonlocal [6]. In the latter case, conductance quantization is observed when the lead is attached to both ends of the superconducting wire. In the two-lead case, it is found that nonlocal transport processes via the Majorana bound state, which are suppressed in the absence of the bath, yield finite conductance contributions significantly different from zero due to the dissipation.

Support by Russian Science Foundation (project № 26-12-00052) is acknowledged.

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THERMALLY INDUCED TOPOLOGICAL CRYSTALLINE INSULATOR STATE IN *N*-DOPED SnTe

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SnTe is a topological crystalline insulator (TCI) characterized by short-range quantum entanglement, bulk gap and gapless pairs of time-reversed states on certain surfaces. The TCI state is an example of a symmetry-protected topological (SPT) state that is protected by crystalline mirror reflection symmetries. Experimental realization of this SPT state in SnTe is often impeded by bulk conduction associated with high hole densities due to intrinsic Sn vacancies. Alloying with Pb enables a continuous tuning from a TCI to a trivial insulator as the Pb content increases, driven by band inversion at the L points of the Brillouin zone. Here we seek to restore the SPT character of SnTe by compensating the intrinsic hole doping with *n*-type doping.

We report a thermally driven tuning of the Fermi level across the Dirac-point in a 650 nm-thick polycrystalline SnTe thin film grown on an *n*-type Si(100) substrate. Electrons from thermal ionization of the impurity donors drive the chemical potential across the bulk gap. The SPT state is realized when there is exact compensation of the holes. In this state, the surface conductance approaches $2e^2/h$ over a finite temperature window, which corresponds to the minimum conductance of the gapless Dirac fermions on the surface. The inferred Dirac-point crossing is further supported by a polarity switch of the nonlinear Hall response and by a Lifshitz transition associated with type-II SnTe surface states, consistent with a redistribution of Berry curvature as the chemical potential traverses the Dirac-point.

Our observation of a surface-dominated topological transport regime in SnTe through temperature tuning makes it an ideal platform to explore the possibility of intrinsic topological

superconductivity on the (001) surface theoretically predicted earlier by one of us [1]. Experimental reports of surface superconductivity in SnTe [2] leads us to suggest that, if the pairing is correlation driven, the superconductor will be topological, of a chiral p-wave type.

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MICROWAVE FLUXON OSCILLATOR BASED ON A LONG JOSEPHSON JUNCTION OF DIFFERENT GEOMETRIES

Khrenov M.M.[1,3], Nazhestkin I.A.[2], Filippenko L.V.[3], Fominskii M.Y.[3], Koshelets V.P.[3], Klenov N.V.[1], Soloviev I.I.[1,4], Yakovlev D.S.[5]

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Scaling of superconducting quantum processors is limited by the number of microwave lines to room-temperature electronics [1,2]. Local microwave sources at the cold stage reduce wiring, heat load, and calibration complexity; such a source should operate at 3-8 GHz with sufficient power and linewidth below the qubit anharmonicity [3].

Long Josephson junctions (LJJs) are attractive here: their large Ic*Rn product yields higher microwave power than small junctions, and resonant electrode dynamics produce nearly constant-voltage steps on the I-V curve [4]. Since the linewidth $\Gamma \sim R_d^2$, operation on a zero-field step (ZFS) gives narrowband emission via fluxon shuttling, without a large field — key for transmon qubits.

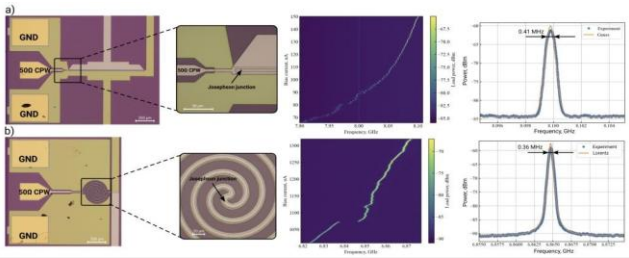

Fig. 1. a) Linear LJJ and its measured RF characteristics; b) Spiral LJJ and its measured RF characteristics

We study a fluxon oscillator using a long SIS Nb/AlOx/Nb junction in two geometries — linear overlap and compact spiral (Fig. 1). The ZFS frequency is set by the junction length L and the Swihart velocity v_{sw}, $f = v_{sw}/(2L)$, so few-GHz operation needs a mm-scale LJJ. Folding it into a spiral cuts chip area while keeping the path length; the resulting current distribution and inductance are compared with the linear geometry [5].

RF and DC measurements were done in a 4 K cryostat; a control current line compensated residual flux and set the ZFS operating point while spectra were recorded along the step. The 1600 um spiral junction radiated near 3.4 GHz on the first three ZFSs, with max power 1.26 pW (2nd ZFS, -3 dB linewidth 0.36 MHz at 1.3 mA). The 800 um linear junction gave up to 0.76 pW near 8.1 GHz, linewidth 0.41 MHz.

These results show the spiral LJJ reduces footprint without prohibitive RF loss. The measured powers suit qubit-driving experiments, and sub-MHz linewidths lie far below typical transmon anharmonicity. Frequency jumps in the spiral spectra indicate coupling to nearby resonant modes, consistent with earlier spiral results [6] — a practical candidate for integrated cryogenic oscillators.

The study is supported by Ministry of Science and Higher Education of the Russian Federation (agreement No. 075-15-2024-538).

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PROPULSION, BRAKING AND ENERGY RECUPERATION IN A MAGLEV HTS RING–COIL–PERMANENT MAGNET TRACK SYSTEM

Kuzmin D.A.[1], *Kolesov K.A.*[1,2], *Bychkov I.V.*[1], *Koledov V.V.*[1,2], *Matyunina M.V.*[1]

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A key challenge for high-temperature superconducting (HTS) magnetic levitation transport is the absence of an integrated, contactless system for controlled acceleration and braking with energy recovery. This work presents a propulsion/braking concept based on the force interaction between a field-cooled HTS ring (onboard the vehicle) and a stationary electromagnetic coil integrated into a permanent magnet (PM) guideway. A three-chain NdFeB track (central chain magnetized upward, side chains downward) provides levitation. The HTS ring (outer radius 17.75 mm, inner radius 8 mm, thickness 10 mm) is field-cooled above the track, trapping a vertical magnetic moment of ~0.13 A·m². A solenoid coil (700 turns, inner radius 57.5 mm, outer radius 77.5 mm, length 28 mm) wound around the guideway generates a non-uniform field upon energisation. A hybrid modelling framework (Magpylib, integral Brandt method with field-dependent critical current density) was developed to calculate forces and energy efficiency of the system.

Experiments show that regardless of current direction, the ring is always attracted toward the coil centre. This occurs because even a weak transverse coil field reorients Abrikosov vortices, aligning induced magnetisation with the coil field. The resulting force is proportional to the square of the current and always points toward the coil centre, enabling both propulsion (when approaching) and braking (when moving away). For 0.4 A, the force is 2–3 mN (~0.03 m/s² for an 85 g vehicle); at 10 A, forces reach 0.1–0.2 N (1–2 m/s²), sufficient for a demonstrator.

During braking, kinetic energy is recovered by using the coil as a generator: the moving flux induces a back-emf and connecting the coil to a regenerative storage converts braking energy into electricity. Because the force remains attractive regardless of current sign, the same coil seamlessly switches between propulsion (power supplied) and regenerative braking (power extracted) without mechanical reversal. The quadratic force–current relation allows precise, jerk-free control of acceleration and deceleration profiles, while the recovered energy improves overall efficiency – especially valuable for urban maglev with frequent stops. This work provides a practical pathway to integrating propulsion, braking, and energy storage directly into HTS maglev systems without moving parts or contact wear.

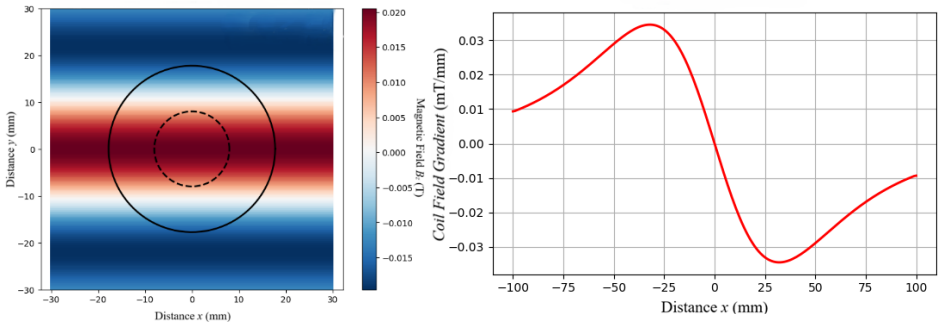

Fig. 1. Non-uniform distribution of three-chain PM guideway B_z field and coil-induced magnetic field gradient.

This work was supported by the Russian Science Foundation Project No. 25-19-20141 (https://rscf.ru/en/project/25-19-20141/).

ORAL SESSION

Soft and Hard Magnetic materials

Wednesday, 19 August, 11:00 - 13:00

MECHANO-MAGNETIC COUPLING IN FLEXIBLE FILMS

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Strain engineering provides a powerful means to control magnetism, offering promising pathways for flexible sensing technologies in applications such as extended reality and humanoid robotics [1,2]. A fundamental understanding of mechano-magnetic coupling in flexible films is essential for advancing high-performance flexible and wearable magnetoelectronic devices [3–7]. Moreover, the complex strain distributions inherent in flexible systems make their regulatory effects on magnetic behavior particularly challenging to unravel [1,8]. In this report, I will introduce our recent findings on the mechano-magnetic coupling in flexible magnetic thin films. This includes the observation of a strain driven exchange bias (EB) effect in a flexible ferromagnetic (FM)/$IrMn_3$ system, as well as evidence of effective manipulation of skyrmions via strain gradients in several systems [9].

We revealled a strain-induced EB in Pt/Co/$IrMn_3$ system. The magnitude and direction of the strain-induced EB could be precisely controlled by adjusting the strain and the predefined polarization of the FM layer. Such phenomenon are primarily attributed to the strain-induced piezomagnetic effect in $IrMn_3$ and the consequent modifications of the interfacial Dzyaloshinskii–Moriya interaction at the FM/$IrMn_3$ interface. Furthermore, the strain-induced EB shows non-volatile characteristics, which could be extended to the development of advanced flexible spintronic devices, such as Wheatstone bridge-based flexible spin valves.

Beyond uniform strain, we also show that strain gradients serve as an additional degree of freedom for manipulating magnetism in flexible films. By creating microscale periodic wrinkled structures in flexible Pt/Co/Ta multilayers, we generated strain gradients with varying magnitudes and directions. Using magnetic force microscopy, we observed synchronous modulation of both skyrmion density and size corresponding to the in-plane strain gradient profile. These effects are explained by strain gradient-mediated Dzyaloshinskii–Moriya interaction, as supported by micromagnetic simulations. In addition, we fabricated Pt/CoFeB multilayers with micro-scale bowl-shaped arrays on elastic substrates, enabling predefined strain gradient distributions. The strain patterning modulates the magnetic domain structures periodically, with coexistence of circular stripe domains and skyrmions. We also predicted that in bilayer heterostructures, twisting offers an efficient route for generating atomic-scale inhomogeneous strain. The non-uniform strain distribution could drive polarized topological arrays and lead to ferromagnetic-to-ferrimagnetic transition. These findings establish strain gradient as a new route for engineering the performance of flexible magnetoelectronic devices.

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EFFECTIVE TUNING OF MAGNETIC PROPERTIES OF AMORPHOUS MICROWIRES BY STRESS-ANNEALING

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Studies of amorphous microwires have attracted attention due to their unique combination of magnetic properties such as their magnetic softness, magnetic bistability, giant magnetoimpedance (GMI) effect, as well as good mechanical properties and high corrosion resistance [1,2].The fabrication technique allows the preparation of amorphous microwires with diameters from 100 nm to 100 μm [1,2]. Magnetic properties can be tuned by appropriate annealing. Consequently, we provide our latest attempts on tailoring of magnetic softness and GMI effect of glass-coated magnetic microwires by stress-annealing.

We provide the results on the effect of stress-annealing (at temperatures, T_{ann}, up to 400 ºC) on the hysteresis loops and GMI ratio, $\Delta Z/Z$, of Co-and Fe-rich glass-coated microwire prepared using Taylor-Ulitovsky method. In most of Co-rich microwires after conventional annealing a transformation of the linear hysteresis loop into a rectangular and elevated coercivities, H_c, ($H_c \approx 100$ A/m) are observed (see Fig.1). After annealing of Co-rich microwires, a change in magnetostriction coefficients, λ_s, from low negative to low positive values is observed. Such magnetic hardening can be suppressed using stress-annealing: after stress-annealing smaller H_c ($H_c \approx 2$ A/m for T_{ann} =350 ºC) is observed (see Fig.1). Similarly, stress-annealing of Fe-rich allows to induce a transverse magnetic anisotropy and substantially reduce H_c –value. Such transverse magnetic anisotropy substantially affected by T_{ann} as well as by stress applied during the annealing. After stress-annealing of both Co-rich and Fe-rich microwires, a substantial increase in GMI ratio is observed. The observed change in the hysteresis loop shape, and in $\Delta Z/Z$ - value and magnetic field dependence of $\Delta Z/Z$ after annealing have been discussed considering the internal stresses relaxation, induced magnetic anisotropy and modification in the λ_s sign and values

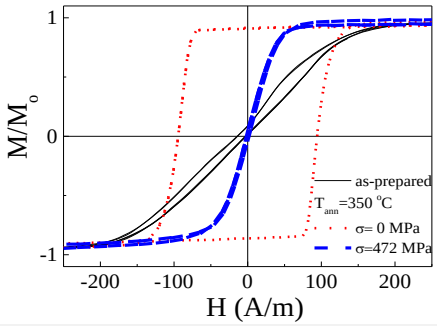

Fig.1. Hysteresis loops of as-prepared, annealed and stress-annealed Co microwires.

Support by Spanish MICIN, under PID2022-141373NB-I00 project, by EU "HARMONY" (Horizon Europe) project and by the Government of the Basque Country, under Elkartek (MOSINCO and ATLANTIS) projects and "Ayuda a Grupos Consolidados" (Ref.: IT1670-22) is acknowledged.

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FROM MAGNETIC ORDER TO SUPERCONDUCTIVITY IN URANIUM TELLURIDES: EVOLUTION OF ELECTRONIC STRUCTURE ACROSS THE U–TE SERIES

Tereshina-Chitrova E.A.[1], Alex S.G.[1], Koloskova O.[1], Havela L.[2], Horák L.[2], Romanyuk O.[1], Huber F.[3], Gouder T.[3], and Diviš M.[2]

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The uranium–tellurium system hosts a remarkable diversity of ground states, ranging from various types of magnetism to the unconventional superconductivity of UTe_2 [1,2]. Understanding how these distinct electronic and magnetic states emerge requires detailed knowledge of the underlying electronic structure and its evolution across the U–Te phase diagram. While UTe_2 has attracted enormous attention in recent years, systematic experimental information linking the electronic structures of different uranium tellurides remains scarce.

In this contribution, we present a comparative photoelectron spectroscopy study of uranium tellurides prepared as thin films and investigated in situ under ultra-high vacuum conditions [3]. X-ray and ultraviolet photoelectron spectroscopy (XPS/UPS) measurements were performed on freshly prepared compounds representing the major phases of the U–Te system, including UTe_2. The use of thin-film samples enables access to clean, well-defined surfaces of these highly reactive materials and allows direct comparison of electronic-structure trends across compositions.

The experimental results are complemented by density-functional calculations performed consistently across the entire U–Te series, together with magnetic and electrical resistivity measurements on the prepared thin films and comparison with available bulk data. The good agreement between the measured physical properties of the thin films and those reported for their bulk counterparts supports the validity of the thin-film approach for investigating the electronic structure of uranium tellurides. The combined analysis reveals a systematic evolution of the electronic structure, reflecting changes in U–Te hybridization and charge-transfer effects across compositions. These trends are discussed in the context of the diverse magnetic and superconducting ground states exhibited by uranium tellurides.

Acknowledgements. This work was supported by the Czech Science Foundation (GA CR) under Grant No. 26-20860S.

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ADDITIVE MANUFACTURING OF PERMANENT MAGNETS

Volegov A.S.[1,2], *Andreev S.V.*[1], *Golovnia O.A.*[1,2], *Golubiatnikova A.A.*[1], *Ivanov I.A.*[1], *Maltseva V.E.*[1], *Neznakhin D.S.*[1], *Protasov A.V.*[1,2], *Selezneva N.V.*[1], *Stepanova E.A.*[1], *Shalaginov A.N.*[1]

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The development of energy, robotics and electric transport, as well as the trend towards miniaturization of high-tech devices containing electric motors and actuators, impose increasingly stringent requirements on permanent magnets and magnetic systems. To meet these requirements, it is necessary either to significantly improve the magnetic hysteresis characteristics of permanent magnets, or to review existing approaches to the design and manufacture of magnetic systems.

One of the promising areas of such transformation is the use of additive technologies to produce magnetic systems. This approach opens up the possibility of manufacturing magnetic elements of complex geometry without using soft magnetic materials as magnetic conductors. This, in turn, makes it possible to reduce the mass of magnetic systems used, for example, in small and medium-power electric motors, miniature generators and other electromechanical devices.

The key problem of additive manufacturing of functional magnetic materials is the formation of a microstructure that ensures the achievement of a given set of magnetic properties or properties comparable to the characteristics of samples obtained by traditional technological methods. At the same time, an important advantage of additive technologies is the possibility of spatial control of the magnetic characteristics of the material. Such control can be implemented by locally changing the chemical composition, grain size, degree of texture, or orientation of crystallites in the volume of the product.

The report will consider approaches to the additive production of magnetically hard materials based on alloys with phases $Nd_2Fe_{14}B$ and $Sm(Fe,Ti,V)_{12}$. Special attention will be paid to the results of the study of their phase composition, microstructural state and magnetic properties. The application of the developed methods made it possible to obtain permanent magnets with a coercivity of up to 19.5 kOe for the $Nd_2Fe_{14}B$ main phase and up to 5.5 kOe for the $Sm(Fe,Ti,V)_{12}$ phase.

The work was financially supported by Ministry of Science and Higher Education of the Russian Federation as part of the Development Program of the UrFU, in accordance with the Priority-2030 Strategic Academic Leadership Program.

SCALING ANALYSIS OF THE ADIABATIC TEMPERATURE CHANGE IN GADOLINIUM AND TERBIUM

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Magnetic phase transitions and the associated magnetocaloric effect (MCE) are of considerable fundamental and applied interest. In this work, we investigate a gadolinium and terbium single crystals using the direct measurement method of the adiabatic temperature change (ΔT_{ad}) in alternating magnetic fields, followed by a detailed scaling analysis.

In the high-field regime (H > 2 T), the data obey nearly ideal scaling:

$$\frac{\Delta T}{H^n} = F\left(\frac{t}{H^{1/\beta}}\right) \quad (1)$$

with the exponent n=2/3. This aligns perfectly with mean-field theory, as high fields suppress critical fluctuations.

This excellent agreement with the mean-field approximation confirms that strong magnetic fields effectively suppress critical fluctuations.

However, in the low-field regime (H<0.3 T), the scaling hypothesis fails, and no single exponent n can collapse the experimental $\Delta T_{ad}(T)$ curves onto a universal dependence. We demonstrate that this violation cannot be attributed to the field dependence of the heat capacity. A detailed discussion of these results reveals that the deviation arises from magnetization mechanisms excluded from standard critical scaling theory—specifically, domain growth and domain-wall motion, which become the dominant mechanisms in weak fields.

Consequently, the weak-field MCE follows $\Delta T_{ad} \propto H^2$, fundamentally differing from the $H^{2/3}$ dependence predicted for strong fields. This distinct behavior explains the absence of a universal scaling exponent across the entire field range.

A similar scaling breakdown in weak fields is observed in terbium, while strong fields still yield a successful data collapse. In this case, however, the violation is likely driven not only by domain dynamics but also by the close proximity of two distinct phase transitions: paramagnet – antiferromagnet and antiferromagnet – ferromagnet.

This work was supported by the Russian Science Foundation, Project No. 24-12-00362.

ORAL SESSION

Magnetic Nanostructures and Low Dimensional Magnetism

Wednesday, 19 August, 15:00 - 17:00

FEAL: A NEW MATERIAL FOR ENHANCED THZ EMISSION AND ULTRASMALL MAGNETIC NANOSTRUCTURING

Sapozhnikov M.V.[1], *Pashenkin I.Yu.*[1], *Krivulin D.O.*[1], *Polushkin N.I.*[1], *Skorokhodov E.V.*
Petrov Yu.V.[2], *Buryakov A.M.*[3], *Gorbatova A.V.*[3]

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Fe–Al alloys attract attention because their magnetic properties, such as the Curie temperature and the magnitude of the anomalous Hall effect (AHE), can be tuned by varying the composition and the degree of atomic ordering. This talk presents two interrelated results that reveal the potential of FeAl films for spintronics and nanomagnetism.

Films of $Fe_{60}Al_{40}$ (30 nm), initially in a chemically ordered paramagnetic state (B2 phase), were locally irradiated with a focused He^+ ion beam (30 keV). The irradiation destroys short-range order and locally transforms the material into a disordered ferromagnetic state (A2), which enabled the creation of regular lattices of magnetic clusters with diameters ranging from 200 nm down to ~5 nm and the same periodicity. A pronounced size effect was observed experimentally (magnetic force microscopy, Hall magnetometry, MOKE): large structures (≥100 nm) exhibit a vortex magnetization distribution; at 20 nm, single-domain states with perpendicular anisotropy and antiferromagnetic ordering due to dipolar interactions are formed; clusters of 5 nm display superparamagnetic behaviour. Micromagnetic simulations reproduce the experimentally observed transition from vortex to uniformly magnetized states, confirming the role of dipolar interactions. Thus, even point-like local disordering of a paramagnetic FeAl film opens a route towards the creation of magnetic structures at the ultrasmall scale with controllable phases.

In fully disordered FeAl films deposited at room temperature without annealing, the ferromagnetic state is present from the outset, and FeAl/Pt heterostructures are built on its basis. A systematic study of the dependence of the AHE and spintronic terahertz generation on Fe concentration was carried out in Fe_xAl_{100-x}/Pt structures. A non-monotonic dependence of both quantities was found, with a maximum at 75–80 % Fe, while the saturation magnetization and the Kerr rotation decrease monotonically. The experimentally observed direct correlation between AHE and the THz signal amplitude proves that both phenomena are governed by the same microscopic parameter, the spin-density-of-states difference at the Fermi level $\Delta N(E_F)$, confirming the validity of the standard ISHE model of spintronic THz generation. For the optimal composition $Fe_{75}Al_{25}$/Pt, a THz signal enhancement of up to 340 % relative to a reference Fe/Pt sample was measured (for a 10 nm thick ferromagnetic layer and low pump power). It is of principal importance that such high efficiency is achieved in films deposited at room temperature without any high-temperature processing, in contrast to Heusler alloys, whose high spin polarization requires the formation of a complex ordered $L2_1$ phase. This makes fully disordered FeAl films a technologically simple and more efficient alternative to Heusler alloys for spintronic THz emitters.

Overall, FeAl films represent a universal material: local removal of order allows the formation of ensembles of ultrasmall magnets with switchable phases, while completely disordered layers provide record efficiency of spintronic THz emission without complicated heat treatments. This paves the way for the purposeful design of magnetic nanostructures based on technologically simple Fe–Al alloys.

The results presented in this talk were obtained within the framework of the state assignment of IPM RAS No. FFUF-2024-0021.

MAGNETIC NANOMATERIALS: FROM INTERFACES TO SELF-ASSEMBLED ARCHITECTURES

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Institute of Structure of Matter (ISM), nM2-Lab, Centre for National Research (CNR), Monterotondo Scalo, Rome 00015, Italy
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Magnetic coupling phenomena at the nanoscale provide unique opportunities for engineering advanced materials with tunable and emergent functionalities for applications ranging from permanent magnets to field-responsive architectures. We will discuss how magnetic interactions across interfaces, between nanoparticles, and within self-assembled systems collectively determine the behavior of magnetic nanomaterials across different length scales (Fig. 1).

We first focus on ferrite nano-heterostructures, where interfacial coupling between distinct magnetic phases enables the tuning of anisotropy, magnetization reversal and magnetic response. By combining magnetic characterization, and hyperfine spectroscopies, we investigate how structural and chemical interfaces govern coupling mechanisms in bi-magnetic systems, providing insight into the design of nanomaterials [1]. We then extend the discussion to dense nanoparticle assemblies, where the interplay between inter- and intraparticle interactions drives the transition from individual to collective magnetic behavior. In these systems, interaction-driven effects may lead to unconventional hysteresis loop shifts and exchange bias-like phenomena, revealing new possibilities for magnetic composite architectures and device-oriented functionalities [2]. Finally, we explore how magnetic interactions can actively direct self-assembly processes. Aerosol-based gas-phase approaches enable the fabrication of chain-like and anisotropic magnetic nanostructures formed under applied magnetic fields, demonstrating how nanoscale interactions can guide mesoscale organization and produce magneto-responsive architectures with tailored shape anisotropy and collective behavior [3].

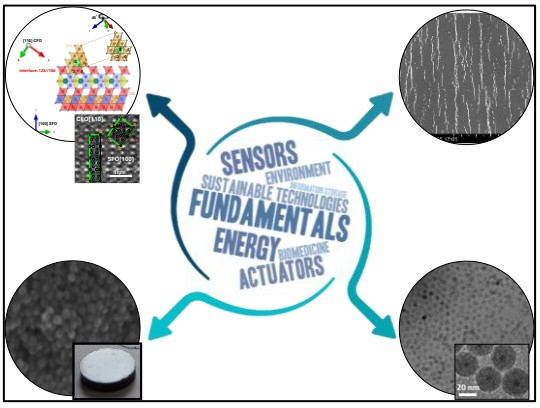

Fig. 1. overview of the magnetic nanomaterial systems discussed in this work

Overall, this study highlights the central role of magnetic coupling phenomena, from interfaces to self-assembled architectures, in the development of next-generation magnetic nanomaterials.

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[3] M. Sedrpooshan, P. Maltoni, D. Peddis, A. M. Burke, M. E. Messing, R. Westerström, *ACS Appl. Mater. Interfaces* **17**, 14 (2025) 21682–21690.

ENGINEERING MAGNETIC STRUCTURE IN FERH THIN FILMS

Merkel D.G.[1], *Lengyel A.*[1], *Nagy D.L.*[1], *Németh A.*[1], *Horváth Z.E.*[2], *Gracheva M.A.*[3], *Hegedűs G.*[1], *Chumakov A.I.*[4], *Bessas D.*[4], *Sajti Sz.*[1], *Radnóczi Gy.Z.*[2], *Szilágyi E.*[1]

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Recently, FeRh thin films have attracted extensive attention, due to the diversity of their possible applications [1]. Their near room temperature metamagnetic transition from antiferromagnetic (AF) to ferromagnetic (FM) order [2,] and the interoperability between FM and paramagnetic (PM) states provide an excellent base for energy-saving spintronic devices [3]. Moreover, the outstanding caloric parameters and non-toxic biocompatibility of FeRh give novel alternatives for developing gas-free domestic magnetic refrigerators, or new medical applications [4].

In this work, FeRh thin films (with a slight excess of iron concentration) were investigated. A reversible modification of the FeRh structural phase between ferromagnetic (FM) B2 and paramagnetic (PM) A1 phase was demonstrated through the application of Ne^+ irradiation and heat treatment. By intentionally inducing the FM → PM transition, FM nanopatterns embedded in PM matrix were fabricated using nanosphere ion-beam lithography. Conversely, the reverse PM → FM transition was exploited to locally generate magnetic domains through laser irradiation.

These results demonstrate that the magnetic and structural phases of FeRh thin films can be precisely and reversibly controlled. Such tunable magnetic patterning provides a versatile platform for engineering functional magnetic nanostructures and represents an important step toward the development of next-generation nanoscale devices.

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[2] Cherifi RO, Ivanovskaya V, Phillips LC, Zobelli A, Infante IC, Jacquet E, Garcia V, Fusil S, Briddon PR, Guiblin N, Mougin A, Ünal AA, Kronast F, Valencia S, Dkhil B, Barthélémy A and Bibes M 2014 Nat. Mater. **13(4)**, 345
[3] Merkel D G, Hegedűs G, Gracheva M A, Deák A, Illés L, Németh A, Maccari F, Radulov I, Major M, Chumakov A I, Bessas D, Nagy D L, Zolnai Zs, Graning S, Sájerman K, Szilágyi E and Lengyel A 2022 ACS Appl. Nano Mater. **5(4)**, 5516
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NEEL VECTOR DEPENDENT MAGNETO-OPTICAL KERR EFFECT OF ALTERMAGNETIC RUO2

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RuO_2 is one of prototype of altermagnetism, a new magnetic phase, with ferromagnetic spin splittng with vanishing total magnetization[1]. While its intrinsic magnetism is still in debate [2-4], here we present first-principles study of magneto-optical Kerr effect (MOKE) for three different Néel vectors, [001], [010], and [110]. Each Néel vector has distinct magnetic space group, whose electronic structure and tensor symmetry are analyzed. While the Néel vector of [001] has vanishing MOKE, the Néel vectors of [010] and [110] have finite MOKE. Our results provide insights into the interplay between magnetic symmetry and electronic properties in RuO_2.

Support by National Research Foundation of Korea (NRF) (NRF-RS-2024-00451261)

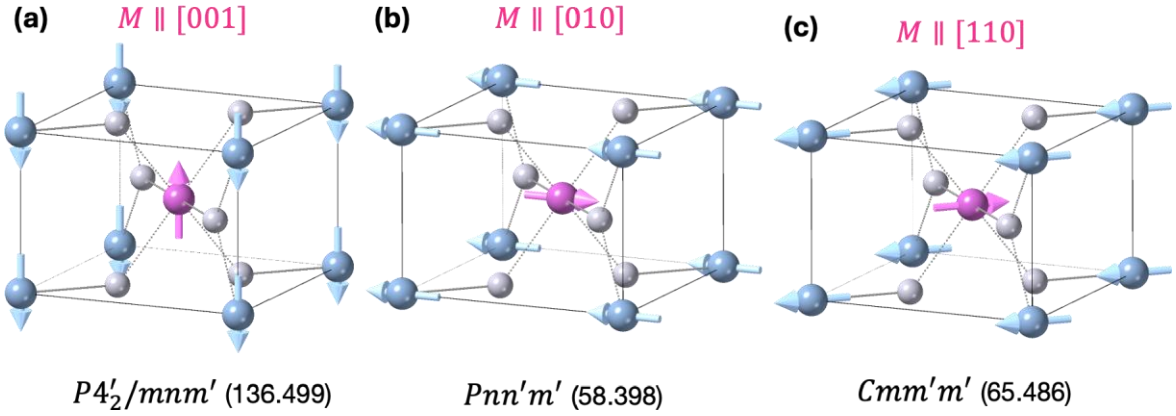

Fig. 1. Crystal structure of RuO2 for three different Neel vectors: (a) [001], (b) [100], and (c) [110] with magnetic space group denoted.

[1] Libor Šmejkal *et al*., Phys. Rev. X. **12,** 040501 (2022).
[2] Philipp Keßler *et al*., npj Spintronics **2**, 46 (2024).
[3] Olena Fedchenko *et al*., Sci. Adv. **10**, eadj4883 (2024).
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[5] Libor Šmejkal *et al*., Phys. Rev. X. **12,** 040501 (2022).
[6] Philipp Keßler *et al*., npj Spintronics **2**, 46 (2024).
[7] Olena Fedchenko *et al*., Sci. Adv. **10**, eadj4883 (2024).
[8] Seung Gyo Jeong *et al*, arXiV:2405.05838

INTERACTION OF THE LOCALIZED NONLINEAR OSCILLATIONS IN CHAIN OF MAGNETIC NANOPARTICLES

Kuzmin D.A.[1], *Ekomasov E.G.*[2], *Sharafullin I.F.*[2], *Bychkov I.V.*[1]

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Understanding and controlling nonlinear magnetization dynamics in low-dimensional magnetic nanostructures is crucial for next-generation magnonic and spintronic devices, including nano-oscillators, logic gates, and neuromorphic computing elements. One of the key challenges is the formation and stability of localized nonlinear excitations — discrete breathers (DB) — in arrays of dipolarly coupled nanoparticles, where long-range interactions and dissipation strongly affect the DB lifetime. In this work, we investigate a linear chain of single-domain magnetic nanocylinders with uniform magnetization. The dynamics obey the Landau–Lifshitz equation with Gilbert damping, including demagnetizing fields (shape anisotropy) and full long-range dipole-dipole coupling. We perform numerical simulations (Runge-Kutta 5(4) scheme) for a finite chain. We focus on the excitation of DB in the centre of the chain. In the absence of dipole coupling, an isolated nanoparticle precesses at a frequency proportional to its longitudinal magnetization m_x. Dipole-dipole interaction raises the precession frequency by a constant shift, but does not destroy the localized mode as long as its frequency stays below the lower edge of the linear spin-wave band of the chain. We derive a threshold condition: when m_x drops below a critical value $\approx 1 - 1.8\beta/\Delta$ (β - dipole strength, Δ - shape anisotropy), the DB frequency enters the linear magnon band, causing resonant energy leakage and finite lifetime.

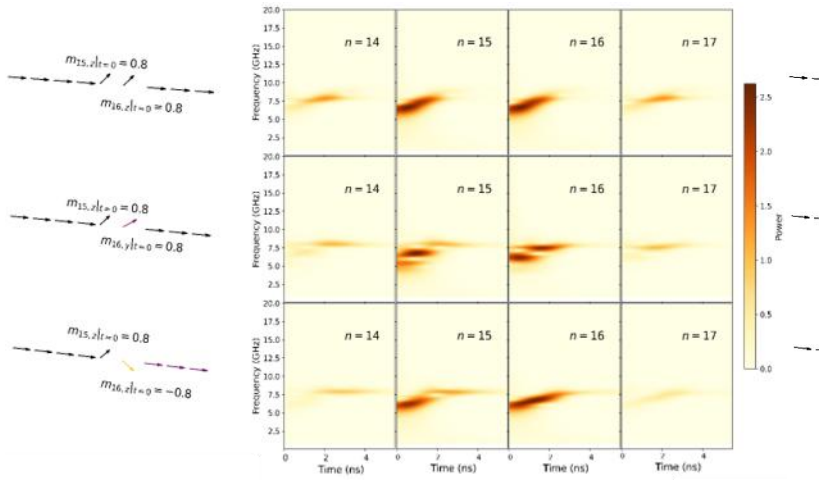

Fig. 1. Initial magnetization configurations and frequency-time evolution of oscillations.

Numerical experiments with parameters of permalloy show that a single initially excited central particle ($m_x = 0.8M_0$) exhibits a gradual frequency increase from ≈6.5 GHz to ≈8.0 GHz over 2 ns due to damping-driven relaxation of m_x. Wavelet analysis confirms the frequency drift. When two adjacent particles are initially excited with a phase shift φ, the coupling becomes phase-sensitive: in-phase excitation behaves like a single DB, while non-zero phase shift does dynamic more complicated and break a symmetry (see Fig. 1).

The DB lifetime in a dipolar nanoparticle chain is finite and controlled by the ratio β/Δ. The relative phase of two neighbouring excited nanoparticles serves as a robust control parameter. These findings provide design rules for phase-sensitive magnonic logic elements and tunable nano-oscillator arrays.

The work was carried out within the framework of State Assignments No. 075-00188-26-00.

ORAL SESSION

Magnetophotonics

Wednesday, 19 August, 15:00 - 17:00

MAGNETOPHOTONICS AT OPTICAL AND THZ FREQUENCIES FOR ADVANCED SPIN CONTROL

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To advance the development of modern microelectronics devices, a substantial increase in their clock frequencies to the terahertz range is required. This necessitates the use of electromagnetic waves from the optical and terahertz spectra for device control. However, the current efficiency of such control is insufficient for practical applications, largely due to the constraints imposed by the diffraction limit. This work focuses on addressing the aforementioned challenge through the design and implementation of nano- and microstructures with inherent optical and terahertz resonances. Such structures include plasmonic and dielectric gratings and metasurfaces. Excitation of the optical resonances provides localization, modification and enhancement of the near field of the electromagnetic waves interacting with magnetic media. As a result, impact of light [1] and THz [2] radiation on magnets is significantly modified. Therefore, nanophotonic structures combined with magnetic materials facilitate the efficient excitation of high-frequency spin dynamics and achieving ultra-fast magnetization reversal by pulses of the electromagnetic radiation. These capabilities are essential for the functionality of information storage and retrieval devices, terahertz emitters and detectors, as well as magnon and spintronic memory components.

Optical and THz frequency range differ much in the sense of the physical mechanisms underlying the interaction between light and electromagnetic waves. Thus, for the light pulses impinging on a transparent magnet (e.g. iron garnet), these are nonthermal inverse magnetooptical (or in other words, “optomagnetic”) effects that govern this interaction. Therefore, the interaction is non-resonant, though light can still excite spin waves and magnetization reversal. If the magnetic film is contacted with a 1D or 2D nonmagnetic nanograting, then the distribution of the effective magnetic field of the inverse Faraday effect describing that interaction is drastically modified at a scale of 100 nm which provides excitation of short spin waves of 100 nm wavelength by a light beam of diameter around 10 μm with increased efficiency [1]. Moreover, if a magnetic film is perforated itself by a nanograting then light can excite exchange dominated spin waves [3].

When passing to THz regime the situation alters. If one deals with rear-earth ferrimagnets or antiferromagnets, then the spin resonance might coincide with frequency of the incident electromagnetic pulse that provides resonant excitation of spins. We have recently demonstrated that a metasurface adjusted to a THz frequency provides additional THz-magnetic field component in the near field and therefore allows to efficiently excite exchange spin modes in a ferrimagnet [2].

Consequently, it is very advantageous to apply the concepts of nanophotonics and metaphotonics for spin control in low dissipative magnets.

Support by IEEE, ARC, and ARCNN is acknowledged.

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[2] L. Gerven et al., PRL, 136 (2026) 116703.
[3] D.O. Ignatyeva et al., PRApp., 21 (2024) 034017.

SWITCHING OF WEAK FERROMAGNETS VIA 1ST AND 2ND ORDER SPIN REORIENTATION TRANSITIONS

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Kinetics of phase transitions triggered by femtosecond laser pulses is in a focus of active theoretical and experimental studies in many areas of physics and chemistry. The complex kinetics of the transition between two equilibrium states may include hidden and metastable phases that span over timescales from subpicoseconds to milliseconds. These phases are often inaccessible under equilibrium conditions, and a key task in the physics of laser-induced transitions is to identify them and their impact on the properties of the final phase. Antiferromagnets are of particular interest in this context, where switching the magnetic state via a spin-reorientation transition is considered promising for next generation memory and logic technologies operating at the limiting fundamental timescales of magnetism.

We present two striking examples how the transient state occurring and existing for a few picoseconds after laser excitation of a weak ferromagnetic dielectric in a vicinity of its spin-reorientation (SR) transitions can be exploited for a 90-degree magnetization switching. First, we discuss the rare-earth orthoferrite (Sm,Pb)FeO_3 where the switching is realized via a 2nd order SR transition [1]. Here, we make use of laser-induced heating and a fast disappearance of the potential minimum between the two orientational states. The switching is then facilitated by additional ultrafast opto-magnetic effect.

In another oxide – iron borate Fe_3BO_6 - the SR transition is of a 1st order and connects two phases with different spin canting. Here we show that laser-driven switching is enabled by ultrafast heating along with a nonthermal fast change of Dzyaloshinskiy-Moriya interaction responsible for the spin canting [2]. By tuning the excitation pulse wavelength, we reveal that the process relies on 3d(Fe)-2p(O) change transfer transitions affecting coupling between iron magnetic moments mediated by oxygen.

To emphasise the role of the transient magnetic state in spin switching, we also discuss the laser-driven SR transitions in systems, where no such delays were found. 2nd order SR transition in a ferromagnetic CoFeB/MgO system is governed by heating typical for metals [3], while the 1st order SR transition is Fe_3O_4 – by melting of a charge ordering [4], both processes being too fast to enable transient states.

Support by RSF grant № 24-12-00401 is acknowledged.

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SPATIALLY-RESOLVED ENHANCEMENT OF MAGNETO-OPTICAL EFFECTS DUE TO GOOS-HÄNCHEN SHIFT IN MAGNETOPHOTONIC STRUCTURES

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Optical resonances in various kind of nanostructures can overcome the issue of the inherently small values of the magneto-optical Kerr and Faraday effects. The surface plasmons in magnetoplasmonic crystals and Bloch surface waves in magnetophotonic crystals are widely used to enhance magneto-optical effects [1]. Magnetooptical effects are conventionally measured as magnetic-field-induced changes in the intensity and polarization of the entire transmitted or reflected light beam, without considering the spatial distribution of the light. However, the reflected and transmitted light experience a spatial shift due to the localization of the electromagnetic field at the interface between two media. The phenomenon of spatial displacement of the reflected beam relative to the position determined by geometric optics is called the Goos-Hänchen (GH) effect [2]. The excitation of surface plasmons and Bloch surface waves significantly enhances the GH effect to tens and hundreds of wavelengths. In the presence of the GH effect, the reflected light does not have a uniform spatial distribution due to the presence of an shifted beam.

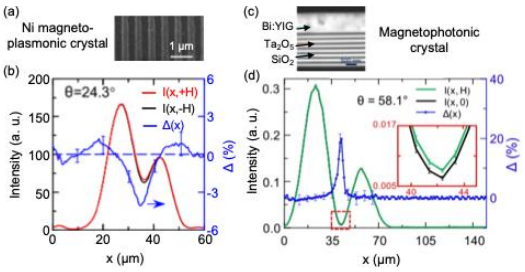

Fig. 3. (a) SEM image of Ni magneto-plasmonic crystal. (b) Intensity cross-section under +H (red curve) and -H (black curve) magnetic field. Magnetic-field-induced intensity modulation Δ(x) (blue curve). (c) SEM image of the magnetophotonic crystal. (d) Intensity cross-section under no magnetic field (black curve) and magnetic field in polar configuration (green curve). (d) Magnetic-field-induced intensity modulation Δ(x) (blue curve)

In this report, the spatially-resolved magneto-optical Kerr effects in a magnetoplasmonic and magnetophotonic crystal are studied in the presence of the GH effect. The magnetoplasmonic crystal was a 1D nickel grating with a period of 575 nm (Fig. 1 (a)). It is shown that in the presence of the GH effect, the application of a magnetic field in the transverse configuration causes a change in the spatial distribution of the intensity I(x) of reflected light (Fig.1(b)). The spatially resolved transverse magneto-optical Kerr effect was defined as: $\Delta(x) = \frac{I(x,+H)-I(x,-H)}{I(x,+H)+I(x,-H)} * 200\%$, where I(x,±H) is the spatial distribution of the intensity of reflected light measured in two opposite directions of the magnetic field. Fig. 1(c) shows that Δ(x) is spatially inhomogeneous and reaches a maximum of -4.2% in the area of the reflected light intensity minimum. These values exceeded 2.6 times the Kerr effect values, measured integrally over the total beam [3]. The similar effect has been observed in the one-dimensional magnetophotonic crystal consisted of seven pairs of SiO_2/Ta_2O_5 layers with a Bi:YIG layer on the top (Fig.1(c)). In this case, the maximum magnetic-field-induced spatially-resolved intensity modulation was $\Delta_{max}(x)$=19.6% (Fig.1(d)). The excess over the integrated modulation was 245 times.

Support by Russian Science Foundation (grant № 24-12-00210).

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PHOTO-INDUCED DYNAMICS OF MAGNETIC POLARONS IN EuO

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Eeuropium oxide EuO is a unique intrinsic ferromagnetic semiconductor exhibiting the strong coupling between spin-related and electronic states [1]. EuO represents a significant interest due to it structural simplicity, exceptional physical properties, and ability of light to directly control magnetic order on ultrafast time scale [2].

We report on an experimental study of ultrafast dynamics of photo-induced magnetic polarons (MP) in EuO. Initially, the pump light $\hbar\omega$ = 2.38 eV excites an electron from the 4f valence band to 5d conduction band of, see Fig. 1a. Figure 1b shows a scheme for measuring the time-resolved photo-induced Faraday effect (PFE). The temperature dependencies of the Faraday effect and PFE in EuO near the Curie temperature T_C reveal MP formation within the first 200 ps around 5d-electrons (see Fig. 1c).

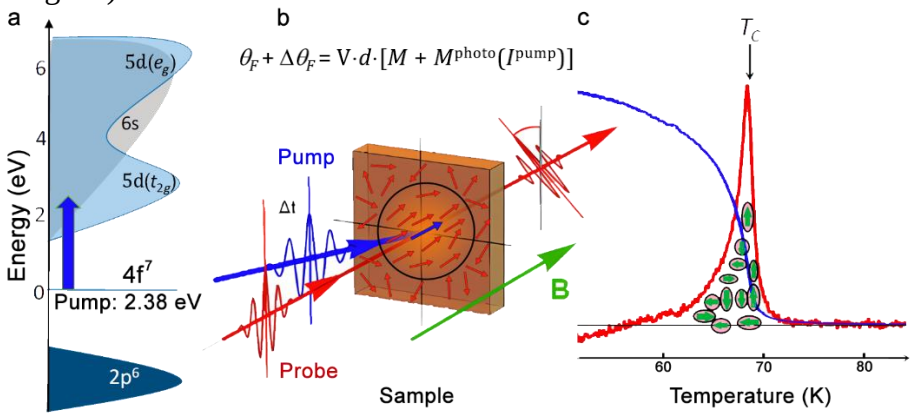

Fig. 1. (a) The band structure of EuO and the optical excitation of the electronic transition $4f^7 5d^0 \rightarrow 4f^6 5d^1$; (b) the scheme for measuring the time-resolved dynamics of MP by the PFE, (c) Temperature dependencies of the Faraday effect and PFE near T_C.

Detailed analysis uncovers complex multistage response of photo-induced magnetization from picoseconds to microseconds [3]. The theory of MP, developed for the entire family of europium chalcogenides EuX (X=O, S, Se, Te) and described by an effective Weiss molecular field (WMF) model, successfully predicts key features like the temperature-dependent magnetic moment across these compounds [4]. While the temperature dependence of the MP moment agrees well with WMF predictions for EuO, the absolute value of the moment reaches record-high values, which far exceeds theoretical estimates. The observed multistage dynamics is not captured by the WMF model. This discrepancy points to the specific role of the enhanced f-d exchange interaction and, possibly, the excitonic nature of the MP in EuO.

Support by the Russian Science Foundation (project No. 24-12-00348) is acknowledged.

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MAGNETO-OPTICS, REVISITED

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Three aspects of magneto-optics are reviewed that have hardly be considered in the past: (i) For MOKE magnetometry it will be shown that the obtained hysteresis loops need to be interpreted very carefully as they are measured locally, determined by the internal (not applied) field and local magnetization processes [1]. Such local loops may be seen as *hysterons* according to the classical Preisach hysteresis model (Fig. 1). (ii) For wide-field MOKE microscopy numerous magneto-optical effects will be discussed that lead to intensitybased domain contrasts in the absence of analyser and compensator [2]. They are summarized in Fig. 2 together with the „conventional“ effects. These effects may require linearly or circularly polarised polarized light for illumination. They can either be applied directly as alternative to the conventional effects (like the transverse Kerr effect for domain imaging in ferromagnetic materials or the linear birefringence effect for imaging domains in altermagnets) or there existence should at least be realised as they can lead to superimposed contrasts and misleading interpretations in magneto-optical microscopy. (iii) Magneto-optical microscopy is also possible in a *lensless* setup by recording diffracted images from a specimen. By some iterative reconstruction algorithm it is then possible to derive the amplitude and the phase of the wave, i.e. real and imaginary part of the magneto-optical amplitude in a spatially resolved way. On the example of a transparent magnetic garnet film a proof-of-principle study of this novel technique will be presented.

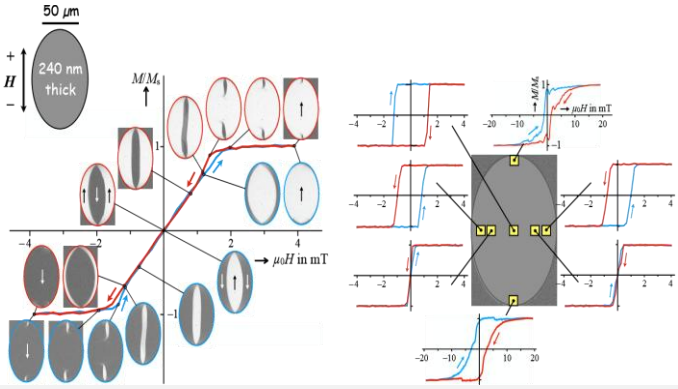

Fig. 1. Global MOKE magnetization curve together with domain images (left) and local loops (right), measured in indicated position on a permalloy film element

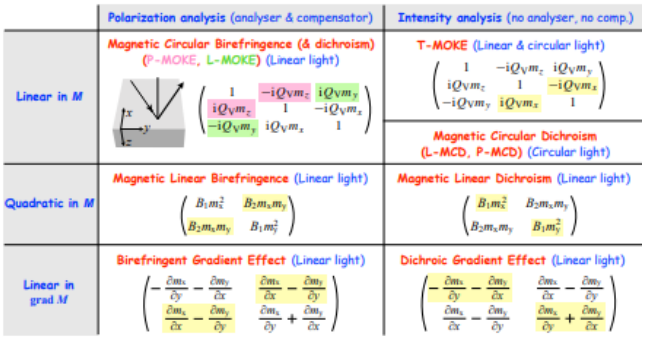

Fig. 2 Summary of magneto-optical effects at visible light, also showing their relevant elements in the dielectric tensors

Acknowledgements: Thanks to Ivan Soldatov (IFW) for contributing to the experiments

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ORAL SESSION

Magnetism and Super-conductivity

Wednesday, 19 August, 15:00 - 17:00

NICKELATES: A NEW CLASS OF HIGH-TEMPERATURE SUPERCONDUCTORS

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The recent discovery of superconductivity in hole-doped infinite-layer thin films of nickelate RNiO$_2$ (R = Sr, Ca, REE) with a nominal valence state Ni$^+$ with a critical temperature T_c ~ 15 K (with a sharp increase to ~30-40 K upon optimizing crystalline quality, compositions, epitaxial lattice strain, and pressure), has received much attention, placing this novel class of superconducting materials at the forefront of modern research [1,2]. More recently, it has been demonstrated that bulk single- and polycrystalline Ruddlesden-Popper nickelates $La_{n+1}Ni_nO_{3n+1-\delta}$ with the double-layer (n = 2 with a nominal 2.5+ valence of Ni ions) and trilayer (n = 3, Ni$^{2.67+}$) crystal structures exhibit superconductivity (SC) under pressure above ~15 GPa with a high transition temperature ~80-100 K (for n = 2) and 20-40 K (n = 3), opening up a new route to tune high-temperature SC [3,4]. This talk will review the experimental and theoretical data on this topic. In particular, the effects of electronic corrections, chemical doping, and pressure on the normal-state electronic structure, orbital-dependent quasiparticle renormalizations, the Fermi surface, and magnetic properties in this new class of high-T_c SC are discussed. It is shown that electron-electron correlations, and in particular spin fluctuations, are important for understanding the properties of the normal and SC state of nickelates [5]. These materials exhibit significant orbital-dependent quasiparticle renormalizations and incoherence of the spectral weights of the Ni $x^2 - y^2$ and $3z^2 - r^2$ orbital states, implying the proximity of the Ni *3d* states to orbital-selective localization. Our results suggest the possible formation of spin and charge density wave stripe states, implying strong spin and charge correlations. It was shown that spin and charge stripe fluctuations tuned by doping and pressure play a key role in superconductivity in nickelates. It has been demonstrated that superconductivity is associated with the suppression of spin and charge density wave ordering, which leads to a sharp increase of spin fluctuations.

Support by the Russian Science Foundation (Project № 25-12-00416) is acknowledged.

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MEMORY EFFECT IN MULTILAYER Nb-Co-Al SPLIT-RING RESONATORS

Bakurskiy S.V.[1], Tyumenev R.[2], Kalashnikov D.S.[2], Fradkin B.V.[2], Golovchanskiy I.A.[2], Neilo A.A.[1], Shishkin A.G.[2], Klenov N.V.[1], Soloviev I.I.[1], Golubov A.A.[2], Kupriyanov M.Yu.[1], Sidorenko A.S.[2], Stolyarov V.S.[2]

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Non-volatile control of kinetic inductance offers a promising route toward reconfigurable superconducting digital, microwave, and neuromorphic circuits [1]. Here we study split-ring resonators fabricated from Nb(20)/Co(2.5)/Nb(8)/Co(1.5)/Nb(8)/Al(20) spin-trigger multilayers. In these structures, the cobalt magnetization configuration controls proximity-induced superconductivity and redistributes the longitudinal supercurrent; microscopic Usadel calculations predict a severalfold change in kinetic inductance [2]. The Al layer acts as a low-resistance shunt enhancing the contrast between parallel and antiparallel magnetic states.

Microwave measurements were performed on multilayer SRRs placed on a planar waveguide in a longitudinal magnetic field at T = 2.4-2.5 K. A nominally 5 GHz resonator exhibited a resonance near 4.7 GHz, shifted from the Nb reference by enhanced kinetic inductance; the kinetic contribution was estimated as Lk ≈ 1 nH within a total inductance of about 8 nH. Field sweeps showed hysteretic changes of resonant frequency and internal quality factor associated with reversal of the Co layers and ferromagnetic-domain states. At zero field after magnetic-field pulses, full magnetization reversal produced a reproducible frequency shift up to 4 MHz. The antiparallel state showed higher resonant frequency and quality factor throughout the superconducting temperature range. Control samples confirm the magnetic origin of the effect: pure Nb resonators showed no noticeable memory, whereas structures without Al exhibited a non-reproducible, sample-dependent shift not exceeding 1-1.5 MHz. Thus, Al enhances the memory contrast by approximately a factor of three, in agreement with the microscopic model [3].

These results demonstrate Nb-Co-Al multilayer split-ring resonators as field-programmable inductive memory elements. The zero-field frequency memory is governed by the magnetic configuration of the spin valve and the redistribution of supercurrent between the superconducting source layer and the proximized Nb/Al shunt.

Fabrication and measurements were supported by the Ministry of Science and Higher Education of the Russian Federation (Agreement No. 075-15-2025-010). Theoretical analysis and modelling were supported by the Russian Science Foundation (project no. 24-19-00187).

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COULOMB CORRELATIONS AND SUPERCONDUCTING PAIRING IN EPSILON-IRON AND LAFEASO PARENT COMPOUND

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The effect of Coulomb correlations and magnetic fluctuations on the superconducting properties of epsilon-iron and iron-based parent compound LaFeAsO is studied within the DFT+DMFT method combining density-functional theory (DFT) and dynamical mean-field theory of correlated electrons (DMFT). Specifically, tendencies to superconducting pairing are evaluated by employing the Bethe-Salpeter equation (BSE) approach using the realistic electronic structure obtained by DFT+DMFT. We found that the quasiparticle mass enhancement m*/m ranges from 1.5 (33 GPa) to 1.8 (12 GPa) for epsilon-iron and reaches 2 for LaFeAsO signaling moderate correlations. In addition, we calculate imaginary time spin correlation functions and the nonuniform spin susceptibility which indicate the presence of strong antiferromagnetic spin fluctuations and short-lived local moments in both compounds. Next, using the DFT+DMFT local self-energy and non-local particle-hole bubble, we construct and solve the multiband BSE with the pairing vertex obtained by the second-order perturbation theory and the ladder-type diagrammatic approach. For epsilon-iron, we analyze the evolution of BSE eigenvalues and eigenfunctions under pressure and speculate on the spin fluctuation-mediated origin of superconductivity. In particular, we show that the tendency to superconducting pairing in epsilon-iron becomes weaker under pressure consistent with the overall damping of spin fluctuations and vanishing of superconductivity at 30 GPa. For the parent compound LaFeAsO, our calculations show the presence of correlation-assisted enhancement of antiferromagnetic spin fluctuations. Most importantly, we demonstrate that taking the vertex corrections into account is crucial for obtaining the singlet pairing with sign-changing gap consistent with the so-called s^{+-} scenario of superconductivity proposed earlier for iron pnictides and chalcogenides. Altogether, our results demonstrate that correlation-driven magnetic fluctuations are the essential ingredient for theoretical exploration of the fundamental properties of superconducting state of iron and iron-based parent compounds.

The research was supported by the Russian Science Foundation (Project No. 24-12-00024).

MAGNETOCALORIC EFFECT IN $TBNI_2$ UNDER A TRAPPED HIGH TEMPERATURE SUPERCONDUCTING FIELD UP TO 3 T

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It is well established that the magnitude of the magnetocaloric effect (MCE), which underpins magnetic refrigeration technology, depends directly on the strength of the applied external magnetic field. Consequently, generating a sufficiently strong external magnetic field constitutes a critical challenge in the development of magnetic refrigeration devices. However, practical implementation of magnetic cooling requires energy-efficient sources of magnetic field. One promising application of high-temperature superconductors (HTS) is the fabrication of permanent magnets capable of producing high-field intensities [1].

In this work, we report on the utilization of trapped magnetic flux in bulk HTS for MCE measurements in the $TbNi_2$ alloy. Magnetic flux trapping in the bulk HTS was performed following a field-cooling protocol. MCE measurements on the $TbNi_2$ sample within the trapped field of the HTS were carried out using an extraction technique. To this end, an original sample insert was developed, comprising a stationary part housing a stack of bulk HTS samples with a central bore, and a movable part accommodating the $TbNi_2$ specimens and a Hall sensor. The samples and the Hall sensor were translated into the central aperture of the HTS stack. The MCE magnitude was measured using a differential thermocouple positioned between two $TbNi_2$ samples.

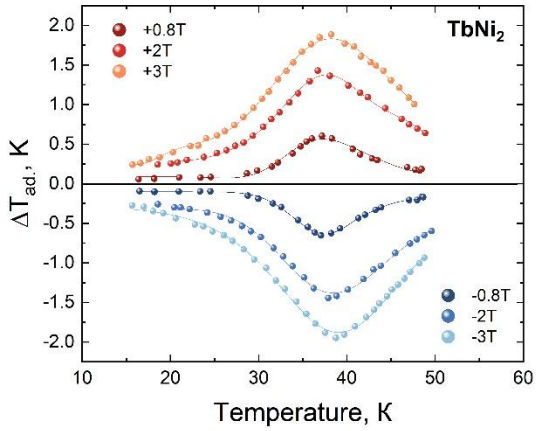

Fig. 1. Magnetocaloric effect in $TbNi_2$ under a trapped field.

The results for the adiabatic temperature change (Fig. 1) demonstrate good qualitative agreement with previously reported data [2]. However, quantitative analysis reveals a systematically lower measured MCE magnitude. The magnitude of the trapped magnetic flux decreases after repeated cycles of insertion of the sample into the HTS trapped-field region.

The study was supported by a grant from the Russian Science Foundation, project no. 25-19-20141, https://rscf.ru/project/25-19-20141/.

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SPIN-WAVE EXCITATIONS IN SUPERCONDUCTOR/FERROMAGNETIC INSULATOR HYBRID STRUCTURES WITH DYNAMIC PROXIMITY EFFECT

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Hybrid nanostructures composed of ferromagnetic-insulator and conventional s-wave superconductor layers offer broad prospects for applications in superconducting spintronics, hybrid magnonics, and the development of new types of metamaterials with tunable properties. Spin pumping into a superconductor can induce dissipationless spin currents that transfer angular momentum in superconducting spintronic structures [1,2].

In this work, we consider a bilayer hybrid structure consisting of a dirty superconductor and a ferromagnetic insulator. We show that the superconducting proximity effect modifies the spectrum of perpendicular standing spin waves, giving rise to additional features in the high-frequency magnetic susceptibility.

The magnetic susceptibility of the hybrid structure (Fig. 1) is calculated from the Landau–Lifshitz–Gilbert equation with modified boundary conditions that account for the nonequilibrium spin density generated at the superconductor/ferromagnetic-insulator interface by interfacial exchange coupling. The spin response of the superconductor is obtained from the linearized Usadel–Keldysh equation, which is valid in the dirty limit. The influence of the precessing magnetization on the dynamics of the superconducting condensate is incorporated through dynamic boundary conditions in the limit of a small spin-mixing angle [3].

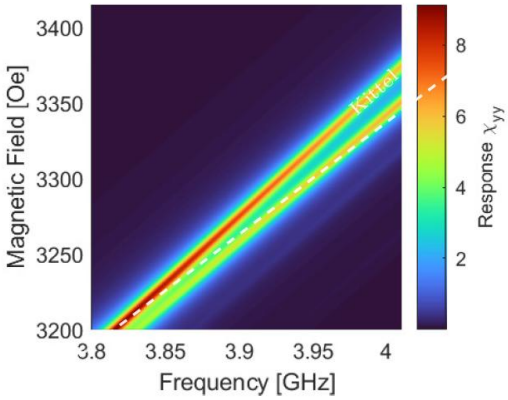

Fig. 1.Calculated transverse magnetic susceptibility of hybrid SC/FI structure.

The obtained results may be used to interpret FMR experiments in ferromagnet/superconductor bilayer hybrid nanostructures [2].

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IDENTIFICATION OF FM SUPEREXCHANGE FROM THE NEUTRON SCATTERNG EXPERIMENTS IN AFM CUPRATES

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In this study, we confirmed that there are strong experimental signatures for the ferromagnetic diagonal superexchange interaction in the spin-wave spectrum of La2CuO4 cuprates [1-2]. The basis for this statement is a calculation of spin-wave dispersion along the boundary of the AFM Brillouin zone(BZ), where the contribution from the direct AFM superexchange interaction between the nearest neighbors is absent [3](see Fig.1).

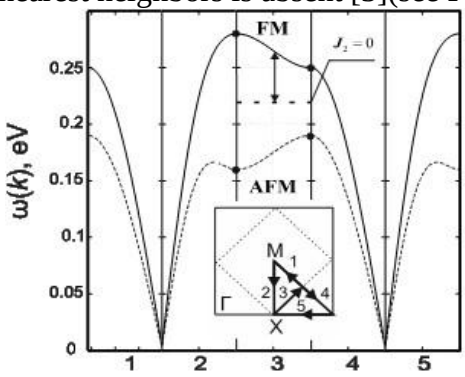

Fig. 1. Spin wave (SW) dispersion calculated with the parameters from [1]. The inset shows the k-directions in the BZ, along which the SW spectrum is presented. It is evident that the nature of the diagonal superexchange J_2 can be obtained from the observed dispersion along the AFM BZ boundary (scan 3). For the La_2CuO_4 cuprate, this is FM exchange. For clarity, scan 3 shows the dispersion-free level with $J_2 = 0$.

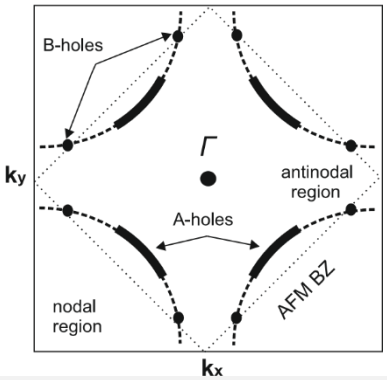

Fig. 2. Fermi arches (solid line) on cylindrical Fermi surface with A-holes in the $^1A_{1g}$ Zhang-Rice state and B-holes in the spin-triplet $^3B_{1g}$ and $^3A_{1g}$ states.

We observe an unusual reduction (or even absence) of the AFM contribution to the diagonal superexchange from virtual electron-hole pairs with A-holes (see Fig.2) in spin-singlet states (- Zhang-Rice states) and analyze consequences of this fact for current theoretical approaches used in magnetic physics of the cuprates.

Support by a RSF grant №. 24-12-00044. is acknowledged.

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TO THE PRINCIPAL LIMITATIONS OF THE MAGNETIC LEVITATIONAL TRANSPORTION BASED ON HIGH TEMPERATURE SUPERCONDUCTORS

Koledov V.V. [1,2], *Matyunina M.V.* [2], *von Gratovski S.V.*[1], *Suslov D.A.*[1], *Bychkov I.V.*[2], *Pavlukhina O.O.*[2], *Orshulevich M.A.* [2], *Maltsev I.V.* [2], *Mashirov A.V.*[1], *Kirillov D.E.*[2], *Garipov R.R.* [2], *Kamantsev A.P.* [1], *Kolesov K.A.* [1,2], *Karpukhin D.A.*[1,2], *Kuzmin D.A.*[2]

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The development of high-speed, economical, and environmentally friendly magnetic levitation transport (MLT) in a vacuum tube using high-temperature superconductors (HTSC) has attracted considerable attention [1,2]. Attractive features include not only the absence of mechanical friction, but also the stability of HTSC movement along a track of permanent magnets, due to the magnetic flux capture effect of the HTSC (see Fig. 1). This raises the question of the fundamental physical limitations on the speed of stable movement of a levitating HTSC with captured magnetic flux along a line of permanent magnets.

The report provides an overview of the state of research on the problem and presents preliminary results of an experimental study of the resistance to movement of HTSC models, using an original method of gravitational of acceleration and deceleration.

This work was supported by the Russian Science Foundation (RSF) Project No. 25-1920141 (https://rscf.ru/ru/project/25-19-20141/).

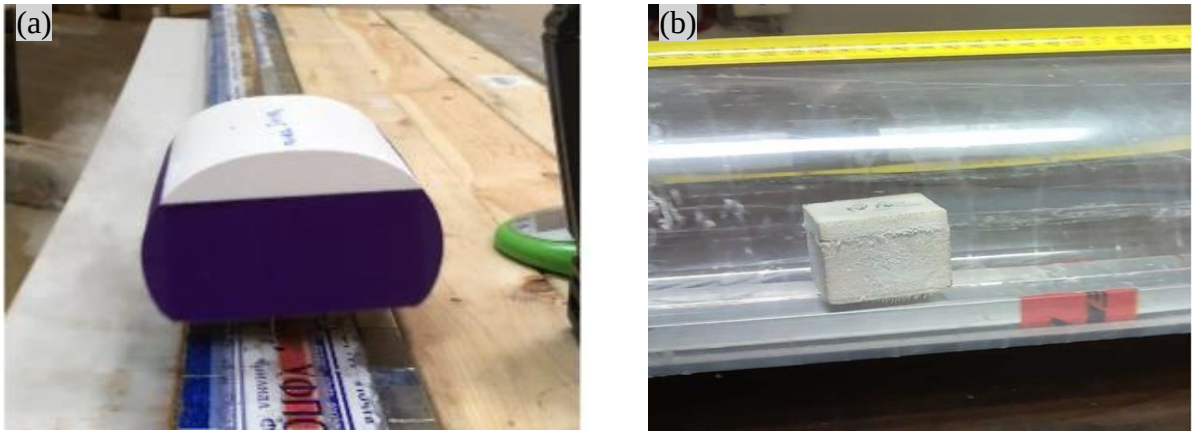

Fig. 1. Experimental study of drag forces during the movement of a HTSC along a magnetic levitation track. (a) Magnetic levitation at gravitational acceleration and deceleration. (b) A setup for studying the movement of MLT in a vacuum.

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ORAL SESSION

Soft and Hard Magnetic materials

Wednesday, 19 August, 15:00 - 17:00

ROLE OF MAGNETIC ANISOTROPY AND MAGNETOSTATIC INTERACTIONS IN MAGNETIC VISCOSITY

Komlev A.S., Vashchenkova A.R., Kostylev S.I. , Perova N.N. , Kiseleva T.Y. , Perov N.S.

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Magnetization relaxation is an important property of magnetic materials. It shows how fast a magnetic system reaches a stable state after a change in magnetic field or temperature. In many materials this process is not controlled only by thermal activation. Magnetic anisotropy, magnetostatic interactions, and structural inhomogeneity can also strongly affect the relaxation time [1]. In this work we analize this problem using two magnetic systems: granular thin films with perpendicular magnetic anisotropy and amorphous Fe-Co-Ni-Si-Nb-B ribbons at crystallization.

In granular films with perpendicular anisotropy, magnetic viscosity was studied in the field range where irreversible magnetization takes place. The time dependences of magnetization relaxation were described by an exponential law. This made it possible to determine the magnetic viscosity and the characteristic relaxation time as functions of magnetic field. Both values show non-monotonic field dependences. The magnetic viscosity has a maximum near the field where many magnetic domains are in a metastable state. The relaxation time also increases near 5.5 kOe. FORC measurements show a broad distribution of coercive fields and strong interaction fields. These results confirm that magnetostatic interactions between domains play an important role in the relaxation process. A phenomenological model was proposed to describe this behaviour. The model includes anisotropy energy, Zeeman energy, and magnetostatic energy. It shows that metastable states appear due to competition between magnetic anisotropy and magnetostatic interactions [2].

In case isothermal crystallization amorphous Fe-Co-Ni-Si-Nb-B ribbons, magnetization relaxation was studied in-situ by vibrating sample magnetometry. During annealing, the magnetization changes with time because new crystalline phases are formed. The crystallization occurs in two main stages. First, a cubic phase appears. At higher temperatures, a hexagonal phase starts to form. These structural changes lead to a strong change in the effective magnetic anisotropy. The effective anisotropy constant was determined from high-field magnetization curves. It decreases during the formation and ordering of the cubic phase and increases when the hexagonal phase appears. This change in anisotropy is related to the non-monotonic temperature dependence of the characteristic relaxation time. The experimental results were described by a model that includes the growth of crystalline phases and the temperature dependence of the effective anisotropy [3].

Thus, both systems demonstrate that magnetic relaxation is strongly governed by internal magnetic energy contributions. Under certain external conditions, the competition between magnetostatic energy and magnetic anisotropy energy can stabilize metastable magnetic states, leading to long magnetization relaxation times.

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MAGNETOELASTIC COUPLING IN IRON BORATE: EFFECTS AND MODELLING

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Due to the peculiarities of the crystal and magnetic structure, iron borate single crystals possess a variety of interesting properties. This fact makes this material a model object for research in the solid-state physics and magnetism, as well as defines the prospects for high-tech applications. A practical absence of the magnetic anisotropy in the basal plane (perpendicular to C_3) and a weak uncompensated magnetic moment lead to an anomalously strong coupling between the magnetic and elastic subsystems of the crystal. This magnetoelastic (ME) coupling manifests itself both in dynamics and statics. We have observed and studied the dynamic effects during the passage of a linearly polarized transverse acoustic wave excited by piezoelectric transducers through the isometric iron borate single crystal [1]. Under the action of magnetization oscillations induced by transverse sound, the degeneracy in the velocities of two acoustic modes with linear polarizations orthogonal to each other was removed. This resulted in an effect similar to the magneto-optical Cotton-Mouton phenomenon. In the work [1] a static manifestation of the ME coupling was also observed, consisting in a significant influence of the experimental mechanical boundary conditions on the nature of the field dependence of the acoustic wave amplitude. The theory of this magnetic birefringence of transverse sound taking into account mechanical boundary conditions was constructed [1]. Despite the known weakness of the ME coupling for longitudinal sound, it was established in iron borate. When irradiating iron borate single crystals with femtosecond laser pulses, along with the usually observed magnetic oscillations at the AFMR frequency, oscillations of magnetic vectors at significantly lower frequencies were detected [2]. It was established that the magnetic oscillations were induced by longitudinal sound that was directly excited by ultra-short laser pulses. We also observed the opposite effect – the influence of magnetic oscillations on the amplitude of longitudinal sound excited by piezoelectric transducers. In order to interpret the experimental results on the longitudinal sound, a theory was developed based on the use of high-order ME invariants constructed by us. The interpretation of the observed unusual effect – the deviation of the antiferromagnetic vector from the basal plane under high quasi-hydrostatic pressure – is provided in [4].

In this paper our results on the study of ME effects in iron borate are analysed and systematized, as well as the theory of longitudinal sound that allows to interpret the experimental results is developed.

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EFFECT OF ELECTRON IRRADIATION ON STRUCTURE AND MAGNETIC PROPERTIES OF $BAFE_{11}TI_{0.5}AL_{0.5}O_{19}$, $SRFE_{11.3}TI_{0.4}AL_{0.3}O_{19}$

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Unique magnetic properties of M-type hexagonal ferrites $(Sr,Ba)Fe_{12}O_{19}$ such as high uniaxial magnetocrystalline anisotropy and high saturation magnetization, high chemical and temperature stability allow to use them in different technological applications: microwave devices, high-density magnetic memory elements, magnetic field sensors. Substituting of the part of iron ions Fe^{3+} with non-magnetic and magnetic ions in strontium and barium hexaferrites leads to significant changes in the magnetic crystallographic anisotropy field, magneto-optical behavior, effective absorption operating frequency band. Analysis of the impact of electron irradiation on changes in magnetic anisotropy, and modifications of magnetization parameters, is a subject of interest for both the field of physics and potential applications of radiation-stable hexaferrite-based devices. In this study, the radiation-stability of Ti- and Al-substituted strontium and barium hexagonal ferrites to 10 MeV electron irradiation with different fluences is investigated [1]. A range of characterization techniques such as X-ray diffraction, scanning electron microscopy, energy dispersive X-ray spectrum microanalysis, X-ray photoelectron spectroscopy, atomic force microscopy, Raman spectroscopy, vibrating sample magnetometry and magnetic force microscopy were employed to analyze the surface structure, electronic structure, lattice vibrations, magnetic domain microstructure and magnetization behavior.

It is obtained that radiation-induced defects lead to the destruction of iron-oxygen chemical bonds and changes in domain structures for strontium and barium hexaferrites. It is demonstrated that the increase in coercivity, reduction of the residual magnetization, change in the field dependence of magnetization with increasing radiation fluence, being attributed to the increase in magnetic-crystalline anisotropy, confirm the manifestation of spin-phonon interaction in strontium hexaferrite. However, when barium hexaferrite is irradiated, changes are not observed in parameters such as coercivity and residual magnetization. The obtained results can be used in the creation of stable magnetic devices based on strontium and barium hexaferrites.

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DYNAMICS OF THE MAGNETOCALORIC EFFECT DURING CYCLIC APPLICATION OF A MAGNETIC FIELD NEAR REVERSIBLE AND IRREVERSIBLE PHASE TRANSITIONS IN HEUSLER ALLOYS

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The potential for using the giant inverse magnetocaloric effect in Heusler alloys for magnetic refrigeration has received considerable attention. However, its practical application is hampered by hysteresis, irreversibility, and, especially, degradation of the effect under cyclically applied magnetic fields. This paper presents a detailed experimental study of the adiabatic temperature change (ΔT_{ad}) dynamics in $Ni_{36.5}Co_{13.5}Mn_{35}Ti_{15}$ and $Ni_{47}Mn_{40}Sn_{12}Cu_1$ Heusler alloys near the magnetostructural phase transition (MSPT). Direct ΔT_{ad} measurements were performed under both single and cyclic exposure to a magnetic field of 8 T.

The $Ni_{47}Mn_{40}Sn_{12}Cu_1$ alloy exhibits irreversible MSPT in magnetic fields up to 8 T. It was found that the irreversibility of the phase transition additionally contributes to the giant inverse magnetocaloric effect, increasing the overall effect by up to 35%. A critical dependence of the magnitude and sign of ΔT_{ad} on the field change rate and thermal history, which is related to the nucleation and growth kinetics, was identified. Rapid cooling was shown to lead to kinetic arrest and the formation of a mixed two-phase state with similar proportions of martensite and austenite, in which the direct and inverse magnetocaloric effects (MCE) compensate each other, explaining the "collapse" of the inverse magnetocaloric effect.

In the $Ni_{36.5}Co_{13.5}Mn_{35}Ti_{15}$ alloy, a giant inverse magnetocaloric effect is realized near the MSPT. The maximum adiabatic temperature change reaches ΔT_{ad}=-11.3 K in a field of 8 T at T_0=313 K. It is shown that the stability of the inverse MCE in a cyclic magnetic field depends on the proximity of the measured temperature to the onset temperature of the austenite phase. In a cyclic magnetic field of 8 T at T=310 K, the $Ni_{36.5}Co_{13.5}Mn_{35}Ti_{15}$ sample demonstrates a completely stable inverse effect of with value -9 K.

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ROLE OF MAGNETOELASTIC COUPLING IN $CoTi_2O_5$

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In this work, a novel mechanism for controlling antiferromagnetic domain states in $CoTi_2O_5$ via the magnetoelastic coupling was demonstrated [1]. In contrast to traditional approaches based on manipulating magnetocrystalline anisotropy, the proposed method is implemented through modulation of frustrated exchange interactions by means of uniaxial mechanical strain coupled to a monoclinic symmetry-distorting deformation of Γ^{2+} symmetry. Based on GGA+U calculations, the magnetic exchange parameters in the high-temperature orthorhombic structure were determined, confirming perfect frustration of the interplanar exchange pathways (J_3, J_4) and their degeneracy with respect to the magnetic wave vectors $\mathbf{k}_{\pm} = (1/2, \pm 1/2, 0)$. Furthermore, GGA+U calculations demonstrate switching between $\mathbf{k}_{+}$ and $\mathbf{k}_{-}$ domains under applied uniaxial stress, thereby realizing a reverse "magnetism–lattice" causality mechanism: the direction of strain selects a specific magnetic configuration of the domain structure.

Analysis of the GGA+U results successfully reproduced the phonon spectrum and revealed anomalous phonon modes [2]. The optical phonon mode has the same Γ^{2+} symmetry as the acoustic shear phonon mode previously detected via inelastic neutron spectroscopy. The results obtained indicate that the magnetic ordering in $CoTi_2O_5$ is driven not by a static structural distortion, but by cooperative magnetoelastic fluctuations, wherein acoustic phonons of Γ^{2+} symmetry act as a dynamic order parameter. Thus, the physics of the phase transition in $CoTi_2O_5$ is governed not by a classical "soft" optical mode followed by static displacement, but by coupled lattice–spin dynamics. This supports the interpretation of the transition as a magnetoelastic-driven process and opens prospects for functional applications of such systems in spintronics controlled by external uniaxial stress.

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REGULATION OF PHOTOCURRENT BY A MAGNETIC FIELD IN THE FERROMAGNETIC SEMIMETAL $MnZn_{1-X}Cr_XSb$

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The bulk photoelectric effect has been observed in MnZn1-xCrxSb Weyl semimetals, which have several pairs of sites with different chiralities. The photocurrent arises from the inversion-asymmetric transition of electrons upon photon absorption and is associated with topological quantities that include the Berry phase curvature singularity. The photoelectric effect is strongest at low frequencies in the mid-IR region. Extreme changes in the photocurrent and photovoltage in MnZn1-xCrxSb Weyl semimetals, both with temperature and magnetic field, have been observed at low temperatures. Localization of photoelectrons in a magnetic field leads to a decrease in the current and an increase in the photovoltage.

A correlation between the temperature behavior of photovoltage and photocurrent and the temperature behavior of magnetization has been established. Near the Curie temperature, photovoltage and photocurrent decrease sharply and change smoothly above Tc. A nonlinear dependence of photocurrent and photovoltage on electromagnetic radiation intensity over a wide frequency range has been found. The maximum sensitivity of photocurrent in the mid-IR range increases with increasing chromium concentration in MnZn1-xCrxSb semimetals. Photocurrent and photovoltage depend on the spectral range, and under identical illumination from a laser, LED lamp, and incandescent lamp, the maximum photoelectric effect is achieved with an incandescent lamp.

By reversing the magnetic field polarity, the direction of the magnetically induced current can be reversed, and the contribution to the photocurrent will be added or subtracted accordingly. The change in photoresistance in a magnetic field for the MnZn09Cr01Sb sample changes sign when switching the polarity of the magnetic field. The resistance of the MnZn0.8Cr0.2Sb sample increases when illuminated in a magnetic field. A shift in the photoresistance extremum temperature with chromium concentration was found.

The change in photoresistance in a magnetic field is explained by the localization of electrons in the vicinity of a Weyl node, which has a nodal annular dispersion, leading to closed cyclotron orbits in magnetic field [1]. The photovoltage and photocurrent are explained by the shift of the Weyl nodes relative to the chemical potential and the transition of electrons between the upper and lower subbands, polarized by spin as a result of spin-orbit interaction.

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COMPLEX MAGNETIC BEHAVIOR IN RuO_2 THIN FILMS DRIVEN BY STRAIN AND SUBSTRATE EFFECTS

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Ruthenium dioxide (RuO2) has been proposed as a prototypical metallic *d*-wave altermagnet, a Néel-ordered compensated antiferromagnetic state exhibiting nonrelativistic momentum-dependent spin splitting; yet, its magnetic ground state remains controversial both theoretically and experimentally. Using comprehensive first-principles calculations, we investigate RuO2 thin films with (110), (100), and (001) orientations, both (un)strained freestanding and supported on a TiO2 substrate. We show that emergent magnetic moments in RuO2 thin films are highly fragile, strongly influenced by strain, surface orientation, and atomic relaxation, while also being highly sensitive to the choice of the Brillouin-zone integration scheme. We find that none of the thin film structures considered can stabilize a compensated antiferromagnetic order; therefore, an altermagnetic ground state cannot be realized. Instead, substrate-supported RuO2 films on TiO2 exhibit pronounced layer- and site-dependent magnetic moment variations and incomplete compensation between the two antiferromagnetically coupled Ru moments, yielding a \emph{ferrimagnetic-like} behavior. On the other hand, freestanding RuO2 films display complex magnetic structures depending on their orientation and applied strain, with distinct behavior at the surfaces and in the inner layers. Our results reconcile conflicting theoretical and experimental reports and underscore the sensitivity of RuO2 magnetism to structural and methodological details.

PECULIARITIES OF OBTAINING DATA ON MAGNETIC SUSCEPTIBILITY OF PARTICLES ACCORDING TO DATA ON SUSCEPTIBILITY OF POWDER OF THESE PARTICLES

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In the article the results are presented about the study of different samples with powder materials to determine their magnetic susceptibility $\langle\chi\rangle$, and thereby the powder particles' susceptibility χ, using the measured data of the magnetic force F acting (in the established executive zone of the magnetometer) on the sample, but one that is sufficiently artificially rarefied. Samples of magnetoactive impurity powders, extracted from crushed tea leaf and granulated sugar, were used, as well as powder used in flaw detection. It has been shown that when obtaining the dependence of the magnetic force F on the volume fraction of the γ of the studied magnetoactive particles in the sample, the initial linear section of this dependence is detected, which confirms the possibility of using the data F from such a section to determine the χ data.

POSTER SESSION

Magnetic Materials II

Wednesday, 19 August, 17:00 - 19:00

FE-INDUCED FERROMAGNETISM IN B-Ga_2O_3 SINGLE CRYSTALS

Sergienko E.S.[1,2], *Yanson S.Yu.*[1], *Kharitonskii P.V.*[3], *Gareev K.G.*[2,3], *Kitsay A. A.*[2], *Nosov Yu.G.*[2], *Nikolaev V.I.*[2]

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β-Ga_2O_3 is a wide-bandgap oxide semiconductor with considerable potential for power electronics and optoelectronic applications. Doping β-Ga_2O_3 with transition-metal ions is of interest as a way to modify its defect structure, electronic properties, and local magnetic states. n this work, we investigated β-Ga_2O_3:Fe single crystals grown by the flux method using a MoO_3 solvent [1]. The crystals were synthesized with different amounts of Fe added to the starting charge: 0.04, 0.10, 0.30, 0.61, and 0.78 g per 3 g of Ga_2O_3. Plate-like crystals with a thickness of less than 100 μm and lateral dimensions up to 2.5 mm were obtained; most crystals were twinned, with (101) or (100) twinning planes. The key result is that Fe incorporation not only modifies the local defect structure of β-Ga_2O_3, but also promotes the formation of magnetically interacting Fe-rich regions responsible for a room-temperature ferromagnetic-like response.

Single-crystal X-ray diffraction shows that the β-Ga_2O_3 structure retains monoclinic symmetry with the space group C2/m after Fe doping. Fe substitutes for Ga in both crystallographic sites, with a preferential occupation of octahedrally coordinated sites. Raman spectroscopy and photoluminescence data also confirm the preservation of the β-Ga_2O_3 structure. At the same time, SEM-EDX reveals a non-uniform Fe distribution within the crystals. For example, in the sample synthesized with 0.61 g of Fe in the starting charge, the substitution index x in the formula $(Ga_{1-x}Fe_x)_2O_3$ varies between approximately 0.012 and 0.026 at different analysis points. EPR spectra of the same sample show a transition from narrow lines of isolated Fe^{3+} ions to a broad resonance line, indicating the formation of interacting Fe-containing regions or clusters.

Magnetometry at 300 K indicates a systematic change in the magnetic state with increasing Fe content. Undoped β-Ga_2O_3 exhibits diamagnetic and weak paramagnetic contributions. In contrast, the Fe-doped samples show nonlinear M(H) dependences and hysteresis loops. The Sshaped M(H) curves and remanent magnetization indicate the formation of ferromagnetic or ferromagnetic-like Fe-containing clusters.

Theoretical analysis using the SDEM model [2] suggests that the ferromagnetic component may be associated with a μ-Fe_2O_3-like monoclinic Fe-rich phase epitaxially stabilized on βGa_2O_3. Such a phase has previously been described as producing a room-temperature ferromagnetic response [3]. Thus, Fe incorporation serves as an effective tool for tuning the defect structure of β-Ga_2O_3 and inducing room-temperature ferromagnetic-like behavior via the formation of interacting Fe-rich clusters

This work was carried out at the Laboratory of Profiled Crystal Physics at the Ioffe Institute of Physics (FFUG-2024-0027) and at the SPbU Research Park: Centre Nanotechnology, MM, DFM, Pharmacology and Nanoelectronics and GERM (124032000029-9, 125021702335-5, 125022803066-3).

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CRITICAL BEHAVIOR AND MAGNETOCALORIC EFFECT IN $LA_{1-Y}SR_YMN_{0.9}FE_{0.05}ZN_{0.05}O_3$ (Y = 0.17, 0.19, 0.3) COMPOUNDS

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The three samples $La_{1-y}Sr_yMn_{0.9}Fe_{0.05}Zn_{0.05}O_3$ (y = 0.17, 0.19, 0.3) undergo a ferromagnetic phase transition [1-3]. The Curie temperature T_C increases on increasing Sr-ions content. The existence of a Griffiths-like phase in these samples was experimentally detected by means of magnetic susceptibility and ESR measurements [1-3]. In this work, we present the critical and magnetocaloric properties of these three compounds. We observe a magnetocaloric effect with a maximum value of magnetic entropy change ($|\Delta S_{max}|$) occurring close to the Curie temperature T_C, corresponding to $|\Delta S_{max}|$ = 2.56, 2.77, and 2.9 J/(kg K) under a magnetic field change (ΔH) of 50 kOe for y = 0.17, 0.19, and 0.3, respectively. The relative cooling power (RCP) values are found to vary between 305 and 258 J/kg. The critical properties of all samples are investigated by analysis of the magnetization data in the vicinity of their Curie temperature T_C. By means of Arrott plots, the nature of the magnetic transition is found to be of second order. The critical exponents β, γ and δ, as determined from modified Arrott plots (MAP) [4], are in fair agreement with the 3D-Heisenberg model.

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FRUSTRATED ANTIFERROMAGNETIC-FERROELECTRIC SUPERLATTICE WITH DZYALOSHINSKII–MORIYA INTERACTION: SKYRMIONS, SPIN WAVES, AND PHASE TRANSITIONS

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Theoretical and experimental investigations on the topological phenomena and skyrmion phases in various materials have been extensively carried out in the context of the effect of Dzyaloshinskii-Moriya interaction (DMI) in magnetic thin films[1,2]. It has been shown that the DM interaction is at the origin of topological skyrmions [3–4] and new kinds of magnetic domain walls [5].

We report a computational study on the antiferromagnetic-ferroelectric superlattices, where a model for the coupling between an antiferromagnetic film on triangular lattice and a ferroelectric film is proposed by introducing a Dzyaloshinskii-Moriya interaction - like interfacial interaction.

The ferroelectric system is represented by an Ising-like model containing ferroelectric nearest neighbor coupling and the magnetic layer is described by a Heisenberg model. First, we obtain the ground-state spin configurations, which are non-collinear spin textures in the absence of applied magnetic field, and skyrmion textures in the presence of an out-of-plane magnetic field. Then we investigate the spin waves in an antiferromagnetic-ferroelectric superlattices by using the Green's function method using various parameters. We investigate the possibility of the existence of skyrmion crystals on the frustrated triangular lattice considering the DM interaction in addition to the frustrating antiferromagnetic interaction J between nearest-neighbors (NN) and an applied magnetic field H perpendicular to the lattice plane.

Besides, we study the phase transition as a function of the Dzyaloshinskii-Moriya coupling and external fields. The thermodynamic properties were investigated by means of Monte Carlo simulations.

This work proposes a model to study the coupling between an antiferromagnetic film and a ferroelectric film, which is useful for the understanding of the superlattice composed of alternating frustrated antiferromagnetic and ferroelectric layers. Such a work could also be an important contribution to the emerging field of skyrmionics. Magnetoelectric materials are of utmost interest in view of both fundamental understanding and novel desirable applications.

This work was carried out within the framework of the state assignment, agreement No. 075-03-2024-123/1 dated 02/15/2024.

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STUDY OF THE MAGNETIZATION CURVE OF THE INTERMETALLIC COMPOUND $GDMN_2SI_2$ IN AN ULTRAHIGH MAGNETIC FIELD

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The magnetization curve of the intermetallic compound $GdMn_2Si_2$ was measured in fields up to 350 T at a temperature of 4.2 K. Up to six magnetic phases induced by the ultrahigh magnetic field are observed. This allowed the calculation of the magnetocrystalline anisotropy constants of the manganese sublattice and the parameters of the exchange interaction between the manganese and gadolinium layers [1].

The magnetic field was generated by the MC-1 magnetocumulative generator [2]. The influence of radial field gradients was eliminated by using a new type of compensation sensor. The sample consisted of powder oriented along the easy magnetization axis in an epoxy matrix.

The work was carried out within the framework of the scientific program of the National Center of Physics and Mathematics, direction No. 7 "Research in high and ultrahigh magnetic fields".

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LANDAU–KHALATNIKOV DESCRIPTION OF MAGNETIZATION RELAXATION WITH MAGNETOCALORIC CONTRIBUTION

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Magnetic materials that undergo first-order phase transitions exhibit an abrupt change in its magnetic state under relatively weak external stimuli. This makes FeRh and $La(Fe,Si)_{13}$ -based compounds promising for solid-state cooling, magnetic recording, sensing and spintronic applications [1-2]. However, near the transition, their response is strongly affected by nonequilibrium effects: the transition temperature or field, the width of the transformation region and the shape of the magnetization curves depend on the rate of temperature or magnetic-field variation. Therefore, the dynamics of such systems requires a kinetic description of magnetization relaxation and, for magnetocaloric materials, an explicit account of the temperature change accompanying the transition.

In this work, magnetization dynamics is considered within a phenomenological model based on the Landau free energy and the Landau–Khalatnikov equation:

$$F(M,H,T) = -HM + \frac{1}{2}A(T)M^2 + \frac{1}{4}BM^4 + \frac{1}{6}CM^6 \quad (1)$$

$$\frac{dM}{dt} = -\Gamma(M)\frac{\partial F}{\partial M} \quad (2)$$

Here Γ(M) is the kinetic coefficient determining the relaxation rate of the magnetic subsystem. This coefficient is usually assumed to be constant. However, analysis of field-dependent magnetization curves of $La(Fe,Si)_{13}$ measured at different magnetic-field sweep rates has shown that this approximation is insufficient: Γ must be magnetization-depend. This dependence is related to interactions between ferromagnetic clusters during the phase transformation.

The field-induced transition is accompanied by a pronounced magnetocaloric response. To account forthis contribution, the sample temperature is written as $T_{\text{sample}} = T_{\text{bath}} + \Delta T$, where ΔT is obtained from direct caloric measurements. Since ΔT is treated as a small deviation from the bath temperature, the temperature dependence of the Landau coefficient $A(T)$ can be expanded near T_{bath}. Keeping the linear term gives

$$A(T_{\text{sample}}) = A(T_{\text{bath}}) + \alpha\Delta T \quad (3)$$

This approach allows magnetization relaxation to be analyzed as a combination of non-caloric mechanisms, described by $\Gamma(M)$, and caloric mechanisms, entering through the measured ΔT. The aim is to separate these contributions and clarify the role of magnetocaloric effect in the dynamic response under finite-rate magnetic-field variation.

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Vashchenkova A.R. acknowledges assistance from the "BASIS" Foundation for the realization of theoretical model calculations.

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ATTENUATION OF ULTRASOUND PROPAGATION IN $LUCO_3$ SINGLE CRYSTAL AT HIGH MAGNETIC FIELD

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Binary intermetallic R-T compounds (R = rare-earth elements, T = 3d transition metals) can exhibit various phase transitions induced by a strong magnetic field [1,2]. Separately, the phase transition of transition metal atoms from a low-spin to a high-spin state (LS-HS) can be distinguished, which was observed, for example, in Ref. [3]. Ref. [4] theoretically shows that ultrasound propagation induces transitions between magnon band states due to absorption of phonons, and this process is highly sensitive to the value of magnetization. The high magnetic field, which governs the crossover, alters the ultrasound propagation regime from off-resonant to resonant. The model is entirely based on measurements of bulk magnetization and magnetic anisotropy without reference to their microscopic origin. Another restriction inherent in the model is the assumption of a rigid lattice, which excludes the possibility of magnetostriction. The latter can play a crucial role in the field-dependence of the ultrasound velocity, since the static lattice deformations induced by the field modify the elastic constants of a material.

In this work, the object of research is the $LuCo_3$ compound, which exhibits field-induced LS-HS transition of Co atoms at temperatures lower than 200 K. At 2 K, this transition occurs at a magnetic field of 47 T. We studied ultrasound attenuation process in $LuCo_3$ under applied fields up to 58 T using various geometries at different temperatures. Figure 1 shows the results of the ultrasound attenuation measurements as an example. Here, the experimental geometry is **k** || **u** || [100], and the magnetic field was applied along the [001] direction. The results show good agreement between the experimental data and the theory proposed in Ref. [4].

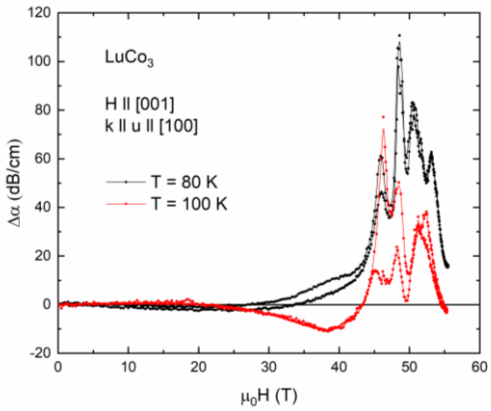

Fig. 1. Magnetic field dependence of the ultrasound attenuation in $LuCo_3$ at 2 K.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation (Ural Federal University project within the Priority 2030 Program).

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MAGNETIC FIRST-ORDER PHASE TRANSITION IN MELT-SPUN Fe-Rh ALLOYS WITH Ni SUBSTITUTION

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The first-order magnetic phase transition in FeRh is extremely sensitive to the synthesis method, external factors, and composition peculiarities [1]. In low-dimensional FeRh-based structures, deviations from the magnetic behavior of bulk samples are observed: a shift in critical temperatures, smearing and asymmetry of the M(T) and *M*(H) loops [2]. In alloys, melt spinning, grinding, and other strong mechanical effects lead to a high content of the metastable fcc paramagnetic phase [3]. Substitution by other 3*d* and 5*d* elements leads to a change in the critical temperature of the phase transition [1,4].

In this work, the combination of the above-mentioned factors affecting the phase transition in melt-spun $(Fe_{0.99}Ni_{0.01})_{49}Rh_{51}$ ribbons exposed to various heat treatments was investigated. Heat treatment at 1000°C almost completely destroys the fcc phase, stabilizing the bcc phase (Fig. 1). This was confirmed by X-ray diffraction analysis and magnetometry. As expected based on the data in Ref. [4], substitution with Ni atoms shifts the phase transition to the room temperature region. This expands the possibilities for experimental studies of this magnetic phase transition.

The *M*(*T*) and *M*(*H*) curves exhibit some peculiarities: an asymmetric transition and a step-like behavior similar to those described in Ref. [2] for mesoscopic structures in the form of stripes made of FeRh thin film. The isothermal entropy change ΔS_m was estimated from the magnetometric data, and the adiabatic temperature change ΔT was measured directly. The obtained values of the magnetocaloric effect parameters correspond to those in bulk alloys. The annealed samples were studied using Mössbauer spectroscopy. Mössbauer spectra were obtained at various temperatures corresponding to antiferromagnetic, ferromagnetic and mixed states. H_{hf} values and the local environment of Fe atoms were determined.

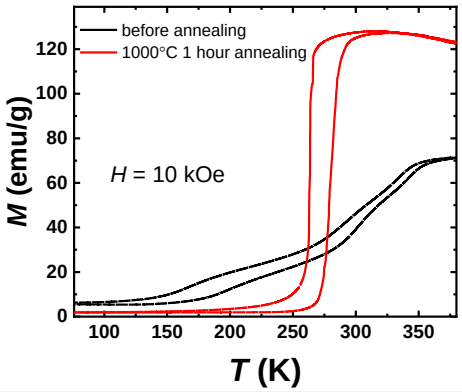

Fig. 1. *M*(*T*) curves in *H* = 10 kOe for as-cast melt-spun alloy (black) and 1000°C 1[h] annealed (red).

Supported by the Ministry of Science and Higher Education of the Russian Federation (Ural Federal University project within the Priority 2030 Program).

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DYNAMICS OF MAGNETOELASTIC OSCILLATIONS AND MAGNETIC REORIENTATION IN A THREE-LAYER PLANAR STRUCTURE

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Research into the dynamics of magnetic and elastic oscillations and magnetic reorientation in multilayer planar structures is of great practical interest due to the practical need to reduce the size of structures, increase their sensitivity to external electromagnetic fields, and expand their operating frequency range [1]. In this work, a system of equations was obtained that describes magnetoelastic oscillations in a planar structure consisting of three layers with different parameters, but close to the parameters of iron-yttrium-aluminum garnet crystals of the composition $Y_3Fe_4A1_lO_{12}$ [2]. To solve the system of equations, the Runge-Kutta-Felberg method of 4-5 orders with normalization of the unit magnetization vector at each step was used. The case of resonant excitation of elastic oscillations of a planar structure by an alternating magnetic field at a frequency of 2.5 GHz was investigated. As a result of numerical solutions of the system of modeling equations, time and frequency dependences of the components of the amplitude of magnetic and elastic oscillations and phase portraits of magnetic oscillations for different constant magnetic fields taken from the range: 2 - 500 mT were obtained. Based on the obtained dependences, the conditions for microwave reorientation of the magnetization vector in the structure layers were determined as a function of the dc magnetic field induction. It was found that microwave reorientation of the magnetization vector of the structure layers occurs only in the presence of two or more potential wells with similar energies in the layer. During magnetic reorientation, the spectrum of magnetic and elastic oscillations contains significant, high-amplitude low-frequency components of magnetic and elastic oscillations. The higher the first constant of magnetic anisotropy of the layer, the shorter the switching time of the magnetic state, but the greater the amplitude of the alternating magnetic field required to switch the magnetic state of the layer. The effect of microwave magnetic reorientation in the planar structures can be used to develop microwave electronic devices, such as data recording and storage devices, actuators and sensor devices.

This study was supported by grant No. 25-72-20063 from the Russian Science Foundation, https://rscf.ru/project/25-72-20063/

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SYNTHESIS AND MICROSTRUCTURE OF SURFACE-MODIFIED POLYANTIMONY ACID PARTICLES

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In this article, the authors show the possibility of modifying the surface of particles of an inorganic proton conductor (polyantimonic acid) with hydrated silicon dioxide, as a result of which sodium and hydrogen forms were obtained with the formation of structures of the “core-shell” type, where the core is nanodispersed particles of polyantimonic acid, isomorphic to the structural type of pyrochlore, and the shell is particles of amorphous silicon dioxide formed on the surface of polyantimonic acid particles. The X-ray diffraction studies carried out in combination with experimentally obtained elemental analysis data made it possible to identify the structural features of hydrated forms of surface modified polyantimonic acid particles and determine their gross compositions. The morphological peculiarities of the surface of synthesized nanodispersed particles were studied using high-resolution transmission electron microscopy methods together with energy-dispersive analysis data. It was established that as a result of surface modification of polyantimonic acid particles with hydrated silicon dioxide, a solid shell of hydrated silicon dioxide is formed without island-type formations. It was shown that the average size of the resulting nanoparticles changes slightly and varies in the range from 80 to 100 nm.

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LOW-FREQENCY MEASURMENTS OF HYSTERESIS LOOPS IN AMORPHOUS RIBBONS USING THE INDUCTION METHOD

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The modern development of power electronics, telecommunications, and wireless charging systems places increasingly stringent demands on component bases, among which soft magnetic materials and magnetic cores based on them have a key role. The range of applications of such materials is very wide — from small-sized chokes and sensors to powerful electric motors. One of the examples of such materials are amorphous magnetic ribbons, which possess gigantic magnetic impedance (GMI) values. It is critical to consider that the material's behaviour under real-world operating conditions significantly depends on the magnetization mode: characteristics can differ dramatically. Therefore, a comprehensive study of magnetic properties over a wide range of frequencies and waveforms is a necessary step in creating effective and reliable technical solutions.

Experimental studies of soft magnetic materials are based on measuring hysteresis loops [1], employing various techniques, including induction, pulse, vibration, and astatic methods.

In this work we consider the results of low-frequency measurements of hysteresis loops by induction method for three magnetic samples made of different materials with identical shapes and sizes. Amorphous ribbons with different magnetostriction signs (negative, near-zero, and positive) were used. Since the measured signal is small, a stroboscopic method was used to obtain the data. This method is based on measurements over thousands of successive field sweep periods, but the data acquisition points are shifted in time from period to period by a small fixed value, Δt. By mathematically processing and combining this data, taking into account phase shifts, it is possible to construct a detailed hysteresis loop containing more experimental points than the ADC speed allows.

Measurements were conducted at magnetization reversal frequencies from 5 to 30 Hz. With increasing frequency, a slight decrease in the apparent saturation magnetization was observed, together with an increase in coercivity and hysteresis-loop area for all studied materials. Since the loop area is proportional to the energy loss per magnetization cycle, its frequency dependence was compared with the change in coercivity [2].

These results provide a basis for further analysis of dynamic magnetic losses. In thin conductive magnetic materials, loop broadening can be attributed to classical eddy-current losses and excess losses associated with non-uniform domain-wall motion [3]. Therefore, at lower frequencies, the loop is expected to approach the quasistatic state. In addition, the magnetometer design allows tensile stress to be applied to the ribbons, making it possible to study the effect of induced magnetoelastic anisotropy on the loop shape and magnetic losses.

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AN EXPERIMENTAL SETUP FOR MAPPING THE MAGNETOCALORIC EFFECT ON A MICROSCALE BASED ON A COMBINATION OF CONTACT AND NON-CONTACT METHODS

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For measurements of the magnetocaloric effect (MCE) in structurally inhomogeneous materials (e.g., Heusler alloys), a combination of high-precision temperature measurement and spatial mapping of the effect is required. Conventional contact methods (thermocouples) provide high accuracy in measuring the adiabatic temperature change but are limited to point measurements and can introduce additional thermal loads due to their mass. Contactless methods based on IR thermography allow visualization of the temperature distribution across the sample surface; however, they have lower sensitivity and are subject to errors associated with reflection and optical aberrations [1-2].

In this work, a laboratory experimental setup has been developed and assembled that enables simultaneous implementation of both contact and contactless methods for measuring the MCE on the same sample. The magnetic field source (1) consists of NdFeB permanent magnets assembled in a Halbach configuration, producing a magnetic field of ~2 T in a working gap of 11 mm. The magnetic system is mounted on a movable platform (2) that travels along linear rails using a ball-screw drive and a stepper motor (3). The experimental insert (4) is a horizontal tube with an outer diameter of 10 mm, fixed on a support. The sample is fixed on a special ring-shaped board with contact pads. A differential copper-constantan microthermocouple (Type T) attached directly to the sample was used to measure the adiabatic temperature change (contact method). For better thermal contact, the ends of the thermocouple were joined using spot micro welding. To reduce induction effects, the thermocouple wires were twisted and bonded. A system consisting of a constantan wire heater and a PT100 resistance thermometer (5) was used to control and stabilize the sample temperature. An IR camera (6) is positioned at the opposite end of the tube. This design enables measurements under quasi-adiabatic conditions during cyclic insertion of the sample into and removal from the magnetic field without changing the distance between the sample and the camera.

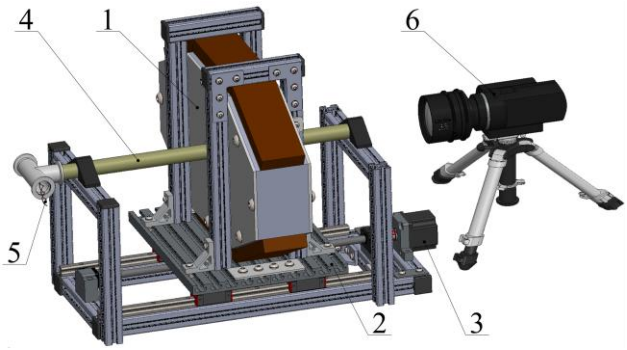

Fig. 1. Schematic of the experimental setup.

The experimental setup allows the study of the influence of microstructural inhomogeneities on the magnetocaloric effect at the local scale, which is not possible using only contact measurements. The technique has been tested on FeRh alloys in different forms: bulk, flakes, ribbons, and microparticles.

This work was supported by the Russian Science Foundation (project no. 24-19-00782, https://rscf.ru/en/project/24-19-00782/).

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MAGNETIZATION RELAXATION INDUCED BY THE CHANGE OF MAGNETOCRYSTOLLINE ANISOTROPY IN AMORPHOUS FECONISINBB RIBBONS

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In this study, soft magnetic FeCoNiSiB-based alloys were investigated. The master alloy was initially prepared by induction melting. Magnetization relaxation kinetics in amorphous FeCoNiSiNbB ribbons was studied by in-situ vibrating sample magnetometry during isothermal crystallization (450 – 660 °C). X-ray diffraction results revealed a nanocrystalline as-quenched structure; Differential Scanning Calorimetry (DSC) showed crystallization in the range of 440 – 500 °C (Fig. 1a). Time dependences of magnetization M were fitted by the Kolmogorov–Johnson–Mehl–Avrami equation. The dimensionality of crystalline phase growth, determined from the temperature-dependent Avrami exponent, transitions from three-dimensional at lower temperatures (< 450 °C) to predominantly two-dimensional at intermediate temperatures (450 – 550 °C), constrained by the ribbon geometry (Fig. 1b). A deviation from this trend above 550 °C signals the onset of hexagonal phase crystallization. The characteristic relaxation time τ shows a non-monotonic temperature dependence (500–575 °C). A phenomenological model represents $\tau(T)$ as a sum of three contributions: two Vogel–Fulcher–Tammann terms, describing relaxation associated with the growth of the cubic (τ_1) and hexagonal (τ_2) crystalline phases with their respective activation energies and crystallization temperatures, and a power-law scaling term $\tau_3 \sim (T_x - T)^{\beta}$ that explicitly accounts for the temperature-dependent evolution of the effective magnetocrystalline anisotropy constant measured experimentally. In this framework, each VFT contribution reflects the distinct kinetics of the corresponding crystallization stage, while the scaling term captures the rotation of magnetization vectors driven by the abrupt change in anisotropy near the onset of hexagonal phase formation at $T_x \approx 540$ °C. As a result, the model quantitatively reproduces the non-monotonic $\tau(T)$ behavior in the 500–575 °C range and demonstrates that the recrystallization of the cubic phase into the hexagonal phase, together with the accompanying change in the effective anisotropy constant, is the primary origin of this anomaly.

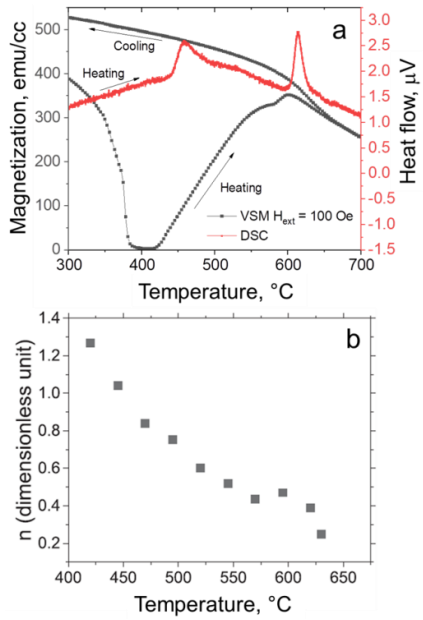

Fig. 1. Temperature dependence of magnetization measured during heating and cooling in a field of 100 Oe and DSC curve measured during heating (a) and temperature dependence of the Avrami index (b).

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Fe-BASED MICROWIRES AS A SENSITIVE MAGNETIC ELEMENT OF MULTIFERROIC POLYMER COMPOSITE

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With the rapid development of the electronics industry, electromagnetic interference (EMI) from industrial devices like relays and frequency converters increasingly disrupts equipment operation [1, 2]. These chaotic electric and magnetic fields generate stray background energy that can be harvested and converted into electrical signals. For this purpose, energy harvesters based on novel multiferroic composites—combining ferromagnetic wires and a flexible piezoelectric matrix—are highly promising due to their exceptional sensitivity to weak magnetic fields (up to 10 Oe) [3, 4]. This work focuses on understanding the fundamental properties of these materials and enhancing the interfacial coupling between magnetostrictive and piezoelectric phases to maximize the magnetoelectric (ME) effect for energy harvesting.

The composite utilizes $Fe_{77.5}B_{15}Si_{7.5}$ and $Fe_{74}B_{13}Si_{11}C_2$ ferromagnetic microwires in a glass shell (core diameter 10–25 μm) as the magnetic filler. Fabricated via the Taylor-Ulitovsky technique, their amorphization is controlled by the drawing speed, though the Fe-rich cores remain amorphous even at the lowest velocities. These microwires possess a positive magnetostriction coefficient, providing a rapid mechanical response to external field variations. Biocompatible polymers, such as polyvinylidene fluoride (PVDF), serve as the matrix, responding to the microdeformations of the filler. Both ordered and disordered wire distributions were fabricated. Comprehensive structural evaluations and FORC-diagram analyses revealed complex internal magnetic interactions. Notably, composites with a disordered configuration of microwires demonstrated the highest magnetoelectric coefficient. The proposed ME element can efficiently recycle background energy from heavy industrial operations, matching the performance of pure piezoelectric analogs while advancing the design of flexible energy harvesters.

This research was funded by the Russian Science Foundation, project No. 25-22-00929.

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THE FORC-ANALYSIS OF SYNTHETIC AND NATURAL IRON ORE

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Developing advanced magnetometric complexes for the mining industry requires precise magnetic reference samples. This study utilizes First-Order Reversal Curve (FORC) analysis [1, 2] to characterize magnetostatic interactions in natural iron ores and compare them to laboratory-synthesized analogs.

Synthetic samples comprised hydrothermally synthesized magnetite and hematite nanoparticles embedded in a non-magnetic CaCO3 matrix, with magnetic mass concentrations ranging from 10% to 30% [3,4]. FORC-distributions, derived from 200 experimental reversal curves per sample, revealed that 10% synthetic mixtures and natural ores feature a single main reversal peak. This signature indicates weakly interacting, magnetically soft single-domain particles. In contrast, increasing the magnetic fraction to 30% caused significant horizontal stretching along the interaction field axis (ΔHu reaching 400–500 Oe), reflecting strong interparticle magnetostatic interactions driven by agglomeration.

Crucially, the FORC-derived interaction field parameter (ΔHu) directly correlates with the materials' nonlinear inductive response. Samples with high interaction fields (ΔHu~300 Oe) generated strong scattering fields that suppressed the second and third harmonic amplitude in studied inductive sensors. By quantifying magnetostatic interaction distributions, FORC-analysis successfully validates these synthetic mixtures as accurate physical references for calibrating highly sensitive industrial magnetometers.

This research was funded by the Russian Science Foundation under Project no. 25-72-30009, https://rscf.ru/en/project/25-72-30009.

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EFFECT OF CHROMIUM ON THE MAGNETIC PROPERTIES OF $Fe_{73.5-x}Cr_xSi_{13.5}B_9Nb_3Cu_1$ RIBBONS

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New alloys based on the so-called FINEMET class of alloys were created by changing the composition to acquire excellent soft magnetic properties, which allow them to be widely used. The addition of Cr and the reduction of Fe content led to an increase in the crystallization temperature and an increase in the resistance to corrosion of the alloys [1]. In this work, the influence of Cr on the magnetic properties of $Fe_{73.5-x}Cr_xSi_{13.5}B_9Nb_3Cu_1$ ribbons obtained by rapid quenching from the melt is presented. Samples containing 1 at.%, 3 at.%, and 7 at.% Cr were studied. AFM data showed that the average surface roughness does not exceed 10 nm (Fig. 1a). Volume magnetic properties were measured using a VSM. The external magnetic field, H, was applied in three configurations: within the ribbon plane along the longitudinal and transverse directions (EA and PEA, respectively), and perpendicular to the ribbon plane.

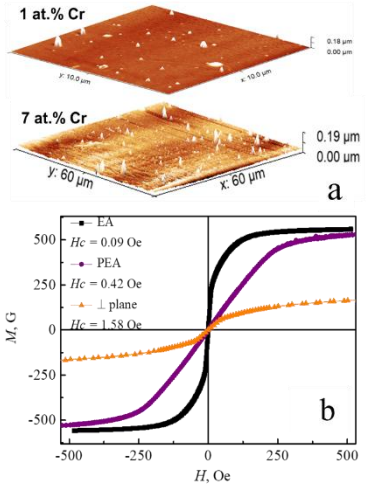

Fig. 1. AFM images (a) and hysteresis loops for the ribbon containing 1 at.% Cr measured under different field orientations (b).

Representative hysteresis loops obtained for the sample with 1 at.% Cr are shown in Fig. 1b. The samples exhibit nearly hysteresis-free loops and extremely low H_C, confirming their excellent soft magnetic properties. With increasing Cr content, an increase in the values of H_S and a decrease in the values of M_S were observed. This behavior can be attributed to the substitution of magnetic Fe atoms by nonmagnetic Cr atoms, as well as to possible changes in the volume fraction of the nanocrystalline phases. The dependence of H_C on Cr concentration was found to be nonmonotonic. The lowest H_C value was observed for the sample containing 3 at.% Cr, which may be associated with the formation of optimal conditions for minimizing the magnetoelastic anisotropy constant during the formation of Fe_3Si nanocrystallites. A further increase in the Cr content to 7 at.% resulted in a sharp increase in H_C, which may be related to a higher fraction of Fe_2B boride phases characterized by strong magnetic anisotropy. DSC data revealed two-stage crystallization with a monotonic increase in T_{x1} and non-monotonic changes in T_{x2}. The values of T_{x2} decreased sharply for the 7 at.% Cr sample — consistent with the increase in H_C observed for this composition.

Supported by the state budget № 120092490029-8.

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SYNTHESIS AND CHARACTERIZATION OF SUBSTITUTED BARIUM HEXAFERRITES $BAFE_{12-x}AL_xO_{19}$ AND $BAFE_{10-x}AL_2CO_xO_{19}$ WITH A MAGNETOPLUMBITE STRUCTURE

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M-type barium hexaferrite $BaFe_{12}O_{19}$ is a promising material for high-frequency electronics, magnetic recording, permanent magnets, sensors and electromagnetic-radiation absorbers because of its chemical stability, corrosion resistance, magnetic anisotropy and high electrical resistivity [1]. Cation substitution enables targeted control of its properties; however, combined Al^{3+}/Co^{2+} substitution remains insufficiently studied [3–4].

The aim was to synthesize $BaFe_{12-x}Al_xO_{19}$ (x = 0–2) and $BaFe_{10-x}Al_2Co_xO_{19}$ (x = 0–1) ferrites with a magnetoplumbite structure. Samples were prepared by the sol-gel method from barium, iron, aluminum and cobalt nitrates with citric acid. Phase composition, crystal structure, morphology, elemental distribution, Curie temperature and magnetic characteristics were studied by X-ray diffraction, SEM/EDX, DSC and magnetometry.

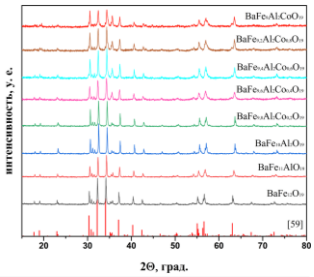

Figure 1. X-ray diffraction patterns

All compositions retained a single-phase barium-hexaferrite structure. Al^{3+} substitution contracted the lattice from a = 5.8908 Å and c = 23.2081 Å to a = 5.8377 Å and c = 23.005 Å; subsequent Co^{2+} incorporation increased the parameters to a = 5.8573 Å and c = 23.048 Å. The ceramics consisted mainly of hexagonal microcrystallites about 4 μm in size and aggregation-prone particles smaller than 100 nm.

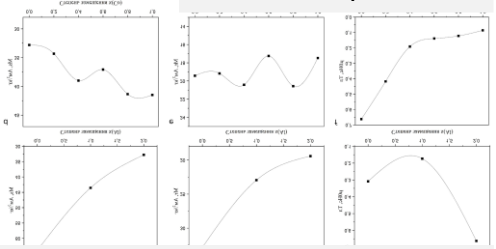

Figure 2. Saturation magnetization, remanent magnetization and coercive force for samples.

In $BaFe_{12-x}Al_xO_{19}$, the Curie temperature decreased from 442 to 333 °C, saturation magnetization from 63.896 to 32.813 A·m²/kg and remanence from 32.813 to 19.423 A·m²/kg; coercivity changed nonlinearly [4]. In $BaFe_{10-x}Al_2Co_xO_{19}$, Co^{2+} increased the Curie temperature from 333 to 346 °C, the saturation magnetization reached 41.5 A·m²/kg for $BaFe_9Al_2CoO_{19}$, and coercivity decreased from 0.4 to 0.1 T. Thus, Al and Co substitution permits targeted tuning of structural, thermal and magnetic parameters for high-frequency and magnetic-storage applications.

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MAGNETIZATION OF $BiFeO_3$ NANOPARTICLES IN PULSE MAGNETIC FIELDS UP TO 30 T: ROLE OF Zn SUBSTITUTION

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Bismuth ferrite $BiFeO_3$ with a perovskite structure, in which magnetic and ferroelectric ordering coexist at room temperature. It has high ferroelectric Curie temperature ($T_C \approx 1100$ K) and antiferromagnetic Néel temperature ($T_N \approx 640$ K) phase transition temperatures and remains one of the promising multiferroics. It is known that in the ground state, $BiFeO_3$ is a G-type antiferromagnet with the Dzyaloshinsky-Moriya interaction, in which the spins of Fe^{3+} ions are not just aligned antiparallel, and are formed into a spatially modulated spin structure (SMSS) with a period of ~62 nm. As a result, the total magnetic moment becomes close to zero. One of the ways to suppress SMSS is the application of high magnetic fields, nanostructuring (films, nanoparticles) and chemical substitution. In our work, we investigate the effect of the aliovalent substitution of Fe^{3+} by Zn^{2+} ions in $BiFeO_3$ multiferroic and pulsed magnetic fields on the magnetization of bismuth ferrite.

$BiFe_{1-x}Zn_xO_3$ (BFZO) samples (x = 0, 0.05, 0.1, 0.15 and 0.2) were prepared by solution combustion method (SCM), using a protocol described in [1]. To exclude the impurity phases, samples were post annealed in the temperature range 600-700 ^oC. The structure of the obtained samples was studied by X-ray diffraction (XRD) method. The morphology and grain sizes of samples were studied using scanning electron microscopy (SEM) and transmission electron microscopy (TEM) methods. Magnetization was measured in pulsed magnetic fields by induction method using special experiment setup (Laboratory of Advanced Magnetic Materials, Mikheev Institute of Metal Physics UB RAS) constructed for measurements in pulsed magnetic fields up to 36 T in the temperature range 4.2-320 K. $M(H)$ loops were measured in pulsed magnetic fields up to 30 T at fixed temperatures of 77 K and 300 K.

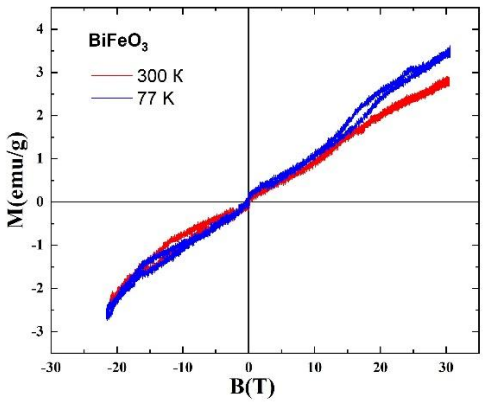

Fig. 1. $M(H)$ curves of $BiFeO_3$ nanoparticles at pulse magnetic fields at 77 K and 300 K.

Magnetization measurements revealed that, for $BiFeO_3$, a jump in magnetization is observed in the 15–20 T range. It is associated with a ferromagnetic contribution resulting from the breakdown of the SMSS, which is consistent with results theoretically predicted and experimentally confirmed in $BiFeO_3$ single crystal [2].

The work was carried out within the framework of state assignment *№ FMSW-2025-0043*

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EFFECT OF MAGNETIC VACANCIES ON THE MAGNETIC PROPERTIES OF $HOFE_{1-X}AL_XO_3$ SINGLE CRYSTALS

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Rare-earth orthoferrites are perovskite-like compounds with the general formula $RFeO_3$ (where R is a rare-earth ion), belonging to space group No. 62. In these compounds, several magnetic sublattices coexist. One of them is formed by Fe^{3+} ions, which order antiferromagnetically at Néel temperatures $T_N > 600$ K. The second sublattice consists of R-ions, which order only at $T < 10$ K. Due to the complex magnetic interaction between the subsystems of the aforementioned 3d and 4f elements, orthoferrites exhibit many unique properties, such as: spontaneous spin-orientation transition [1], ultrafast laser-induced magnetization reversal [2], anisotropic evolution of magnetic entropy [3], formation of soliton lattices [4], and quasi-onedimensional structures [5].

A promising direction in orthoferrite research involves introducing substitutions into the Fe^{3+} and/or R-ion sublattices. For example, in work [6], using $HoFe_{1-x}Mn_xO_3$ as an example, our group successfully demonstrated a shift of the spin-orientation transition to room temperature, as well as a change in the transition type: from $\Gamma_2 \leftrightarrow \Gamma_4$ to $\Gamma_1 \leftrightarrow \Gamma_4$. The introduction of Mn^{3+} ions, which possess their own magnetic anisotropy, led to a modification of the original system of magnetic interactions, resulting in the observed effects.

One effective approach to modifying the magnetic properties of orthoferrites is the substitution of Fe^{3+} ions with nonmagnetic aluminum, which leads to the appearance of controlled magnetic vacancies. As shown in works [7], the introduction of Al in concentrations up to 10% makes it possible to explain the behavior of the magnetic system within the framework of the theoretical approach developed by the authors. In our work, single-crystal samples of $HoFe_{1x}Al_xO_3$ (x = 0.05, 0.1, and 0.2) were obtained by the optical floating zone method, and their temperature and field dependences of magnetization were measured.

The study was supported by a grant from the Russian Science Foundation No. 26-22-20006 (https://rscf.ru/project/26-22-20006/)

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SUBSTITUTION EFFECT OF MAGNETIC MAX PHASE $(CR_{1-X}MN_X)_2GE_{1-N}SI_NC$

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MAX phases form a family of layered ternary compounds with the formal stoichiometry $M_{n+1}AX_n$ (n = 1, 2, 3...), where M is a transition metal, A is a p-element (Si, Ge, Al, S, Sn, etc.) and X is carbon or nitrogen. MAX phases exhibit the unique physical properties typical of both metals and ceramics [1]. Like ceramics, they have low density, high strength, good corrosion, and high-temperature oxidation resistance; like metals, they are high electrical/thermal conductivities, relatively soft, appreciable machinability, thermal shock resistance, and good damage and radiation tolerance. They are highly promising candidates for various applications, such as structural materials, corrosion protection, and nuclear fuel cladding coating materials. Currently, there is a great interest in the study of magnetic MAX phases. The few magnetic MAX compounds that have been synthesized so far exhibit outstanding properties that are attractive for both fundamental research and advanced applications [2].

In this study we examined the impact of substituting chromium (Cr) ions with manganese (Mn) in M site and germanium (Ge) ions with silicium in A site on the electronic and magnetic properties of the MAX phase $(Cr_{1-x}Mn_x)_2Ge_{1-n}Si_nC$. An analysis was conducted of the atomic structure, magnetic and electronic properties of Mn_2GeC, Cr_2GeC and $(Cr_{1-x}Mn_x)_2GeC$ and Cr_2GeC, Cr_2SiC and $Cr_2(Ge_{1-n}Si_n)C$. A comparison was then made of the electronic and magnetic properties of the obtained compounds. The calculations were performed in the framework of density functional theory (DFT) using the B3LYP functional and the pob-DZVP-rev2 basis in the CRYSTAL 17 program [3].

The research was supported by the grant of the Russian Science Foundation № 25-12-20012, https://rscf.ru/project/25-12-20012/, grant of the Krasnoyarsk Regional Science Foundation.

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LOCAL CHARGE AND MAGNETIC ENVIRONMENT OF ^{11}B NUCLEI IN $Co_3B_2O_6$

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Oxyborate compounds are characterized by a large crystallochemical diversity, which is due to the tendency of the electronic shell of boron to exhibit a dual hybridization (sp^2 and sp^3). The diversity of structures naturally leads to a variety of magnetic properties in oxyborates based on iron group metals [1]. The system with the structure of kotoite $Co_3B_2O_6$ has a significant magnetization and magnetic anisotropy with an antiferromagnetic transition at a temperature of T_N = 34 K [1]. The boron ions (B^{3+}) participate in the formation of the structural planar BO_3 triangles and play an important role in the exchange interactions between the magnetic Co^{2+} ions. The magnetic anisotropy of the system studied in this work made it possible to obtain powder samples oriented by an external magnetic field in a volume sufficient for NMR research. Fig. 1(a,b) shows the NMR ^{11}B spectra of a polycrystalline and structured sample and their fitting by a theoretical curve. The spectrum structure in Fig. 1b corresponds to the spectrum of a single crystal, indicating that the powder crystallites are oriented along a single crystallographic direction that coincides with the direction of the external magnetic field (H_0 = 9.28 T). The study of structured samples allowed us to determine both the parameters of the EFG tensor (ν_Q = 1.34 MHz, η = 0.00) and the direction of its principal axes relative to the crystal axes. The principal axis of the EFG tensor at the positions of the boron nuclei is directed along the normal to the BO_3 planar triangle and is predominantly determined by the lattice contribution. Fig. 1c shows the ^{11}B NMR spectra obtained on an oriented sample in a wide temperature range (292 – 20 K) corresponding to the paramagnetic and ordered states of the $Co_3B_2O_6$ system. From the spectra, it can be seen that the position of the central transition line remains nearly unchanged and close to the value of the shift ^{11}K = 0 throughout the entire temperature range of the paramagnetic state. This behavior of the spectrum is not typical for magnets [2] and indicates that the local magnetic field at the positions of the boron nuclei is very weak. At a temperature of T = 20 K, the spectrum experiences significant broadening due to the antiferromagnetic order that forms in the sample.

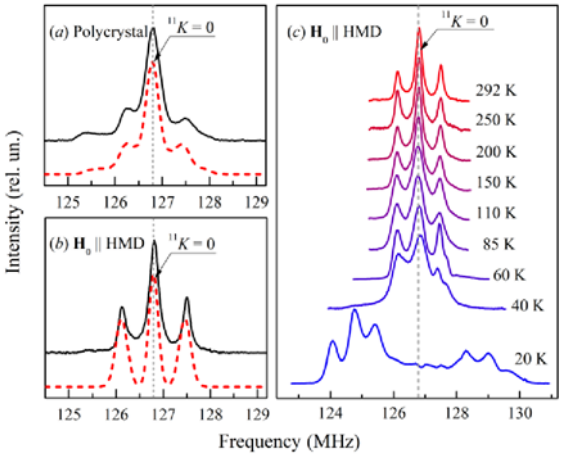

Fig. 1. NMR ^{11}B spectra in polycrystalline (a) and structured (b,c) Co_3BO_6 samples obtained at different temperatures, the dotted curve is the result of spectrum fitting. ^{11}K – shift relative to the field H_0 = 9.28 T.

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MAGNETIC PROPERTIES AND MICROSTRUCTURE OF SM(FE,TI,V)$_{12}$-BASED BULK MAGNETS WITH SM-GA BINDER

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Due to the tendency to reduce CO_2 emissions into the atmosphere, it has become necessary to develop highly efficient electric motors and converters of mechanical energy into electromagnetic energy. These electric motors use Nd-Fe-B permanent magnets with high magnetic hysteresis characteristics. The most effective permanent magnets contain rare earth metals (REM), including Dy and Tb. Due to the high cost of REM, it is economically advantageous to produce permanent magnets using a minimum of REM.

One of the candidates for the manufacture of highly efficient permanent magnets with minimal REM content is the compound $Sm(Fe,Co)_{12}$ with $ThMn_{12}$ type structure. This compound contains 29% less REM than $Nd_2Fe_{14}B$ and has greater temperature stability of saturation magnetization and coercivity [1]. The combination of a high intrinsic hard magnetic properties of the $Sm(Fe,Co)_{12}$ phase and increased temperature stability of magnetic hysteresis properties make sintered magnets based on this phase potential rivals to sintered Nd-Fe-B magnets.

In previous work [2], we showed that the $Sm_{80}Ga_{20}$ alloy can be successfully used for the synthesis of an isotropic permanent magnet with a coercivity H_c = 8 kOe. The present work is devoted to the determination of the effect of the $Sm_{80}Ga_{20}$ binder content in sintered $Sm_{7,7}Fe_{76,9}Ti_{6,9}V_{8,5}$ alloys on their magnetic properties. A powder mixture of rapidly quenched alloy (RQA) $Sm_{7,7}Fe_{76,9}Ti_{6,9}V_{8,5}$ and a binder $Sm_{80}Ga_{20}$ was used to obtain sintered magnets. The content of the binder varied from 5 to 25 wt. %. Liquid-phase sintering was carried out under vacuum conditions at temperatures of 973-1173 K.

The reversible magnetic susceptibility of RQA in the absence of a magnetic field after its application $\chi_r(H)$ in the reverse fields demonstrates a sharp minimum (Fig.1), which is directly related to the features of the microstructure. It has been established that in sintered by liquid-phase sintering with 25 wt. % binder the most likely scenario of the remagnetization process is nucleation of reversed domains.

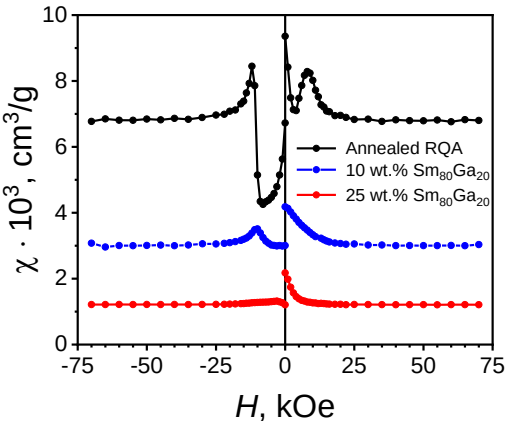

Fig. 1. Reversible magnetic susceptibilities $\chi_r(H)$ of $Sm_{7,7}Fe_{76,9}Ti_{6,9}V_{8,5}$ annealed RQA and sintered magnets with $Sm_{80}Ga_{20}$ binder

The report will contain the synthesis method, magnetic hysteresis properties in the temperature range of 2-400 K, reversible magnetic susceptibility under the application of a magnetic field and in its absence, the microstructure and phase composition of the obtained samples.

Authors gratefully acknowledges research funding from the Ministry of Science and Higher Education of the Russian Federation (Ural Federal University project within the Priority 2030 Program).

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MAGNETIC PROPERTIES OF THE DILUTED MANGANITES SYSTEM $LA_{1-C}SR_CMN_{1-Y}ZN_YO_3$ ($C + Y$= 0.15 AND 0.17 WITH CONCENTRATION Y = 0.025, 0.05, 0.1, AND 0.125)

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Hole doped lanthanum manganites of the composition $La_{1-c}Sr_cMn_{1-y}Zn_yO_3$ ($c + y$ = 0.15 and 0.17 with Zn concentrations y = 0.025, 0.05, 0.1, and 0.125) have been investigated by means of x-ray diffraction, magnetic susceptibility, magnetization, and ESR measurements. X-ray diffraction analysis showed that the compounds with a concentration of $y < 0.1$ belong to the space group

$R\bar{3}c$, while compounds with a concentration of $y \geq 0.1$ have got an orthorhombic structure with the space group *Pbnm*. The magnetic investigations indicate that $La_{1-c}Sr_cMn_{1-y}Zn_yO_3$ compounds with concentration $y < 0.1$ undergo a ferromagnetic phase transition (T_c) and the compound with concentration y = 0.125 exhibits cluster spin-glass behavior, while the compound with y = 0.1 shows superparamagnetic behavior. The ordering temperature T_c decreases with increasing y. The shape of the ESR spectra on passing into the ordered regime in samples with $y < 0.1$ clearly differs from those on approaching the spin-glass phase with y = 0.125.

TEMPERATURE AND LOAD ANNEALING DEPENDENCE OF MAGNETIC AND TRANSPORT PROPERTIES OF $FE_{68.5}CR_5SI_{13.5}B_9NB_3CU_1$ NANOCRYSTALLINE RIBBONS

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In this work, the magnetic and transport properties of rapidly quenched $Fe_{68.5}Cr_5Si_{13.5}B_9Nb_3Cu_1$ ribbons were studied. Samples were annealed at $T = 520$°C for 2 h without load (FM-AN) and under the load of 150 MPa (FM-SA). Ribbons of different width, c, 0.88 mm (FM1, FM4) and 0.60 mm (FM2, FM3) were produced in each series. XRD data confirmed their nanocrystalline structure with a grain size of 15 nm after annealing. AFM data showed that for the samples FM-AN the average surface roughness, R_a, is about 20 nm, and for FM-SA - $R_a \approx 10$ nm. The volume magnetic characteristics measured by the VSM in the temperature range of 90–420 K indicate that M_S decreases with T due to the thermal disorientation of spin moments for all samples. Stress annealing induces transverse magnetic anisotropy, leading to more inclined hysteresis loops and an increase in coercivity H_C (Fig. 1a). The exchange-coupled state destruction temperature, T_{ex}, for ribbons with $c = 0.60$ mm decreases, indicating a decrease of the ferromagnetic coupling strength between α-Fe-Si grains due to the phase transition of the interfacial component. The dM/dT dependence obtained from curves measured in ZFC mode allowed to determine the $T_C = 360$ K of the amorphous matrix for the FM3 sample (Fig. 1b), being close to its T_{ex}. Wide domains with 180º domain walls were MOKE-observed for FM-AN samples. The competition between shape and induced anisotropy leads to a zigzag domain structure (DS) in FM-SA samples. Transport studies revealed a significant contribution of the anomalous Hall effect (AHE) to the angular dependence of the Hall signal (Fig. 1c), which is significantly different from standard cosine-shape due to the pronounced magnetization anisotropy of studied ribbons. Ribbons with $c = 0.60$ mm demonstrate higher amplitude of the AHE correlated with higher resistivity values due to an increase of scattering rates of charge carriers. In addition, while all samples exhibit negative magnetoresistance (MR) in transverse magnetic fields, only load-annealed samples (FM3, FM4) demonstrate negative MR in low planar magnetic fields (Fig. 1d). These results suggest that the annealing conditions do not alter the fundamental transport parameters, they determine the specific character of the MR response.

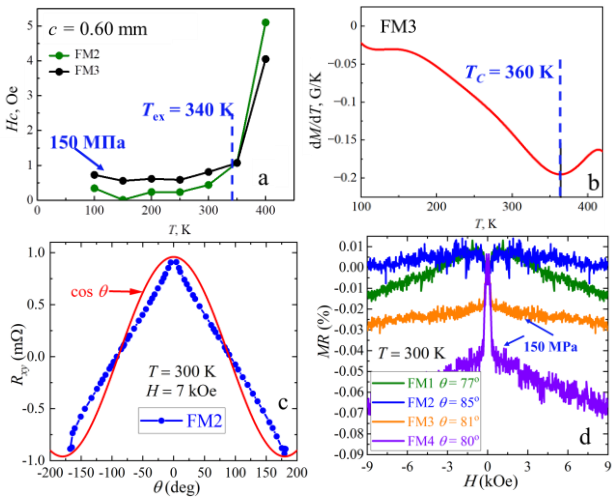

Fig. 1. Temperature dependence of H_C (a); dM/dT (b); angular dependence of the Hall signal (c) and magnetoresistance curves (d).

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FEATURES OF THE IMPACT OF RADIATION ON $BaFe_{12}O_{19}$

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Barium hexaferrites possess high coercivity and chemical stability, making them leading materials in the fields of high-frequency electronics. With the rapid development of nuclear energy, accelerator technology, and space exploration, studying the radiation resistance of materials is a pressing issue. Some of the components of radiation sources are photons and electrons, which cause point defect formation and contribute to changes in magnetic properties.

Electron irradiation of the samples was performed using an accelerator with an energy of 5 *MeV*. The effects of gamma irradiation were studied using a ^{60}Co source at a dose rate of 84 *rad/s*. The time (dose) for both types of irradiations was selected based on the doubling principle, and intermediate values were also measured. The samples are plates, obtained by solid-phase synthesis.

The sample structure was confirmed using X-ray diffraction analysis and Mössbauer spectroscopy. The sample structure remains unchanged over time, indicating its radiation resistance. However, localized mechanical defects alter the magnetic properties of $BaFe_{12}O_{19}$.

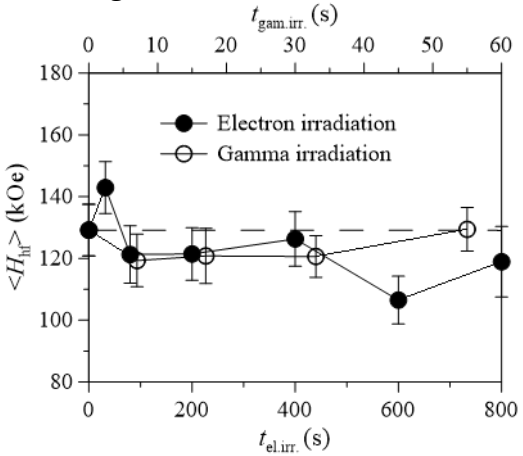

Fig. 4. correlation of the hyperfine field $\langle H_{hf} \rangle$ with increasing irradiation time.

Based on the Néel model, the average hyperfine magnetic field $\langle H_{hf} \rangle$ taking into account its orientation: with spin up in three lattice positions (12*k*, 2*a*, 2*b*) and spin down in two positions ($4f_{IV}$ and $4f_{VI}$), proportional to the total magnetic moment of Fe^{3+} atoms, was calculated. No clearly defined systematic change in $\langle H_{hf} \rangle$ was observed with increasing irradiation time (Fig. 1). Rather, along with local disturbances in the crystal structure, the data obtained indicate the radiation resistance of barium ferrite.

The data of saturation magnetization M_s and coercive force H_c were determined from the hysteresis loops obtained on VSM in the 140 *kOe* field to ensure complete saturation of the sample. The observed features in the behavior of magnetic characteristics, as well as of X-ray and Mössbauer data, depending on the dose of gamma and electron irradiation are discussed.

This work was supported by the Basis Foundation (grant # 24-2-2-15-1).

MAGNETOCALORIC EFFECT IN RCo_5 AND R_3Al_2 COMPOUNDS (R = Gd, Tb, Dy, Ho): COMPARATIVE ASSESSMENT AND AREAS OF EFFECTIVE OPERATION

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This work presents a comparative assessment of the magnetocaloric effect (MCE) in RCo_5 and R_3Al_2 compounds, where R = Gd, Tb, Dy, Ho, in order to determine the areas of their effective operation in cryogenic magnetic cooling systems, in particular for natural gas liquefaction.

The alloys were synthesized by arc melting. The phase composition and structure of the samples were characterized using X-ray diffraction analysis (Bruker D8 Advance), scanning electron microscopy and energy-dispersive spectrometry (JEOL JSM-6510LA). Magnetic properties were measured by vibration magnetometry in fields up to 3 T (Versa Lab Quantum Design). The magnetic entropy change ΔS_m was calculated using the Maxwell relation.

It was found that both types of compounds exhibit MCE, but the nature of its manifestation differs significantly. For RCo_5-type compounds, the MCE values are small, ranging from 0.1 to 0.5 J/(kg·K), but the effect is observed over a wide temperature range. In contrast, for R_3Al_2 -type compounds, the temperature intervals in which MCE occurs are rather narrow, but the MCE values are high — from 3 to 5 J/(kg·K). The highest absolute ΔS_m values were recorded for compounds with heavy rare-earth elements (Tb, Dy, Ho) in both groups, which is due to their high magnetic anisotropy and large magnetic moment [1-2].

Thus, RCo_5 and R_3Al_2 compounds (R = Gd, Tb, Dy, Ho) are promising candidate materials for working bodies of cascade magnetic natural gas coolers. The results of this work can be used in the development of environmentally friendly cryogenic devices as alternatives to traditional compressor-based analogs.

This work was carried out within the framework of State Assignments (topic FEGG-2025-0012).

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MAGNETIZATION AND REMAGNETIZATION BEHAVIOR OF Nd-Fe-B MAGNETS AT DISTINCT TEMPERATURES ABOVE 150 K

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Coercivity is one of the key properties that defines the application area of permanent magnets. To achieve a high coercive state without remanence reduction, an understanding of remagnetization processes is necessary. Investigation of these processes in the entire volume is possible only with magnetometry methods.

In this work, we examine the features of magnetization and remagnetization processes in a sintered magnet of composition $Nd_{17}Fe_{76}B_6$ (at.%).

The measurements were performed using PPMS DynaCool T9 with VSM module, SQUID-magnetometer MPMS XL7, and a vibrating sample magnetometer KVANS-1. Investigation of magnetization processes was carried out from the thermally demagnetized state.

The analysis of magnetization and remagnetization was conducted using Kelly's plots, differential susceptibility, ac susceptibility, minor hysteresis loops, and the angular dependence of coercivity.

It is shown that magnetization processes in microcrystalline magnets are independent of temperature. Cascading irreversible magnetization has magnetostatic nature and occurs when the external field is higher than the sample's own demagnetizing field. The latter is weakly dependent on temperature.

Free movement of domain walls in microcrystalline grains with an initial multidomain state leads to anomalous local minima on the minor hysteresis loops, which is related to formation of magnetization channels [1]. The grains in these channels are in single domain state and don't reverse magnetization until the external field amplitude exceeds their coercivity.

As opposed to magnetization processes, remagntetization processes are strongly depend of temperature. At room temperature, the contribution from reversible and irreversible processes are comparable. The high value of ac-susceptibility in the coercivity region indicates the formation of a multidomain state. Decreasing temperature leads to a reduction in the contribution of irreversible processes. At 150 K, the contribution of ac-susceptibility to the total susceptibility becomes minimal. The latter can be interpreted as domain walls localization between highly anisotropic single-domain grains. In this case, remagnetization of individual grains or grain conglomerates occurs via a jump without the formation of a multi domain state. This leads to a change in the angular dependence of coercivity between 300 and 150 K. In general, this change is associated with a change in the remagnetization mechanism [2].

The authors gratefully acknowledges research funding from the Ministry of Science and Higher Education of the Russian Federation (Ural Federal University project within the Priority 2030 Program).

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CHAOTIC BEHAVIOR OF THE MAGNETIZATION VECTOR DURING REORIENTATION IN THIN YIG FILMS

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Despite the dominance of solid-state drive technology in the data storage and recording device market, scientific research into magnetic recording continues vigorously. Current research aims to develop future storage devices that combine the energy efficiency and high switching speeds of magnetic technologies with reduced domain sizes, all while ensuring long-term data retention without external power. In this study, we investigate the magnetic dynamics of thin yttrium iron garnet (YIG) films under magnetic excitation. YIG is characterized by intrinsically weak magnetocrystalline anisotropy fields; consequently, even under excitation by a weak alternating magnetic field with an amplitude on the order of a few millitesla, complex and chaotic magnetic dynamics of the film magnetization vector are observed.

Through numerical simulations, we have determined the threshold amplitudes required for magnetization reorientation in YIG films drived by an in-plane circularly polarized magnetic field. When a static bias field of 100 mT is applied perpendicular to the film plane, the reorientation threshold is found to be on the order of a few millitesla. The bifurcation diagrams and reorientation graphs were obtained, reflecting the final equilibrium orientation of the magnetization vector after the alternating field was switched off. Furthermore, the dependence of the largest Lyapunov exponent (Fig. 1) was calculated as a quantitative measure of chaotic behavior in magnetization dynamics. These results reveal that chaotic dynamics predominantly emerge immediately above the reorientation threshold. As the amplitude of the driving field increases to values an order of magnitude or more above threshold, the system gradually transitions toward regular, non-chaotic behavior, indicating a suppression of dynamical complexity at higher excitation levels.

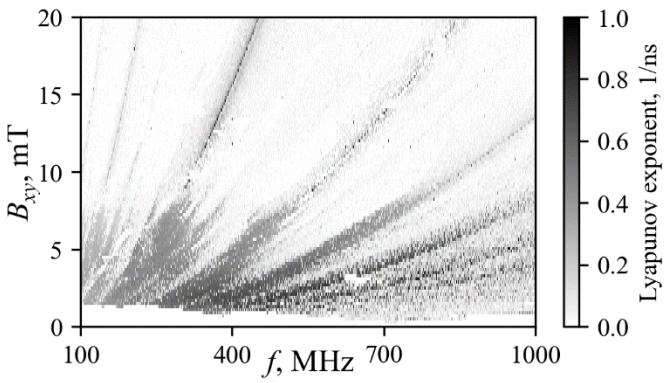

Fig. 1. Dependences of the Lyapunov exponents.

The analysis provided in this work is applicable to the ongoing development of spintronic and magnonic devices, including magnetic memory, logic elements, and field sensors.

This work has been supported by Russian Science Foundation, project No. 25-72-20063. https://rscf.ru/project/25-72-20063/

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ELECTRON SPIN RESONANCE ANISOTROPY IN SAMARIUM HEXABORIDE

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Samarium hexaboride (SmB_6) is known to be a strongly correlated topological isolator with the surface chiral states, which are protected by non-trivial electron spectrum topology (at Γ/X and K/M points of Brillouin zone) for (100), (110) and (111) planes [1,2] or by lattice symmetry (at Y-point of BZ) for (110) plane [2]. While the related surface conductivity strongly depends on the sample surface preparation [3], the fine structure and parameters of electron spin resonance (ESR) lines have been found to be almost identical for the surfaces subjected to mechanical polishing (MP) and/or chemical etching (CE) [4]. Note that ESR signal appearance at temperatures $T < 5.6$ K [4] correlates with the onset of the conductivity mode determined by surface charge carriers [3]. In this respect there is still an open question on the nature of interaction of ESR-active magnetic moments with surface chiral electron states.

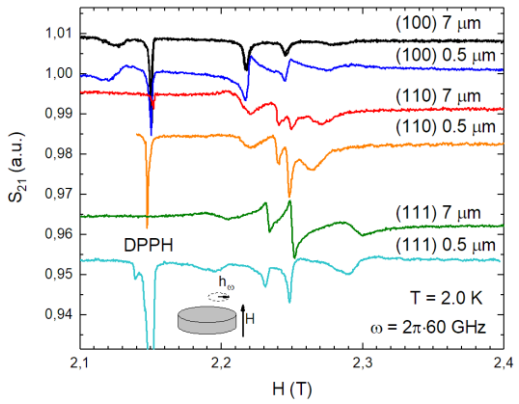

Fig. 1. SmB_6 60 GHz ESR lines measured at 2 K for three different surface orientations (100), (110), (111). Surfaces are investigated after coarsest (7 μm) and finest (0.5 μm) polishing. Lines are shifted for clarity.

In the present work we show results of experimental study of ESR in SmB_6. Measurements were performed with the help of the authentic ESR spectrometer (GPI RAS) [5] at 60 GHz microwave frequency in magnetic fields up to 7 T at temperatures $1.8<T<15$ K. The cylindrical cavity geometry with sample mounted as a part of cavity wall was used [5]. Three samples of SmB_6 with main planes (100), (110) and (111) sliced from one single crystal were sequentially polished by diamond powders (from 7 to 0.5 μm grains size, 1700-15000 grit), etched in nitric acid (CE) and chemical-mechanically polished (CMP).

We discovered strong dependency of ESR lines position and shape on the surface orientation along the applied magnetic field (Fig.1). We note that *g*-factors of all four lines stay constant for (100) plane, but depend slightly on the surface conditions for other (110) and (111) planes. The distinct asymmetry of the ESR lines found for (100) and (111) planes (Fig.1) points to the essential out-of-phase ESR absorption, which has to be allowed for the estimations of surface chiral states contribution to the ESR response of this extraordinary compound.

The study was supported by a grant from the Russian Science Foundation No. 25-72-20032 (https://rscf.ru/en/project/25-72-20032/).

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EFFECT OF ION IRRADIATION ON THE TOPOGRAPHY AND MAGNETIC PROPERTIES OF COBALT AND NICKEL NANOWIRES

Perov N.S.[1], *Zagorskiy D.L.*[2], *Gushchina N.V.*[3], *Sopetik A.V.*[1,2], *Shalomov K.V.*[3], *Artemov V.V.*[2]

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Nanowires (NWs) are a promising one-dimensional (1D) material, akin to threads with a diameter of 100 nm or less. A common method for their production is matrix synthesis using track-etched membranes as a template. This method enables the production of arrays of a huge number of identical NWs, located in a matrix and/or on a common base and oriented in approximately the same direction. Such objects can exhibit quantum-size effects, which, combined with high shape anisotropy and interactions between adjacent NWs in the array, enable targeted modification of certain material properties.

In this work nanowires arrays made of magnetic materials-cobalt (of two types, cubic and hexagonal) and nickel- were studied. These samples were obtained by electrodeposition of corresponding metal into the pores of a polymer track-etched membrane (fabricated in JINR, Dubna, Russia: with pore diameter 100 nm and surface density $1{,}2 \cdot 10^9$). The effect of irradiation by accelerated ions was investigated: it is interesting due to the possibility of estimation radiation stability and to modify some of the material`s properties. Arrays of these NWs were irradiated with the Ar+ ion flux, with energies ranging from 15 to 40 keV and a dose stepwise varying from 10^{11} to 10^{18} ions/cm^2.

The comparison of irradiated NWs with the virgin ones was conducted. A topography study (SEM) shoved that irradiation has small effect on Ni NWs: only the exposure by high-energy ions (40 keV) at a sufficiently high dose (10^{16}) leads to a slight sharpening of the NWs tips. Co NWs, however, undergo more pronounced changes, and this occurs even after the irradiation with low-energy ions (15 keV) and at significantly lower doses (10^{13}). The shape of the NW tips greatly changed, acquiring a faceting close to hexagonal. It can be assumed that this process involves radiation-stimulated recrystallization of the NWs.

Magnetic properties measurements (VSM) revealed a non-monotonic dependence. For cobalt nanoparticles, saturation magnetization (SM) reached its maximum at doses of 10^{13}, followed by a decrease. A similar dependence was observed for Ni samples, but maximum was at higher energies and at lower doses. Coercivity (CF) for hexagonal Co samples also exhibited a non-linear dependence, with a maximum being reached at the dose 10^{13}. No clear dependence on CF was observed for the other samples. The increase and subsequent decrease of CF during irradiation can be explained by the accumulation of radiation defects at the first stage and their subsequent annihilation at the last stages. For explanation of the dose dependence of SM further experiments are required.

Acknowledgments The fabrication of NWs was supported by Statetask of NRC "Kurchatov Institute", irradiation of the samples was supported by Statetask of Institute of Electrophysics.

SATURATION MAGNETIZATION OF THE CONCENTRATION TRIANGLE $NIFE_2O_4$–$ZNFE_2O_4$–$COFE_2O_4$

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One of the first commercially successful materials was ferrites based on the $NiFe_2O_4$–$ZnFe_2O_4$ solid solution. Varying the ratio of magnetic (Ni^{2+}) and diamagnetic (Zn^{2+}) cations allows the Curie temperature and initial magnetic permeability to be tuned. Further doping with Co^{2+} cations significantly modifies the magnetocrystalline anisotropy, coercivity, frequency characteristics, and temperature stability of properties. The introduction of cobalt oxide also increases the electrical resistivity, thereby reducing high-frequency losses. There are articles that research Nickel-Zinc-Cobalt ferrites (NZCF), however it is difficult to unite existing data because of different methods of synthesis, synthesis conditions. This work aims to present saturation magnetization data of NZCF samples with unified synthesis and experiment conditions in entire concentration range. Samples with formula $Ni_xZn_yCo_{(1-x-y)}Fe_2O_4$ (step $\Delta x = \Delta y = 0.1$) were obtained by solid state reaction at 1150°C for 5h.

The concentration dependences of saturation magnetization on the elemental composition of NZCF presented on fig. 1.

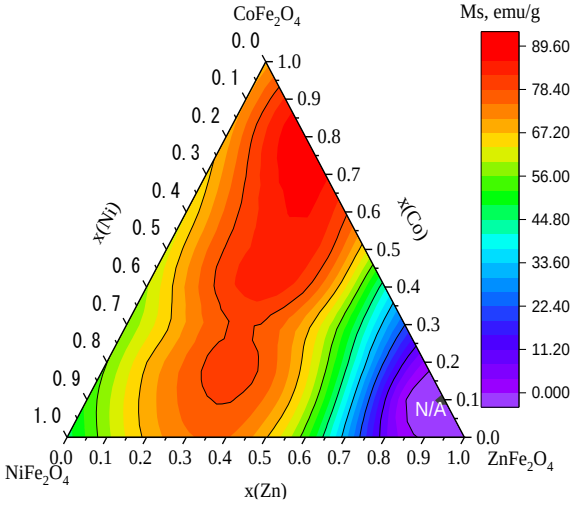

Fig. 1. Saturation magnetization as a function of composition for the NZCF.

Analysis of obtained data suggests non-linear saturation magnetization change depending on concentration. It is worth noting that maximum of saturation magnetization can be obtained only for Co-Zn and Ni-Zn-Co, where Ni is lowering required Co concentration.

It can be assumed that the distribution of magnetic cobalt and iron cations on the A and B sublattices at x(Co) < 0.4 leads to an enhancement of the dominant intersublattice A–B superexchange interaction. For x(Co) > 0.4, the A–B interaction weakens, while the intra-sublattice B–B superexchange interactions are strengthened, which leads to a random spin orientation on the B sublattice relative to the direction of the A sublattice spins. Thus, randomly oriented spins lead to a decrease in the experimental magnetic moments with increasing Co concentration for x > 0.4.

Cation distribution of the corresponding elements is presented in the following form: $(Zn^{2+}_{0.7-x}Co^{2+}_{x-y}Fe^{3+}_{0.3+y})[Ni^{2+}_{0.3}Co^{2+}_{y}Fe^{3+}_{1.7-y}]O_4$. (round brackets – A sublattice, square brackets – B sublattice), i.e. zinc cations preferentially occupy the A sublattice, while nickel cations – the B sublattice, cobalt and iron cations are uniformly distributed in both positions. It was proven that Co^{2+} ions doesn't occupy only B sublattice, but migrate to the A-sublattice at the expense of Fe^{3+} ions.

QUANTIFYING THE ROLE OF EXTERNAL HYSTERESIS IN THE KINETIC OF THE FIRST-ORDER METAMAGNETIC PHASE TRANSITIONS IN LA(FE,SI)13

Makarin R.A.[1,2], *Karpenkov D.Yu.*[1,3], *Karpenkov A.Yu.*[3], *Zheleznyi M.V.*[1,3]

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The thermal and field hysteresis accompanying magnetocaloric materials exhibiting first-order magnetostructural phase transitions (FOMPT) constitutes not merely a materials-science challenge, but a fundamental obstacle to the rigorous theoretical description of the magnetic phase transition. Hysteresis broadening in real systems arises from a combination of contributions, conventionally partitioned into intrinsic and extrinsic categories [1].

Intrinsic contributions are associated with crystallographic defects, lattice-site vacancies, and compositional inhomogeneity of the dopant distribution. Extrinsic broadening, by contrast, originates from factors that evolve dynamically during the transition itself: spatially non-uniform demagnetization fields and the thermal load imposed on the specimen by the magnetocaloric self-heating effect [2].

This work quantifies the contribution of sample self-heating to the field hysteresis observed during cyclic magnetization--demagnetization. The analysis spans a broad range of thermal regimes: isothermal, quasi-isothermal, adiabatic, and quasi-adiabatic, the latter emulating heat-removal conditions characteristic of real multistimulus refrigerators.

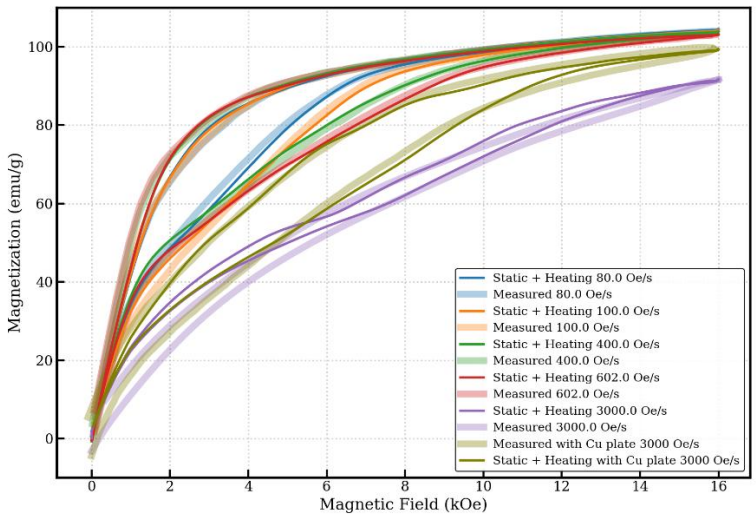

Figure 1. M(H) reconstructed from surface M(H,T, dH/dt = 20 Oe/s) and specimen self-heating

Using $LaFe_{11.6}Si_{1.4}$ as a model system, this study shows that an accurate kinetic description of the field-induced first-order transition, for sweep rates between 50 and 3000 Oe/s, must explicitly account for the magnetocaloric temperature change of the sample (Fig. 1). Neglecting this term leaves the observed kinetics unreproducible. The hysteresis loop area varies non-monotonically with sweep rate. This finite-rate hysteresis enhancement traces back to heat exchange between the refrigerant and its surroundings - the cryostat chamber, or the heat-transfer fluid in real prototypes.

This work was supported by RSF grant 25–22–00371. Makarin R.A. thanks the BASIS Foundation for scholarship support.

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POSTER SESSION

Magnetic Nanostructures and Low Dimensional Magnetism II

Wednesday, 19 August, 17:00 - 19:00

EFFECT OF HYDROGEN ABSORPTION ON THE MAGNETIC PROPERTIES OF RE/TM HETEROSTRUCTURES

Makarova M.V.[1,2], *Devyaterikov D.I.*[1], *Ghezlyaev G.E.*[1], *Matyukhov V.V.*[1,2], *Salamatov Yu.A.*[1], *Kravtsov E.A.*[1,2]

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The study of magnetic nanostructures, which allow nonmagnetic field control of their magnetic order is a rapidly growing field in nanospintronics. Reversible and controllable hydrogenation of these nanostructures offers a promising way to manipulate their magnetism and advance the development of next-generation spin-based devices. In particular, layered magnetic nanostructured materials, composed of alternating layers of transition metal (Fe, Co) and rare earth elements (Gd, Dy), are of great interest, as they can exhibit complex magnetic order determined by various factors such as intra-layer and inter- layer exchange interactions, finite size and proximity effects, and epitaxial strain. It is known that rare earth metals easily absorb hydrogen from the surrounding pressures [1, 2]. By controlling the hydrogen pressure and temperature conditions, one can adjust the hydrogen concentration within these layers and, consequently, control their structural, magnetic and electronic properties.

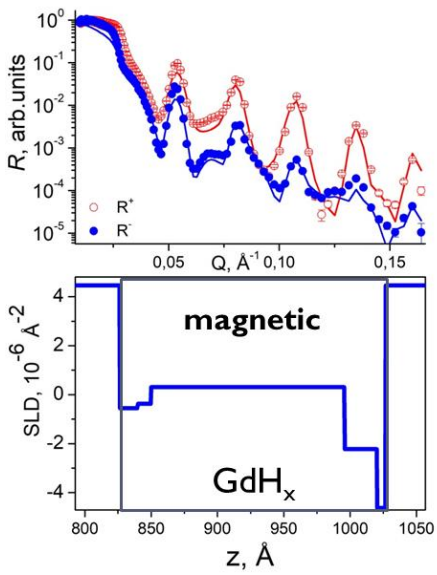

Fig. 1. Polarized neutron reflectivity after hydrogen absorption for sample $[Gd18\ nm\ /Fe3.5\ nm]_{10}$ at T=3.5 K and in magnetic field 1kOe (up) and the magnetic scattering length profile (down).

In this work, we carried out a comprehensive investigation into the effects of hydrogen on the structure and magnetic properties of Gd- and Dy heterostructures, as well as on Co/Dy/Co multilayers and Fe/Gd superlattices.

Using low-temperature magnetometry and polarized neutron reflectometry, it was found that hydrogen concentrates in the center of the Gd layers, forming the crystalline phases GdH_2 and GdH_3. The hydrogen content is reduced near the interfaces. There is a magnetic effect of the proximity of the Fe layers, resulting in the formation of an induced magnetic moment near the interfaces in the GdHx layers at all temperatures up to room temperature. At low temperatures, the GdHx layers are ferromagnetic, and the magnetic moment and Curie temperature are lower than in non-hydrated Gd layers, but much higher than in bulk and thin-film gadolinium hydrides.

The work was carried out in the framework of the Russian Science Foundation (project No. 24-12-20024).

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SIZE EFFECTS ON THE MAGNETIC PROPERTIES OF A SYSTEM OF E-FE_2O_3 NANOPARTICLES

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The ε–Fe_2O_3 iron oxide modification seems to be the most interesting one, since the ε-Fe_2O_3 particles ~20 nm and more in size exhibit the record room-temperature coercivity: about 20 kOe [1]. Due to the high coercivity, the natural ferromagnetic resonance of the particles lies in the microwave range [2], which afford ground for creating the materials effectively absorbing electromagnetic radiation [2]. Considering the fact that the iron oxide phase exists in the form of various nanoparticles, it is necessary to note the important role of surface and size effects, which make a fundamental contribution to the formation of the physical properties of this system, as well as any other nanosized objects.

A representative series of samples consisting of fine ε-Fe_2O_3 nanoparticles uniformly distributed over the SiO_2 xerogel matrix with an iron oxide content of 5–33 wt % has been synthesized and studied by mutually complementary physical methods. It has been shown by the X-ray diffractometry and high-resolution electron microscopy examination that, with increasing iron oxide concentration, the average particle size <*d*> increases from 4 to 11 nm.

As the average particle size <*d*> increases, a monotonic increase in coercivity H_C and remanent magnetization M_R of the synthesized systems at room temperature is observed, which is indicative of their magnetic hysteresis. The magnetic transition known to occur in the ε–Fe_2O_3 oxide manifests itself in all the investigated samples as a drastic change in the H_C and M_R values at 150–75 K. At the same time, a thorough analysis of the temperature dependence of the real part of the *ac* magnetic susceptibility χ′ has shown that the particles with a size smaller than a critical value of d_C ~ 6.5 nm do not undergo the magnetic transition and have a much lower magnetic anisotropy constant as compared with coarser particles ($d > d_C$).

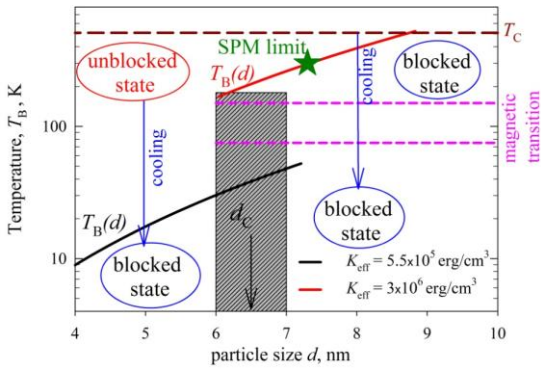

Fig. 1. Schematic of the magnetic state of ε-Fe_2O_3 particles depending on their sizes.

According to the results of this study and other available data, a schematic diagram of the state of the ε-Fe_2O_3 particle magnetic moments depending on the particle sizes can be proposed (Fig. 1).

Support by the Russian Science Foundation and Krasnoyarsk Territorial Foundation for Support of Scientific and R&D Activities, project no. 24-12-20011.

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INFLUENCE OF COLUMNAR DEFECTS ON THE PROPERTIES AND DYNAMICS OF MAGNETIC SKYRMIONS

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Magnetic skyrmions are spin vortex-like, topologically stable inhomogeneities with nanoscale parameters and topological safety, making them promising for use in spintronic devices. Skyrmions can be controlled by low-density currents and external magnetic fields, increasing their importance for applications in information storage and computing, particularly in non-traditional computing methods (e.g., neuromorphic computing) [1]. One of the main potential applications of magnetic skyrmions is racetrack memory [2]. However, this type of device has a limitation associated with the skyrmion Hall effect [1], which deflects skyrmions from their intended trajectory in the transverse direction. This can lead to annihilation of magnetic structures at the edges of the film as they move, resulting in data loss.

One possible solution to this problem could be the use of a chain of columnar "potential well" type defects, in the region of which the magnitude of perpendicular magnetic anisotropy abruptly decreases. In [3], it was shown that skyrmions at such defects are energetically more favorable and exhibit increased resistance to external influences (e.g., magnetic fields). Furthermore, the introduction of such defects also allows for the regulation of skyrmion size.

The motion of magnetic skyrmions along a rectangular nanostructured film in which circular defects of radius R_0 were introduced, in the region of which the perpendicular magnetic anisotropy K_{u2} has a reduced value compared to the rest of the film K_{u1} ($K_{u1} > K_{u2}$), was studied using micromagnetic modeling in the OOMMF software package [4]. The material parameters of the model correspond to Co/Pt films. The results showed that a skyrmion is capable of moving between two and three defects without noticeable deviation from a rectilinear direction. Defects act as localization regions that "attract" skyrmions. In their absence, the skyrmion is deflected toward the edge of the film and annihilates during its motion. Thus, the introduction of "potential well" type defects allows one to avoid the influence of the skyrmion Hall effect. Moreover, the defects themselves can serve as memory cells on the film, through which the skyrmion, “jumping”, denotes the state “0”, and when localized, the state “1”.

Support by State assignment of Russian Federation (no. 075-03-2024-123/1 15.02.2024) is acknowledged.

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TOPOLOGICAL MAGNETIC STATES IN A NANOSCALE MULTILAYER FILM: EFFECT OF CUBIC ANISOTROPY

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The study of three – dimensional topological structures remains highly relevant in physics and spintronics [1]. Recent advances in multilayer engineering enable precise control over magnetic interactions through layer-by-layer design, allowing the stabilization of complex spin textures with non-trivial topology.

Our work focuses on the topological magnetic states (skyrmions, Bloch points, chiral bobbers) in a ferrite–garnet film and the conditions required for their nucleation and stability. The film under consideration is a four-layer exchange-coupled system with an alternating magnetic anisotropy: the outer (boundary) layers possess "easy plane" anisotropy, while the inner layers possess "easy axis" anisotropy. As we showed earlier [2], this system hosts Bloch points, whose presence is essential for the nucleation of various topological states, including skyrmions and bobbers. The key features of these Bloch points include their dependence on the competition between the anisotropies of the inner and outer layers, their stability over a finite range of magnetic fields, and their intrinsic magnetoelectric coupling, which makes them act as tunable sources of electric polarization and charge.

Building on these findings, our current study addresses cubic magnetic anisotropy and its influence on these topological states. Unlike uniaxial anisotropy, cubic anisotropy introduces multiple equivalent “easy axes” (⟨100⟩ or ⟨111⟩ directions dependent on the sign of the constant K_c), which alters the energy landscape for spin rotation and affects both the internal magnetization distribution within the Bloch point, and the critical conditions for its nucleation and annihilation. To isolate these effects, we apply an in-plane magnetic field along different crystallographic directions and analyze the resulting stability diagrams.

The results reveal several distinct trends. The inclusion of cubic anisotropy generally enhances the stability of the Bloch point under an in-plane magnetic field, making the topological state more resistant to deformation. Increasing the magnitude of the cubic anisotropy constant K_c tends to raise the annihilation field strength, suggesting that larger cubic anisotropy can prolong the existence of the Bloch point under an applied in-plane field, although this behavior is modulated by the sign of K_c and the crystallographic direction of the field. It was also determined that cubic anisotropy included in the third and fourth layers is more advantageous for Bloch point robustness than incorporating it into the inner uniaxial layers, as the annihilation field strength in the former case is lower, implying a broader operational range.

These results demonstrate that cubic anisotropy provides an additional, previously unexplored control knob for tailoring the stability, nucleation, and electric properties of three-dimensional topological textures in magnetic multilayers, opening new pathways for anisotropy-engineered spintronic memory and logic devices.

Support by Ministry of Science and Higher Education of the Russian Federation, Grant Agreement No. 075-03-2024-123/1 is acknowledged.

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STRUCTURAL AND MAGNETIC CHARACTERIZATION OF FeRh MICRO-(NANO)PARTICLES SYNTHESIZED BY DIFFERENT METHODS

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FeRh alloys are attractive functional materials due to the first-order antiferromagnetic–ferromagnetic (AFM–FM) phase transition occurring near room temperature. This transition is accompanied by abrupt changes in magnetization, magnetic entropy, and lattice parameters, making FeRh particularly interesting for biomedical applications, including magnetically controlled drug delivery, hyperthermia, and multifunctional theranostic systems [1,2]. The possibility of tuning the transition temperature through composition, particle size, and thermal treatment further expands the application potential of FeRh-based materials.

In this work, FeRh micro-(nano)particles were synthesized using three different approaches: mechanochemical processing, thermal decomposition of metal-organic precursors, and thermal decomposition of $[Rh(NH_3)_6][Fe(CN)_6]$. The obtained materials were characterized by X-ray diffraction (XRD) and temperature-dependent magnetic measurements. Depending on the synthesis route, particle sizes ranged from approximately 3 nm to several micrometers. XRD analysis confirmed the formation of the ordered *B2*-FeRh phase (CsCl-type structure) in nanoparticles prepared by different synthesis methods. The presence of this phase is essential for the occurrence of the AFM–FM transition. Magnetic measurements performed in external magnetic fields revealed a pronounced magnetic transition in the temperature range of 320–360 K. Variations in the transition temperature are attributed to differences in particle size, chemical composition, degree of atomic ordering, and microstructural defects introduced during synthesis. The observation of the *B2* phase together with a well-defined magnetic transition demonstrates that the synthesized micro-(nano)particles retain the key functional characteristics of bulk FeRh despite substantial size reduction.

These results demonstrate the feasibility of producing FeRh nanoparticles with preserved magnetic functionality using different synthesis approaches. Future work will focus on improving phase purity and atomic ordering, investigating the influence of particle size on the AFM–FM transition, and developing biocompatible polymer coatings for biomedical applications, particularly in targeted drug delivery systems.

This work was supported by the Russian Science Foundation (project no. 24-19-00782, https://rscf.ru/en/project/24-19-00782/).

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NEURAL NETWORK APPROACH TO MAGNON DYNAMICS IN A FERROMAGNETIC SEMICONDUCTOR CHAIN

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Low-dimensional magnetic systems attract considerable interest due to their unusual physical properties and potential applications in spintronic and magnonic technologies [1]. In particular, one-dimensional ferromagnetic semiconductor spin chains provide an important platform for studying collective spin excitations and nonlinear interaction effects. In the present work, nonlinear magnon dynamics in a one-dimensional ferromagnetic semiconductor chain are investigated using the Green's function formalism combined with neural-network modeling. The system is described by a microscopic Hamiltonian that includes exchange interaction between localized spins, spin–electron coupling, and the effect of an external magnetic field:

$$H_M = -\frac{1}{2}\sum_{i,j} J_{i,j} S_i S_j - g\mu_B H_0 \sum_i S_j^z, \qquad H_I = -I\sum_i S_i s_i - g_e \mu_B H_0 \sum_i S_j^z \tag{1}$$

Analytical expressions for the linear magnon spectrum are obtained within the random-phase approximation. Nonlinear corrections are then incorporated using a neural-network approach.

Fig. 1 illustrates a schematic model of a one-dimensional ferromagnetic semiconductor chain. Localized spins interact through the exchange interaction, while collective spin-wave excitations propagate along the chain as magnons.

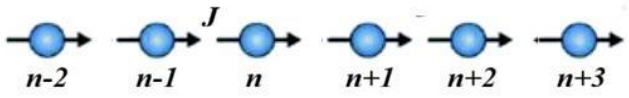

Fig. 1. Model of a ferromagnetic semiconductor chain.

To analyze nonlinear effects, self-consistent corrections to the magnon spectrum are considered. These corrections lead to frequency renormalization and damping of spin-wave excitations due to magnon–magnon and spin–electron interactions. In low-dimensional magnetic systems, such interactions become especially important because thermal fluctuations strongly influence the collective excitation dynamics.

Since the resulting nonlinear equations are difficult to solve analytically, a neural-network approach is employed to approximate the dependence of the magnon characteristics on the wave vector and temperature. The neural-network model enables efficient prediction of the excitation spectrum while preserving the essential physical properties of the system [2]. Compared with conventional numerical approaches, this method reduces computational complexity and provides stable numerical results for nonlinear spin dynamics and damping phenomena.

The obtained results indicate that nonlinear interaction effects play an important role in the spin dynamics of ferromagnetic semiconductor chains. An increase in temperature enhances the magnon population and strengthens scattering processes, leading to stronger renormalization and damping of the excitation spectrum. The proposed approach demonstrates that neural-network techniques can serve as efficient computational tools for studying complex many-body phenomena in low-dimensional magnetic systems and may be useful for future investigations of magnon transport and spin-wave excitations in nanoscale magnetic structures.

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INFLUENCE OF VARIABLE EXTERNAL MAGNETIC FIELD ON STABILITY OF SKYRMION LATTICE PHASE IN FERROMAGNETIC FILMS

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We investigate the processes of formation and destruction of skyrmions by sinusoidal external magnetic field in the model of thin ferromagnetic film.

Consider a model of a thin ferromagnetic film with a primitive cubic lattice and dimensions of 80 nm × 80 nm × 1 nm. The film region is divided into discrete cells of equal size 1 nm^3. In addition to the variable field, neighboring cells interact via ferromagnetic exchange and Dzyaloshinskii-Moriya interaction:

$$H = -A\boldsymbol{m}\cdot\nabla^2\boldsymbol{m} + D\boldsymbol{m}\cdot(\nabla\times\boldsymbol{m}) - \mu_0 M_s\boldsymbol{m}\cdot\boldsymbol{H}(t), \quad (1)$$

where A is the exchange interaction parameter (J/m), $\boldsymbol{m}$ is the film magnetization (A/m), D is the Dzyaloshinskii-Moriya interaction constant (J/m^2), μ_0 is the magnetic constant, M_s is the saturation magnetization of the film (A/m), $\boldsymbol{H}(t)$ is the external magnetic field (2):

$$\boldsymbol{H}(t) = \boldsymbol{H}_{amp}\sin(\omega t), \quad (2)$$

where $\boldsymbol{H}_{amp}$ and ω are the magnitude and frequency of the field

The dynamics of the film magnetization m is described by the Landau-Lifshitz-Gilbert equation (3):

$$\frac{d\boldsymbol{m}}{dt} = -\gamma_0\left(\boldsymbol{m}\times\boldsymbol{H}_{eff}\right) + \alpha\left(\boldsymbol{m}\times\frac{d\boldsymbol{m}}{dt}\right), \quad (3)$$

where $\gamma_0 = \mu_0\gamma$ is the gyromagnetic ratio, α is the Gilbert damping constant and $\boldsymbol{H}_{eff} = -\frac{1}{\mu_0 M_S}\frac{\delta\omega(\boldsymbol{m})}{\delta\boldsymbol{m}}$ is the effective field.

We initialized the system with random (paramagnetic) magnetization distribution and minimized energy using OOMMF micromagnetic modeling package [1]. Topological charge Q of the film was calculated using the Berg-Luescher method [2].

We have obtained the conditions for destruction of skyrmion lattice phase depending on the magnitude and frequency of the field, as well as a lifetime of these phases and have mapped the phase diagram of skyrmion lattice stability against $\boldsymbol{H}_{amp}$ and ω.

This work was carried out within the framework of the state assignment, agreement No. 075-03-2024-123/1 dated 02/15/2024.

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THEORETICAL STUDY OF SPIN WAVES IN HEXAGONAL FERROMAGNETIC SEMICONDUCTOR NANOTUBES

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Previous studies have mainly focused on planar and one-dimensional ferromagnetic systems, while the effect of nanotube geometry on local spin excitations remains insufficiently investigated [1]. In the present work, Hexagonal Ferromagnetic Semiconductor Nanotubes (HFSNT) are theoretically studied within the framework of the Green's function method. This approach provides a microscopic description of spin excitations and allows the spin wave spectrum to be obtained analytically [2]. The influence of exchange interactions and structural parameters on the dispersion characteristics is also investigated.

The Hamiltonian describing the localized spin subsystem of the system can be written as follows:

$$H_M = -\frac{1}{2}\sum_{i,j} J_{i,j} S_i S_j - g\mu_B H_0 \sum_i S_i^z - I\sum_i S_i s_i - g_e \mu_B H_0 \sum_i s_i^z$$

This Hamiltonian includes the exchange interaction between spins, the external magnetic field, and the spin–electron (s–d) interaction.

To investigate the spin excitations of the system, two types of retarded Green's functions are introduced. Within the Tyablikov random phase approximation, the dispersion relation for local spin waves is obtained. The results are illustrated in Fig. 2.

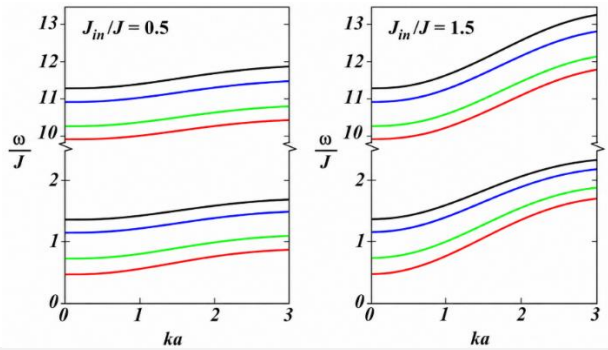

Fig.1. Dependence of spin wave frequencies on $ka$for the considered nanotube. The parameters are: $g\mu_B H_0/J = 0.3$, $g_e\mu_B H_0/J = 0.4$, $\langle S^z\rangle = 0.5$, $\langle s^z\rangle = 0.5$, $I/J = 10$, $J_{in}/J = 010$

Fig. 1 shows the dependence of the spin wave frequency on the wave vector in HFSNT. In both cases, the magnon frequency increases monotonically with increasing ka. The upper panel corresponds to high-frequency modes, whereas the lower panel represents low-frequency excitation branches. Each panel contains four dispersion branches associated with the layered hexagonal structure of the nanotube.

It is observed that the energy gap between the branches changes with the variation of exchange interaction parameters. The obtained results indicate that the spin excitation spectrum in HFSNT is highly sensitive to structural parameters and exchange interactions, which may be important for future spintronic applications.

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POSTER SESSION

NANOCOMPOSITES

Wednesday, 19 August, 17:00 - 19:00

EFFECT OF MAGNETIC FIELD ON THE ELECTRICAL AND MAGNETIC RESISTANCE OF MULTI-NANOLAYER $[(COFEB+SIO_2)+ZNO]_{50}$ FILMS

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Multi-nanolayer films are considered a promising material for creating high-precision sensors and biosensors that respond to electromagnetic fields [1]. Research in this area may lead to improved performance of ultra-fast magnetic memory devices and the development of new functional coatings. Sputtering of multi-nanolayer films [(CoFeB+SiO2)+ZnO]50 on glass-ceramic substrates was performed at VSTU using the UVN-2M vacuum setup [1]. Composite films of the composition $(Co_{42}Fe_{38}B_{20})_{54}(SiO_2)_{66}$ and semiconductor ZnO films, previously sputtered onto glass-ceramic substrates, were used as targets [1]. The elemental composition and thicknesses of the layers and films were determined using a TESCAN MIRA 3 LMN microscope [2]. During sputtering, multi-nanolayer films were obtained in which the bilayer thickness varied from 4 to 9 nm, and the thickness of the semiconductor layers dp varied from 1.5 to 4.5 nm. The magnetic field dependences of the surface electrical resistance of multi-nanolayer films were studied in magnetic fields from 0 to 9 T, in the temperature range of 2 - 400 K, using a PPMS-9 complex with an EverCool-II temperature attachment. The influence of the magnetic field B and the thickness of the semiconductor layers dp of the films on the surface electrical resistance R and magnetoresistance $R_M = (R_B - R_0) / R_0$, where R_0, R_B are the resistance of the films in zero and in a magnetic field with induction B, was investigated. The studies showed that the resistance R of the films exponentially decreases with an increase in the thickness of the semiconductor layer d_p from 1.3 to 2.5 nm. For all films, a negative magnetoresistance R_M was observed, which decreases with increasing sample temperature from 20 to 400 K and with a decrease in the magnetic field directed perpendicular to the film surface from 9 to 0.1 T. The highest magnetoresistance R_M = -0.28 and -0.13 at T = 100 K and 300 K, respectively, was observed for films with a thickness of d_p = 1.5 nm in a magnetic field of 9 T. It was found that the R_M magnitude is greatly affected by magnetic ordering in the composite layers at low temperatures, which depends on the thickness of the semiconductor layers d_p. It is shown, that the hopping mechanism is dominant in the formation of surface electric current and magnetoresistance in multilayer composite-semiconductor films. Wide ranges of change in electrical and magnetic resistance with a change in the thickness of semiconductor layers from 1.3 to 2.2 nm indicate the high sensitivity of the electromagnetic properties of multi-nanolayer films to the conditions of their production and to the possibilities of controlling these properties.

This study was supported by grant No. 25-72-20063 from the Russian Science Foundation, https://rscf.ru/project/25-72-20063/

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MICROWAVE CONDUCTIVITY OF COMPOSITE (CoFeB+$LiNbO_3$) IN MAGNETIC FILD

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This work presents a study of the microwave conductivity of composite (CoFeB+$LiNbO_3$) films in magnetic fields ranging from 8 to 700 mT. The films were fabricated at Voronezh State Technical University using ion-beam sputtering [1]. They were deposited onto glass-ceramic substrates and integrated onto a coplanar waveguide (CPW). A microwave signal from a generator propagates through a transmission line with the composite films to a spectrum analyzer. The transfer coefficient of microwave signal the measured by the analyzer is defined as $K=10Lg(P_a/P_g)$, where P_a is the power reaching the analyzer, P_g is the power from the generator.The generator output impedance, analyzer input impedance, and characteristic impedance of the waveguide (without the film) were all 50 Ω. The films bridged the signal and ground electrodes of the CPW, creating a direct shunting path that attenuated the transmitted microwave power. The magnetic field was applied in the plane of both the film and the waveguide. Measurements were carried out over a frequency range of 0.1–2.5 GHz at room temperature. The elemental composition of the films was determined using a TESCAN MIRA 3 scanning electron microscope (SEM) equipped with an AZTEC X-ACT energy-dispersive X-ray spectroscopy system (Oxford Instruments).

The power transmission spectra of the composite films revealed a resonant minimum whose position shifts toward higher frequencies as the metallic phase concentration decreases. This behavior was interpreted using an equivalent electrical circuit model incorporating capacitive and inductive elements.

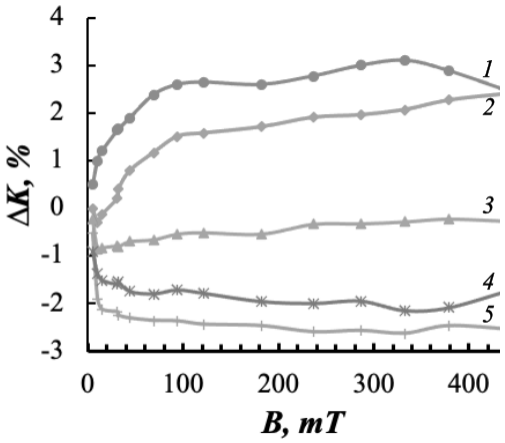

Fig. 1. Change of the transmission coefficient as a function of magnetic field where frequency (GHz): 1-0.01, 2-0.5, 3-1.0, 4-3.0, 5-2.5.

Fig. 1 shows the change in the transmission coefficient as a function of the magnetic field for the film with a resonant minimum at 1 GHz. Here, $\Delta K = [K(B) - K(B_0)] \times 100 / K(B_0)$, where K(B) is the transmission coefficient at field B and $K(B_0)$ is its zero-field value. The external magnetic field modulates the transmission coefficient, with the magnetosensitive response reaching up to 3%. Below 1 GHz, increasing the magnetic field raises the transmission coefficient, indicating reduced microwave conductivity of the film. Above 1 GHz, the opposite trend is observed. Near the resonant minimum, the field dependence of the transmission coefficient is weakest. When the magnetic field was swept in the reverse direction, showed a different trajectory upon field reversal, indicating magnetic hysteresis.

This work has been supported by Russian Science Foundation (project No. 25-72-20063, https://rscf.ru/project/25-72-20063/).

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THE EFFECT OF A MAGNETIC FIELD ON THE MICROWAVE REFLECTIVE PROPERTIES OF METAL-DIELECTRIC COMPOSITE FILMS WITH DIFFERENT STRUCTURES

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The creation of microwave materials and devices for storing and processing information based on them is a promising task [1]. Metal-dielectric composite films with a chaotic distribution of granules can be used to create such devices. This paper presents the results of experimental studies of the effect of a magnetic field on the microwave reflective properties of composite films with different structures in the frequency range of 8-78 GHz. The objects of study were composite films (CoFeB + MgO) in which the metal concentration varied in the range x = 30 - 75 at.%.

The composition and thickness of the films were determined using a TESCAN MIRA3 LMH scanning electron microscope and AZTEC software (Oxford Instruments). Studies of the surface relief and magnetic phase contrast (MPC) of the composite films were carried out using an atomic force microscope (AFM) with a cantilever and an MFM10 probe [1]. The microwave reflection coefficient R for composite films was measured using microwave panoramic systems comprising rectangular waveguides, sweeping frequency generators, and a Ya2R-67 indicator measuring the standing wave ratio (SWR) in the waveguide and attenuation. During microwave measurements, each composite film on a Mylar substrate was pressed against the window of a rectangular waveguide. A standing electromagnetic wave was created in the waveguide. The effect of a magnetic field on microwave reflection was studied by placing a section of a rectangular waveguide containing a film in the gap between the poles of an electromagnet. The magnetic field varied from 0 to 0.7 T. In all experiments, the magnetic field was directed parallel to the plane of the films. Magnetic field induction measurements were performed using a magnetometer. The microwave reflection coefficient R of the films was calculated based on the measured SWR values using the voltage in the rectangular waveguides. All measurements were conducted at a temperature of T = 300 K.

As studies have shown, the reflectivity R for composite films with a granular structure increases slowly with increasing magnetic field strength. For composite films with a granular-percolation structure, the reflectivity R exhibits a non-monotonic increase depending on the magnetic field. Analysis of the magnetic-field dependences of the reflectivity R for composite films with different metal concentrations x and structures shows that the reflectivity R depends not only on the metal concentration x, but also significantly on the structure of the composite films, and this dependence increases with the higher the microwave frequency.

The research was carried out at the expense of a grant from the Russian Science Foundation, No. 25-72-20063, https://rscf.ru/project/25-72-20063/

[1] L.N. Kotov, Yu.V. Sudienkov, M.P. Lasek, *Technical Physics Letters*, **51** (2025) 64 - 67.

MICROWAVE CONDUCTIVE PROPERTIES OF (CONBTA)(MGO) COMPOSITE FILMS IN MAGNETIC FIELDS

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This work presents a study of the microwave conductive properties of (CoNbTa)(MgO) composite films in magnetic fields up to 700 mT. The composite films were deposited by ion-beam sputtering onto a PET substrate [1]. The elemental composition was determined using a TESCAN MIRA 3 scanning electron microscope. The metal atomic fraction ranged from 0.37 to 0.77. The films were integrated on a measurement cell and placed in a magnetic field. The cell consisted of a coplanar waveguide with three copper electrodes on an FR-4 substrate. A swept-frequency signal from a generator propagated along the coplanar waveguide electrodes perpendicular to the magnetic field and was measured by a spectrum analyzer. The magnetic field was applied in the plane of both the film and the waveguide. The composite film shunted the signal and ground electrodes, attenuating the power transmitted from the generator to the analyzer. The spectrum analyzer measured the power transmission coefficient K, defined as $K = 10 \cdot \log_{10}(P_{as}/Pg)$, where P_{as} is the power at the analyzer input and Pg is the power at the generator output. The generator output impedance, analyzer input impedance, and characteristic impedance of the waveguide (without the film) were all 50 Ω. Variations in the coefficient K under magnetic field were used to evaluate the influence of the magnetic field on the microwave conductivity of the composite films.

The transmission coefficient increased by up to 40% with increasing magnetic field for the film with a metal concentration of 0.40. The relative change of the transmission coefficient was calculated as: $\Delta K = (K - K_0)/K_0 \times 100\%$, where K is the transmission coefficient in a magnetic field and K_0 is the zero-field value. The ΔK vs. field dependence for x = 0.40 is shown in Fig. 1.

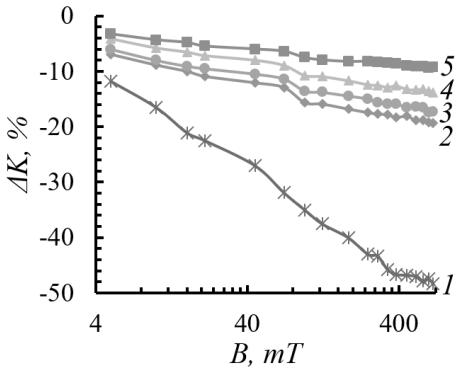

Fig. 1. ΔK vs magnetic field at frequencies (GHz): 1 – 0.01; 2 – 0.5; 3 – 1.0; 4 – 1.5; 5 – 2.5.

The magnetic field dependences decrease monotonically linearly when the field B is plotted on a logarithmic scale. The change of the transmission coefficient decreases with increasing frequency. For films with other concentrations, the relative change was 2–5%. Thus, increasing magnetic field weakens the shunting effect of the film, leading to an increase in its microwave resistance. The reduced magnetic field effect at higher frequencies is attributed to the decrease in the capacitive reactance of the films. The strongest magnetic field influence on the microwave resistance is observed near the percolation threshold.

This work has been supported by Russian Science Foundation, project No. 25-72-20063, https://rscf.ru/project/25-72-20063/

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EFFECT OF MAGNETIC FIELD ON THE ELECTRIC AND MAGNETIC RESISTANCE OF (CoFeB+SiO_2)/(CoTaNb+MgO) COMPOSITE FILMS AT TEMPERATURES OF 77º AND 295º K

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Thin composite films based on ferromagnetic alloys are promising for spintronics, magnetoresistive sensors and flexible electronics [1]. In this work, the influence of a magnetic field on the electric R and magnetic resistance R_B of composite films of two series with compositions (CoFeB + SiO_2) (*G* series) and (CoTaNb + MgO) (F series) at temperatures of 77º and 295º K was investigated. Composite films were obtained by ion-beam sputtering of magnetic metal alloy targets and dielectric materials on flexible polymer sheets [1]. The composition and thickness of the films were determined using a TESCAN MIRA3 LMH scanning electron microscope. The film thickness was 0.4-0.9 μm, and the total concentration x of metals varied from 30 to 80 at. %. The surface relief and magnetic phase contrast (MPC) of the films were studied using an atomic force microscope (AFM) with a cantilever and an MFM10 magnetic probe [1]. For films of the G and F series, a granular and granular-percolation structure is observed depending on x. For films of the G series, percolation is shifted towards higher x by 15 at. %. The resistance of the samples in different magnetic fields was measured using a setup including an electromagnet in which the magnetic field between the poles varied from 0 to 0.7 T and the following devices: a B7-23 universal digital voltmeter, an E6-13A teraometer, and a Hall magnetic field sensor. When measuring the resistance of the films at T = 77 K, the sample was placed in a foam box with liquid nitrogen, which was installed between the poles of the electromagnet. As studies have shown, the resistance and magnetoresistance of the films depend strongly on the type of magnetic metal alloy: the resistance of *G* series films is 50 times higher than that of *F* series films, while the magnetoresistance is 50 times lower. The highest resistance and magnetoresistance are observed for films with a granular structure, and the lowest resistance is observed for films with a granular-percolation structure. As the temperature of *G* series films decreases from 300 to 77 K, the resistance and magnetoresistance of films with a granular structure increase by 50 and 400 times, respectively. As the temperature decreases from 300 to 77 K, the resistance of films with a granular-percolation structure increases threefold, and the magnetoresistance of the films decreases by 20 times. The study shows that *G* series films are characterized by higher electrical and magnetic resistance compared to *F* series films. The change in resistance and magnetoresistance when the temperature of samples decreases from 300 to 77 K depends on the type of magnetic alloy and the structure of the composite films.

This study was supported by grant No. 25-72-20063 from the Russian Science Foundation, https://rscf.ru/project/25-72-20063/

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THE EFFECT OF MAGNETIC FIELD ON THE TRANSMISSION COEFFICIENT IN A LINE WITH COMPOSITE FILMS (COFEB+SIO2+N2)

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Composite metal-dielectric films exhibit unique electromagnetic properties in the microwave range, uncharacteristic of other films, making them attractive objects for scientific research [1]. In this paper, we study the influence of a magnetic field on the frequency spectra of the transmission coefficient *K* in a line with composite films ($CoFeB+SiO_2+N_2$) with different structures. The films were obtained by ion-beam bombardment of targets made of a magnetic metal alloy $Co_{41}Fe_{39}B_{20}$ and a dielectric SiO_2 in an argon atmosphere with a pressure of 24 mPa and a nitrogen atmosphere with a pressure of 3.5 mPa. The introduction of nitrogen into the film deposition atmosphere partially encapsulates CoFeB particles flying from the target, forming insulating shells that suppress percolation and stabilize the granular structure [2]. The composition and thickness of the films were determined using a TESCAN MIRA3 LMH scanning electron microscope. The studies of the relief and magnetic phase contrast (MPC) of the film surface were carried out using an atomic force microscope (AFM) with a cantilever and an MFM10 magnetic probe [1, 2]. The film thickness was 1.2-2.2 μm and the total concentration x of Co, Fe metals varied from 31 to 49 at. %. For films with a low concentration x = 31-36 at. %, a granular structure is observed, and for films with x = 38 - 49 at. %, a granular-percolation structure is observed [2]. The microwave current power transmission coefficient *K* spectra were measured using a GSP-79330A spectrum analyzer in the frequency range of 0.01-3 GHz. Samples of composite films on a polymer substrate were placed in a measuring cell between contact lines forming a sandwich structure. After that, the cell with the sample was placed in the gap of an electromagnet, in which the magnetic field varied in the range of 28-680 mT. The *K* coefficient spectra and the value of $\Delta K/K_0 = (K_B-K_0)/K_0$ were obtained, where K_0, K_B are the transmission coefficient values in zero and magnetic fields. For the studied films in different magnetic fields, the $\Delta K/K_0$ value had a negative sign, which corresponds to a decrease in the power of the transmitted microwave signal in the signal line with the composite films during magnetization of the films. The greatest change in the microwave spectra of the K transfer coefficient was observed for films with a granular-percolation structure at frequencies above 1.5 GHz. For films with *x* = 42 at. % in a magnetic field of 128 mT, a peak in the $\Delta K/K_0$ value was observed in the frequency range of 2.4-2.8 *GHz*, which is associated with resonant current oscillations in the percolation regions. A comparison of the microwave spectra of the K transfer coefficient for a line with films of different structures shows that the structure of the composite films is an important factor in controlling the *K* transfer coefficient in a line with $CoFeB/SiO_2$ composite films.

This study was supported by grant No. 25-72-20063 from the Russian Science Foundation, https://rscf.ru/project/25-72-20063/

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THE INFLUENCE OF COMPOSITION AND STRUCTURE ON THE FERROMAGNETIC RESONANCE PARAMETERS OF COMPOSITE FILMS WITH DIFFERENT MAGNETIC ALLOYS *CoFeB* AND *CoTaNb*

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Composite metal-dielectric films have unique electromagnetic properties that are not typical of other films, which makes them attractive objects for scientific research [1]. Due to the presence of a gigantic magnetic resistance and a high value of the absorption coefficient of ultrahighfrequency radiation, composite films can be used as a basis for creating sensors and biosensors with high sensitivity to electromagnetic fields [1,2]. In this work, the concentration and angular dependences of the parameters (width ΔB and position of the line or resonant field B_r) of the ferromagnetic resonance (FMR) of two series of *F* and *G* composite films obtained by ion beam bombardment of targets of magnetic metal alloys $Co_{41}Fe_{39}B_{20}$ and $Co_{86}Ta_{12}Nb_2$ and MgO dielectric have been studied. The composition and thickness of the films were determined using a TESCAN MIRA3 LMH scanning electron microscope and AZTEC (Oxford Instruments) software [1,2]. Studies of the relief and magnetic phase contrast (MFC) of the surface of composite films were carried out using an atomic force microscope (AFM) with a cantilever and an MFM10 magnetic probe [1]. Using a radio spectrometer RE-1306 with an operating frequency of 9.4 GHz, the magneto-field dependences of the microwave electromagnetic response of samples were studied using the EPR modulation technique. The films were studied for various angles φ between the permanent magnetic field and the sample plane, varying from 0^0 to 50^0. Image analysis of MFC films shows that the percolation region (metal leakage) for *G*series films occurs at a low concentration of metals x than for F-series films. In addition, Gseries films with large *x* are characterized by long magnetic (metallic) stripes. The paper shows that the parameters of the FMR line ΔB and B_r of composite films of both *F* and *G* series depend on the concentration of metals *x*, and, as a rule, decrease with increasing *x*, and the behavior of the concentration dependences $\Delta B(x)$ and $B_r(x)$ is significantly influenced by the magnetic structure of the films. The line width ΔB and the resonant field B_r for films of both *F* and *G* series increase nonmonotonically with increasing angle φ, which is associated with an increase in the external demagnetizing field of the films. The results of the analysis of the behavior of the concentration and angular dependences of the FMR parameters, relief, and magnetic structure of films indicate the high structural sensitivity of the FMR method in the study of the electromagnetic properties of magnetic composite films.

The research was carried out at the expense of a grant from the Russian Science Foundation, No. 25-72-20063, https://rscf.ru/project/25-72-20063/

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NUMERICAL CALCULATIONS OF MAGNETIC RESONANCE FREQUENCIES IN MULTI-SUBLATTICE FERRIMAGNETS

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Currently, ferrimagnetic materials are widely used in spintronics, magnonics, magnetophotonics, and other actively developing areas of applied research. Of particular interest are ferrimagnets with a compensation temperature, especially due to the non-collinear magnetic phase that arises near the magnetic compensation temperature.

The Smit and Beljers approach [1] has become widespread for calculating the frequencies of magnetization precession in ferromagnets. In this work, this approach is extended to an *N*sublattice ferrimagnet. The uniaxial anisotropy constant, *g*-factor, and Gilbert damping parameter α are taken into account separately for each sublattice.

A computer program written in Python is proposed, which allows one to obtain a system of equations of motion for given sublattices, taking into account magnetostatic interaction and demagnetizing fields, exchange, and magnetic uniaxial anisotropy contributions. As a result of numerically solving the system of 2*N* equations, the resonance frequency is obtained as a complex number $\omega = \omega' + j\omega''$. The real part determines the precession frequency, and the imaginary part determines the damping.

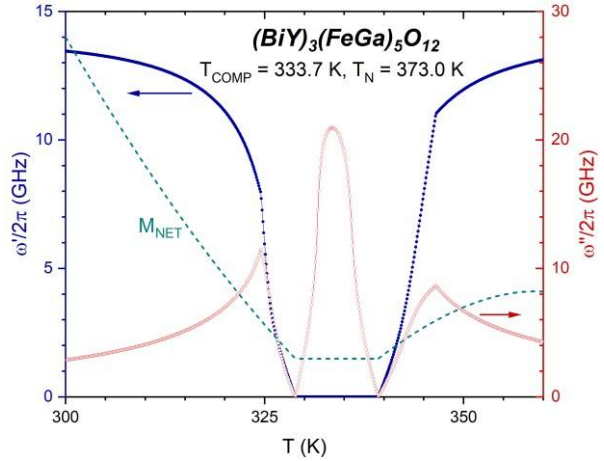

Fig. 1. Two-sublattice ferrimagnetic garnet

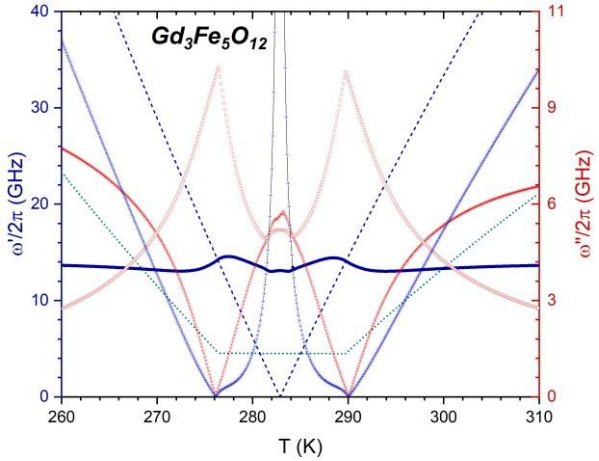

Fig. 2. Three-sublattice ferrimagnetic garnet

The program uses the results of numerical calculations of the magnetization of cationsubstituted iron garnets using the molecular field method. As an example, Figs. 1 and 2 show the calculation results for two ferrimagnetic garnets with $\alpha = 2 \cdot 10^{-3}$, identical for all sublattices. The non-collinear Clark–Callen phase [2] in a magnetic field H = 5 kOe was used.

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MAGNETORESISTANCE OF COFEB-LINBO$_3$ NANOCOMPOSITES IN CIP AND CPP GEOMETRIES

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We present the results of a comparative study of magnetoresistance (MR) of $(CoFeB)_x(LiNbO_3)_{100-x}$ thin films in two geometries, resembling current-in-plane (CIP) and current-perpendicular-to-plane (CPP) transport. In the first, current-in-plane geometry, MR exhibits non-monotonic temperature dependence and reaches approximately -1% in fields of 15 T at 300 K. In the second geometry, Cu/CoFeB-$LiNbO_3$/$LiNbO_3$/Ni structure, called vertical or capacitor structure, and which is used to create memristors [1, 2], $LiNbO_3$ very thin spacer was placed between Ni electrode and $(CoFeB)_x(LiNbO_3)_{100-x}$ nanocomposite. In this case a negative MR of about -2% at 300 K was found, weakly saturating in fields up to 15 T.

Despite of similar negative values of MR at room temperature the field dependences of the MR of planar and vertical structures are significantly different. We believe that this difference is due to the dominant contribution to MR in the case of capacitor structures of the Schottky tunnel barrier at the Ni/nonstoichiometric $LiNbO_3$ interface. Namely, in this case, the injection of electrons from the Ni electrode into the conduction band of the $LiNbO_3$ is controlled by a barrier, the height of which depends on the magnetic field due to the presence of paramagnetic centers. Moreover, the filling of energy-distributed traps in the $LiNbO_3$ layer, observed above a certain voltage on the structure, leads to a sharp increase in current and the manifestation of the resistive switching effect, the influence of the magnetic field on which reaches 5%.

The work was supported by the Russian Science Foundation (grant No. 25-22-00554). The measurements were carried out using the equipment of the Kurchatov Institute Resource Center.

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ANOMALOUS ORIENTATIONAL TRANSITIONS IN A THREE-LAYER YIG STRUCTURE AT HIGH TEMPERATURE

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Nonlinear dynamics of the magnetization vector in a three-layer "YIG/non-magnetic spacer/YIG" structure at high temperature (500 K) was studied by numerical solution of the Landau–Lifshitz–Gilbert equation. Anomalous regimes of orientational transitions, unusual for low temperatures, were discovered.

At room and low temperatures, the cubic magnetic anisotropy of YIG crystals forms a system of four energy minima located along the spatial diagonals of the cube [1]. Phase portraits of magnetic oscillations at 100 K and 300 K exhibit four pronounced "clusters" of trajectories corresponding to these minima. At 500 K, where the saturation magnetization and anisotropy constants are significantly lower ($M_s \approx 70$ G, $K_1 = -0.5 \cdot 10^3$ erg/cm^3, $K_2 = -0.02 \cdot 10^3$ erg/cm^3), the ratio K_2/K_1 reaches its minimum (0.04 vs. 0.115 at 100 K and 0.333 at 300 K). This leads to the appearance of additional metastable states at certain frequencies of the alternating field.

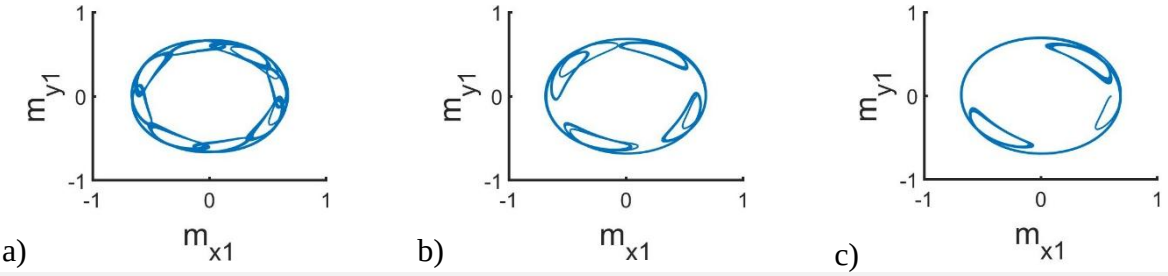

Fig. 1. Phase portraits of magnetic oscillations at T = 500 K for various alternating field frequencies: (a) 300 MHz; (b) 260 MHz; (c) 245 MHz

Figure 1 shows phase portraits $m_z(m_x, m_y)$ for various excitation frequencies f_0 at fixed amplitude $h_0 = 10$ Oe and static field $H_0 = 700$ Oe. At $f_0 = 300$ MHz, eight clusters are observed (a) – twice the usual number – indicating the emergence of additional energy minima between the main diagonal directions. At $f_0 = 260$ MHz (b), the four-cluster regime is restored. Upon reduction to $f_0 = 245$ MHz (c), a bifurcation transition to a regime with two dominant orientational states occurs. The time dependences of the magnetization components at 500 K demonstrate hysteresis effects associated with the weakening of potential barriers.

The discovered anomalous regimes have not been previously reported for YIG-based structures. Their existence is related to the competition between the contributions of the first and second cubic anisotropy constants at high temperatures. The obtained results are important for understanding nonlinear magnetic dynamics in multilayer structures and can be used in the development of thermosensitive spintronic and microwave devices.

The work was supported by the Russian Science Foundation grant (project No. 25-72-20063) https://rscf.ru/project/25-72-20063/.

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MAGNETIC PHASE TRANSITION BEHAVIOR IN B2-FERH FILMS AND NANOPATTERNS

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FeRh alloy is known for its magnetostructural phase transition between antiferromagnetic and ferromagnetic phases near 370 K, accompanied by changes in magnetization, resistance, lattice volume, and magnetic anisotropy. These properties make FeRh promising for magnetic recording and spintronic applications, where nanoscale patterning is essential. However, phase-transition behavior below the magnetic domain size remains insufficiently understood.

In this study, we present a systematic investigation on MPT behavior of nanostructured FeRh patterns via in situ magnetic force microscopy. The patterns include stripe, ring, and circle geometries, with dimensions varied from 100 to 1000 nm spanning both under and over the magnetic domain characteristic size. As a result, no obvious size-dependent MPT behavior with a gradual FM evolution is exhibited in the range of nano- to film scale upon heating, while an abrupt transition from FM to AFM state within a 1–2 K temperature window is observed in the patterns comparable and below the domain size accompanied by a supercooling phenomenon.

Particularly, as the pattern size decreases, the circle geometry exhibits earlier onset and significant supercooling compared to the stripe and ring counterparts. In addition, pronounced perpendicular magnetization remains observable at 390 K, with the proportion progressively increasing as the pattern size decreases, and finally, exhibiting a unique alternating bi-stable arrangement. These results can be understood as the pattern area-size modulating AFM nucleation energy and shape anisotropy energy, wherein the reduction in the pattern area not only reduces the conventional nucleation sites for forming AFM domain but also weakens the prominently lateral demagnetization energy.[1-5]

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INFLUENCE OF LAYER THICKNESS ON THE FERROMAGNETIC RESONANCE PARAMETERS OF MULTI-NANOLAYER FILMS $[(COFEB+SIO_2)+ SIO_2/ZNO]_{50}$

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In recent years, there has been growing interest in studying multi-nanolayer films and structures that exhibit a wide range of unique electromagnetic properties, mainly due to the presence of numerous interfaces and nanoscale layer thicknesses [1]. Of particular interest are films with magnetic composite layers containing magnetic nanogranules and microregions whose electromagnetic properties depend on the external magnetic field [2]. The aim of this work was to investigate the influence of the thickness of dielectric d_d and semiconductor d_p nanolayers on the ferromagnetic resonance (FMR) parameters of multi-nanolayer films: composite - dielectric/semiconductor with compositions $[(CoFeB+SiO_2)+SiO_2/ZnO]_{50}$ in the magnetic field range from 0 to 0.7 T. The deposition of films of two series with composite, dielectric or semiconductor layers on glass-ceramic substrates was carried out at VSTU using a UVN-2M vacuum unit modernized for ion-beam sputtering [1]. The process of alternate deposition of layers of the composite $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ and dielectric SiO_2 (or semiconductor ZnO) on glass-ceramic substrates was carried out in an argon atmosphere. The elemental composition and thickness of the multi-nanolayer films were determined using a TESCAN MIRA 3 LMN electron microscope [2]. The film thickness ranged from 250 to 450 nm, and the thickness of the dielectric and semiconductor ZnO layers varied from 1.3 to 4 nm. Film studies were conducted using the FMR method on a RE-1306 radio spectrometer at an electromagnetic field frequency of 9.4 GHz at different angles φ = 0º, 30º, 50º, and 60º between the constant magnetic field and the film plane. Based on the obtained FMR spectra, the dependences of the linewidth ΔB and the resonant field Br on the thickness of the dielectric and semiconductor layers $\Delta B(d_d)$, $B_r(d_d)$, $\Delta B(dp)$, $B_r(dp)$ were constructed for different angles φ. The obtained results show that the dependences of the parameters ΔB and Br on the layer width are significantly affected by the conductivity type of the layers: for films of one series, an increase in the parameters ΔB and B_r with increasing layer width is characteristic, while for films of another series, their decrease is observed. The resonance field Br at $\varphi = 0$ for films with dielectric layers initially decreases with increasing dd and then increases, while for films with semiconductor layers it only decreases with increasing d_p. The linewidth ΔB at $\varphi = 0$ for films of both series increases with increasing layer thickness. Analysis of the obtained results shows that the FMR method is an informative tool for studying the microwave electromagnetic properties of multi-nanolayer films.

This study was supported by grant No. 25-72-20063 from the Russian Science Foundation, https://rscf.ru/project/25-72-20063/

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FEATURES OF THE CHANGES IN MAGNETIC PROPERTIES OF AMORPHOUS-NANOCRYSTALLINE COMPOSITES OBTAINED BY SEVERE PLASTIC DEFORMATION

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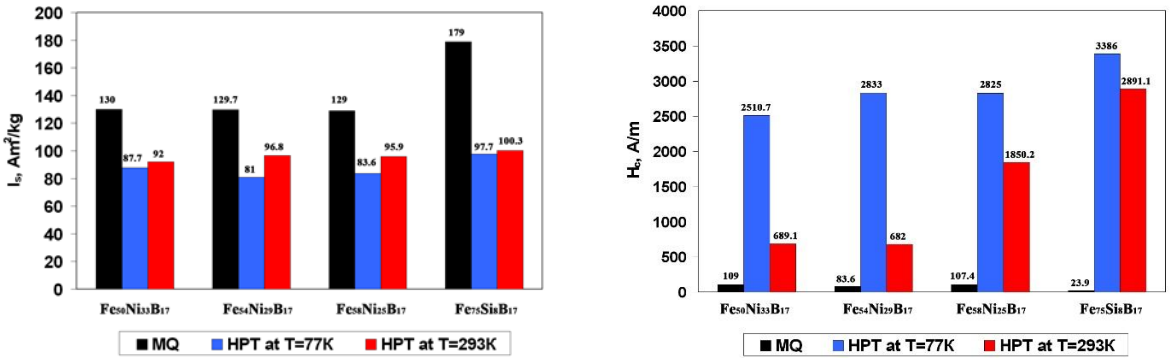
The atomic structure of melt-quenched (MQ) amorphous metal alloys remains poorly understood in materials science. Current realistic models suggest a cluster structure derived from the supercooled melt during partial relaxation. Multicomponent alloys, particularly metal-nonmetal systems, exhibit significant short-range topological and compositional order, rather than a random atomic distribution. The amorphous state is also characterized by geometrically necessary volume and excess free volume. Due to their low thermodynamic stability, these alloys can undergo diffusion-driven transitions to more stable metastable states under external stress—a process termed structural relaxation.

High-pressure torsion (HPT) is a powerful method for modifying the structure of such alloys. This study examines HPT-induced local atomic changes in soft magnetic Fe-based amorphous alloys ($Fe_{50}Ni_{33}B_{17}$, $Fe_{54}Ni_{29}B_{17}$, $Fe_{58}Ni_{25}B_{17}$, $Fe_{75}Si_8B_{17}$) at 77K and 293K, using EXAFS, XRD, TEM, and DSC. The results show HPT alters the local atomic environment of Fe and Ni. Magnetic properties, measured by VSM, correlate with specific saturation magnetization and local atomic structure.



a) b)

Fig. 1. Magnetic properties of the $Fe_{58}Ni_{25}B_{17}$, $Fe_{54}Ni_{29}B_{17}$, $Fe_{50}Ni_{33}B_{17}$, and $Fe_{75}Si_8B_{17}$ alloys after MQ and HPT (n = 1) at 293 and 77K: (a) I_s in a field of 1.7 T, (b) H_c.

After HPT at 77K, XRD and TEM confirm the alloys remain amorphous. EXAFS reveals changes in the chemical environment of Fe atoms and in average interatomic distances (Fe-Fe, Fe-Si, Fe-Ni). In $Fe_{58}Ni_{25}B_{17}$ and $Fe_{75}Si_8B_{17}$, the short-range order around Fe changes, and Fe-Fe distances decrease. In $Fe_{50}Ni_{33}B_{17}$ and $Fe_{54}Ni_{29}B_{17}$, interatomic distances are unchanged, but some Fe atoms in the first coordination shell are replaced by Ni. Both local changes reduce saturation magnetization after 77K HPT. The sharp rise in coercive force at 77K is attributed to suppressed thermal activation, which blocks relaxation channels for elastic stresses. Finally, HPT at 77K produces an amorphous state more resistant to crystallization than the as-quenched state.

The work was carried out with financial support from the Russian Science Foundation (grant 25-22-00132).

EFFECT OF SURFACE CHEMISTRY ON THE STRUCTURAL AND MAGNETIC PROPERTIES OF $Ti_3C_2T_X$@Fe_3O_4 COMPOSITES

Shilov N.[1], *Magomedov K.*[1], *Sobolev K.*[2], *Rodionova V.V.*[1], *Kolesnikova V.G*[1]

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MXenes are a novel class of two-dimensional materials with the general formula $M_{n+1}X_nT_x$, where M is a transition metal, X is either C or N, and T_x is a surface functional group, usually –OH, –O or –F; n is an integer index that typically takes the values from 1 to 3. Two-dimensional $Ti_3C_2T_x$ MXenes possess excellent sorption properties, but a magnetic field can be applied to remove them efficiently from water. Therefore, the fabrication of composites with superparamagnetic nanoparticles is required [1-4]. Notably, the sorption capacity of such composites critically depends on the initial state of the MXene surface [1,2]. In this work, we investigated the effect of various surface terminations of the $Ti_3C_2T_x$ MXene (functionalized with –O, –F, and –OH groups) on the structural, colloidal, and magnetic properties of $Ti_3C_2T_x$@Fe_3O_4 nanocomposites.

In this study, $Ti_3C_2T_x$ MXenes were synthesized using a mixture of hydrofluoric and hydrochloric acids. Subsequently, an additional surface treatment was performed to achieve a surface dominated by one of the functional groups (–O, –F, or –OH). After that, the MXene surface was decorated with magnetite nanoparticles via co-precipitation in an ultrasonic bath at different MXene:Fe_3O_4 ratios (2:1, 1:1, and 1:2) [1]. The structural and magnetic characteristics of the obtained samples were then comprehensively characterized.

According to the X-ray diffraction results, an increase in the MXene interlayer spacing was observed due to the growth of magnetite nanoparticles [1-4]. For the series of composites with the –OH terminated MXene surface, the crystallite size of magnetite exceeds 20 nm, whereas for the other two series, the size is approximately 13 nm. Energy-dispersive X-ray spectroscopy revealed the presence of iron across the entire MXene surface. All composites exhibited superparamagnetic behavior [1-4]. The ζ -potential for the composite series with –OH and –O modified MXene surfaces changes linearly, while for the series with the –F modification, it varies erratically. This chaotic behavior might be associated with MXene aggregation during the synthesis, where the nanoparticles grow on the outer surfaces and shield the negatively charged areas of the MXene.

Thus, varying the surface functionalization of $Ti_3C_2T_x$ MXenes is an effective approach to tailoring the properties of the $Ti_3C_2T_x$@Fe_3O_4 composite.

This work was supported by the Russian Science Foundation, grant № 25–72–30009

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POSTER SESSION

Multiferroics

Wednesday, 19 August, 17:00 - 19:00

TERAHERTZ ELECTRIC-FIELD DRIVEN MAGNONS IN THE MAGNETOELECTRIC ANTIFERROMAGNET CR_2O_3

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The relentless pursuit of energy efficient information technologies has pushed spintronics to its limits. Antiferromagnets stand as a cornerstone of next generation spintronics due to their terahertz spin dynamics. The efficient control of the antiferromagnetic vector in insulating systems remains an outstanding challenge because conventional electric current driven approaches are inapplicable.

Here we demonstrate novel mechanisms for terahertz electric field control of spin dynamics in the prototypical insulating magnetoelectric antiferromagnet Cr_2O_3 (Fig. 1) [1]. We theoretically investigate this phenomenon across different magnetic phases using rigorous symmetry analysis combined with a Lagrangian formalism. In the collinear phase we reveal that the Néel spin orbit torque can be realized in insulators. The displacement current induced by a terahertz pulse couples directly to the antiferromagnetic vector through an electric dipole order parameter. The equations of motion uncover a fundamental competition between this new torque and the linear magnetoelectric effect [2]. Crucially this torque scales with the time derivative of the terahertz electric field.

Furthermore we extend our framework to the spin-flop phase of Cr_2O_3 where a spontaneous toroidal dipole moment emerges. We uncover a distinct toroidal magnon mode associated with the dynamical modulation of this moment. The toroidal magnon is excited primarily by the terahertz electric field through the linear magnetoelectric effect. Its frequency and amplitude are immune to the external magnetic field (Fig. 1).

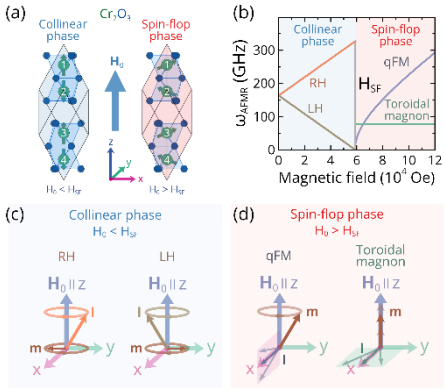

Fig. 1. (a) Structure of Cr_2O_3. (b) Field dependence of the magnon frequencies. The magnon eigenmodes in the (c) collinear and (d) spin-flop phases.

Our unified findings establish that both the displacement current driven spin orbit torque and the dynamical toroidal moments offer new pathways for ultrafast electric field control of antiferromagnetic spins in magnetoelectrics. These mechanisms position insulator antiferromagnets as a highly viable platform for terahertz rate spintronic devices and establish universal design principles for non metallic spin orbit torque materials.

Support by Ministry of Science and Higher Education (FSWR-2024-0003) and RSF (22-12-00367) is acknowledged.

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FEATURES OF THE INHOMOGENEOUS MAGNETOELECTRIC EFFECT IN FERROMAGNETIC FILMS: OOMMF SIMULATION

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In ferrite-garnet films (e.g., (210) and (011) orientations), magnetic anisotropy exhibits a complex character, which facilitates the formation of various micromagnetic structures such as domain walls, magnetic bubbles, and skyrmions. These structures are difficult to model numerically using standard approaches due to the intricate anisotropy and the demagnetizing fields. Therefore, numerical simulations were performed using the OOMMF micromagnetic package, into which an inhomogeneous magnetoelectric (flexomagnetoelectric) interaction was implemented by the authors.

To verify the correctness of the implemented module, known results describing the transformation of a 180° Bloch domain wall (DW) into a 180° DW with a Néel component were reproduced under the action of a nonuniform electric field. As shown in Fig. 1, increasing the electric field strength leads to a gradual transformation of the domain wall structure: the Néel component grows, and the wall acquires an electric polarization due to the flexomagnetoelectric effect. This behavior is consistent with previously reported theoretical data [1–5].

Furthermore, the influence of an electric field on cylindrical magnetic domains (bubbles) in the presence of an external magnetic field was investigated. It was shown that the electric field can significantly modify the bubble domain stability, size, and collapse field. These findings are important for potential applications in magnetoelectric memory devices and domain-wall-based logic elements.The obtained results confirm that the implemented OOMMF module correctly reproduces the known physics of flexomagnetoelectric coupling and provides a reliable tool for further studies.

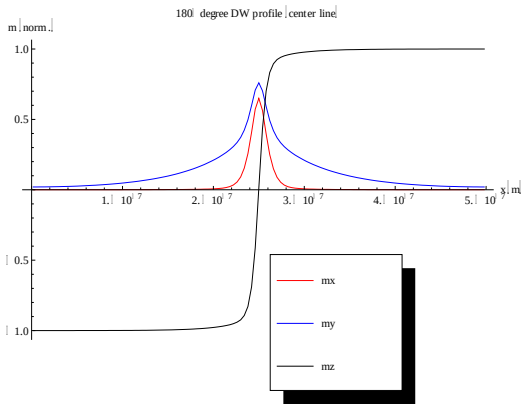

Fig. 1. Dependence of the mx, my, mz components on the x-coordinate for a 180° domain wall at an electric field E = 1.5×10^7 V/m directed along the Z-axis.

Support by the Ministry of Education and Science of the Russian Federation (State Assignment No. FRRR-2026-0010 "Structure and dynamics of topological solitons in nanosystems with magnetoelectric interactions").

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EFFECT OF DEPOSITION TEMPERATURE AND POST-GROWTH ANNEALING OF THIN MAGNETOSTRICTIVE FILMS ON THE MAGNETOELECTRIC EFFECT

Bolotina E.V.[1], *Turutin A.V.*[1], *Temirov A.A.*[1], *Kubasov I.V.*[1], *Perova N.N.*[2], *Kislyuk A.M.*[1], *Malinkovich M.D.*[1], *Parkhomenko Y.N.*[1]

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Magnetoelectric (ME) composite materials have attracted considerable attention in modern functional electronics due to their ability to efficiently convert magnetic signals into electrical ones. These composite structures show great potential for applications in highly sensitive magnetic field sensors, contactless measurement systems, and microelectronic devices.

With the rapid advancement of microelectronics and microelectromechanical systems (MEMS) technologies, the development of thin-film ME structures fabricated by vacuum deposition of functional layers has become an important and timely area of research.

One of the key factors determining the efficiency of ME conversion is the properties of the magnetostrictive layer. Amorphous FeCoSiB alloys are of particular interest because they combine high magnetostriction with excellent soft magnetic properties. It is well known that the structural and magnetic characteristics of amorphous alloys strongly depend on both the fabrication conditions and subsequent heat treatment.

In this study, the effect of substrate temperature during the deposition of thin magnetostrictive FeCoSiB films on the magnetoelectric response of composite structures based on bidomain lithium niobate (BLN) was investigated. Both the coercive field and the magnetoelectric coefficient were found to depend on the substrate temperature during the synthesis of the magnetostrictive layer.

The influence of post-deposition annealing at various temperatures on the magnetoelectric effect in BLN–FeCoSiB composite structures was also investigated. Annealing at 300°C in a magnetic field was found to be optimal, leading to improved soft magnetic properties and an increased magnetoelectric coefficient. In contrast, increasing the annealing temperature to 320°C and 350°C resulted in a deterioration of the soft magnetic properties and a reduction in the magnetoelectric effect.

Magneto-optical Kerr microscopy revealed that annealing at 300°C in a magnetic field promoted the formation of a more ordered stripe-domain structure. Prior to annealing, the domains exhibited a less ordered morphology resembling island-stripe domains.

Therefore, the optimization of the synthesis conditions and post-deposition annealing represents an effective approach for controlling the magnetoelectric properties of composite structures.

This work was supported by the Russian Science Foundation, grant no. 24-49-10017, https://rscf.ru/project/24-49-10017/

DYNAMICS OF MAGNETOELASTIC OSCILLATIONS AND MAGNETIC REORIENTATION IN A STRUCTURE WITH IRON-YTRIUM-ALUMINUM GARNET LAYERS

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The development of devices operating in the terahertz and ultra-high-frequency (UHF) ranges requires the study of nonlinear phenomena and processes in thin magnetic films and planar structures [1]. In this work, a system of equations was obtained that describes magnetic and elastic oscillations (**MEO**) in a planar structure consisting of three layers with different parameters, but close to those of yttrium-iron-aluminum garnet (YIAG) crystals of composition $Y_3Fe_4Al_1O_{12}$ [2]. The calculations were performed taking into account the values of the first K_1 and second K_2 constants of magnetic crystallographic anisotropy, saturation magnetization M_S of the YIAG crystal at three different temperatures: 50, 300 and 500 K. The external influence was specified by a circularly polarized alternating magnetic field and a constant magnetic field B directed normal to the layers of the structure. To solve the system of equations, the Runge-Kutta-Felberg method of 4-5 orders was used with normalization of the unit magnetization vector at each step. The thickness of the structure layers was chosen such that the conditions for resonant excitation of elastic oscillations by an alternating magnetic field at a frequency of 2.5 GHz were satisfied. As a result of numerical solutions of the system of equations, the time and frequency dependences of the components of the MEO amplitudes and phase portraits of magnetic oscillations were obtained at three different temperatures over a wide range of constant magnetic fields. It was found that, at all temperatures, magnetization vector reorientation occurs only at constant magnetic fields that are much weaker than the resonant field. At a low temperature of 50 K, the MEO dynamics are determined by magnetic crystallographic anisotropy, which forms complex multifrequency oscillation spectra in the YIAG layers of the structure. In the presence of magnetization vector reorientation, the peak of the MEO frequency spectrum is located at very low frequencies. At 300 K, when magnetic resonance conditions are met, harmonic oscillations occur at the frequency of the alternating field without magnetic reorientation. At a high temperature of 500 K, magnetic and elastic oscillations with a large number of orientation transitions are observed in the layers of the YIAG structure. The results of studies of the MEO dynamics at three different temperatures make it possible to select the YIAG crystal parameters that may be of greatest practical interest for the development of controlled frequency converters and signal processing elements in the microwave and terahertz frequency ranges.

This study was supported by grant No. 25-72-20063 from the Russian Science Foundation, https://rscf.ru/project/25-72-20063/

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MAGNETIZATION OF STRAINTRON HETEROSTRUCTURES ON PMN-PT AND PZT SUBSTRATES UNDER THE ACTION OF ALTERNATING AND PULSED ELECTRIC FIELDS

Klimov A.A.[1,3], Lapteva M.S.[1], Buryakov A.M.[1], Krutyansky L.M.[1,2], Preobrazhensky V.L.[1,2], Safin A.R.[3], Nikitov S.A.[3]

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Research into the influence of deformation on the physical properties of materials and structures has evolved into a promising area of solid-state electronics, commonly known as “straintronics” [1]. A convincing example of the application of the straintronic principle to the creation of materials with new properties are artificial multiferroics consisting of elastically coupled (strain-mediated) magnetostrictive and piezoelectric components. Such materials are characterized by strong magnetoelectric coupling, which is of considerable interest for a variety of technical applications. One of the intensively researched applications is a spintronic emitter of terahertz (THz) radiation controlled by a magnetic field [2]. Piezoelectric control of THz generation processes in spintronic emitters located on ferroelectric substrates is an essential step towards creating highly efficient controlled THz sources [3,4].

Currently, electrical control in the PMN-PT/W/FeGa/Pt structure. Using magneto-optical analysis, it was shown that the use of magnetic induction as a FeGa is “EA” anisotropy. An experiment was performed using time-resolved terahertz spectroscopy (THz-TDS) in transmission mode [5]. The control of the amplitude of THz radiation up to 50% and the rotation of the polarization of THz radiation by 52° was achieved by applying a constant electric voltage varying from 0V to 200V.

The first experimental data were obtained in PMN-PT/W/FeGa/Pt and PZT/$TbCo_2FeCo$ heterostructures under the application of alternating electric voltage in the frequency range up to 500 kHz [6]. The acoustic resonance frequencies of the samples were determined, and magneto-optical responses were recorded in both continuous pumping and pulsed modes.

The measured frequency characteristics of the electromechanical impedance are related to the structures (PMN-PT/W/FeGa/Pt/), (PZT/W/FeGa/Pt/) and (PZT/CoW) compatible with the numerical calculation results in the COMSOL package. The result can be used for energy-efficient control of terahertz radiation parameters in magnetic heterostructures. The report presents the strain-electronic characteristics of a PZT/CoW sample under the action of pulses of an electrical control voltage of 30 V.

The research was supported by the RSCF (grant No. 23-19-00849-П) is acknowledged.

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POSTER SESSION

Miscellaneous

Wednesday, 19 August, 17:00 - 19:00

CORRELATION BETWEEN LATTICE DYNAMICS AND OPTICAL PROPERTIES IN $HOFE_3(BO_3)_4$ FERROBORATE

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Rare-earth ferroborates $RFe_3(BO_3)_4$ attract considerable attention due to the coexistence of magnetic, optical, and magneto-optical phenomena originating from the interaction between Fe^{3+} and rare-earth subsystems [1]. Among them, $HoFe_3(BO_3)_4$ is of particular interest because of its strong spin–lattice coupling, structural anisotropy, and optical activity. In the present work, the vibrational and optical properties of $HoFe_3(BO_3)_4$ single crystals were investigated by Raman spectroscopy and optical absorption measurements.

Single crystals of $HoFe_3(BO_3)_4$ were grown by the flux method from a bismuth borate-based melt [2]. Raman spectra were recorded at room temperature using a RENISHAW inVia Raman microscope with 532 nm laser excitation in the spectral range 100–2000 cm^{-1}. Optical absorption measurements were performed in the wavelength range 190–1100 nm using a Specord 50 spectrophotometer.

The Raman spectrum demonstrates several characteristic phonon regions associated with lattice and internal vibrations of the crystal structure. Weak low-frequency modes below 300 cm^{-1} originate from external lattice vibrations involving Ho^{3+} ions. Bands in the range 400–700 cm^{-1} correspond to vibrations of FeO_6 octahedra. The most intense Raman features are observed in the high-frequency region 1200–1450 cm^{-1} and are attributed to internal B–O stretching vibrations of planar BO_3 groups. The dominant Raman peak near 1255 cm^{-1} indicates strong structural rigidity of borate units.

Optical absorption spectra reveal weak narrow bands in the visible and near-infrared regions related to intra-4*f* electronic transitions of Ho^{3+} ions. A strong increase in absorption is observed in the ultraviolet region due to $O^{2-} \rightarrow Fe^{3+}$ charge-transfer transitions inside FeO_6 octahedra. The optical band gap of $HoFe_3(BO_3)_4$ was estimated to be approximately 3.3–3.5 eV.

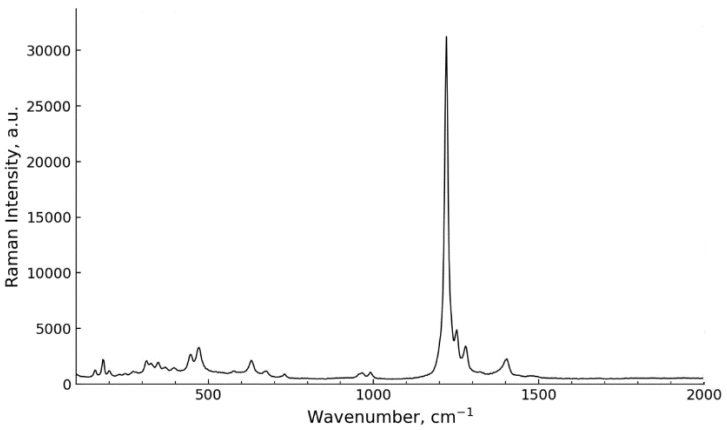

Fig. 1. Raman spectrum of $HoFe_3(BO_3)_4$ single crystal measured at room temperature.

The combined Raman and optical analysis demonstrates a direct correlation between lattice dynamics and electronic structure in $HoFe_3(BO_3)_4$. The coexistence of rigid BO_3 groups and FeO_6 octahedra provides structural stability, wide optical transparency, and potential applicability of the material in optical and magneto-optical devices.

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SUBPICOSECOND SIGN CHANGE OF TRANSVERSAL MAGNETO-OPTICAL KERR EFFECT DURING INHOMOGENEOUS DEMAGNETIZATION OF NICKEL MAGNETOPLASMONIC CRYSTALS

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The “pump-probe” femtosecond spectroscopy technique allows one to induce changes in a material properties by the first “pump” pulse and to detect consequent response by the second delayed “probe” pulse. This approach is widely employed to study ultrafast magnetization dynamics, where the “pump”-induced perturbation of the magnetization state is typically assumed to directly correspond to the measured time-resolved magneto-optical signal obtained by the “probe” pulse. However, an important and nontrivial question arises: How do ultrafast changes in optical properties affect “probed” magneto-optical response? This issue becomes particularly significant in the presence of strong spatial inhomogeneity in pump pulse absorption. An additional level of complexity emerges when resonant modes are excited by the probe pulse.

In this work, the set of three one-dimensional nickel magnetoplasmonic crystals with sinusoidal surface profiles and different corrugation depths were experimentally studied by femtosecond “pump-probe” spectroscopy. The samples support excitation of two plasmonic modes: surface plasmon-polariton (SPP), which propagated along sample surface, and standing surface plasmon (standing SP), which localized at the magnetoplasmonic crystal walls. The samples were magnetized in the transversal geometry. The pump pulse, with a fluence of 6 mJ/cm², induced ultrafast demagnetization, while the probe pulse measured the transverse magneto-optical Kerr effect (TMOKE) in the visible spectral range.

At wavelengths corresponding to SPP excitation, the observed temporal evolution of TMOKE was typical for ultrafast demagnetization of nickel: the sub-picosecond TMOKE decrease by ~40% was followed by recovery on a 10-picosecond timescale. In contrast, in the spectral window near the standing SP resonance, the transient TMOKE exhibited a sign reversal from negative to positive within the first 150 fs. This effect was further analyzed numerically. The calculations revealed pronounced spatial inhomogeneity in ultrafast heating induced by the pump pulse, leading to a corresponding inhomogeneous magnetization distribution at the surface. Probed TMOKE values at the SPP wavelengths reflected the average surface magnetization and was largely insensitive to this inhomogeneity. Whereas, the TMOKE sign reversal observed near the standing SP resonance was attributed to interference between a non-resonant reflected wave and a resonantly re-emitted wave. These contributions probe different spatial regions of the magnetoplasmonic crystal, thereby breaking the direct correspondence between the magnetization state and the measured magneto-optical response.

This work was supported by the Russian Science Foundation (project No. 24-12-00210).

MAGNETICALLY INDUCED CONVERSION OF ORBITAL ANGULAR MOMENTUM OF VORTEX BEAMS IN BISMUTH-SUBSTITUTED YTTRIUM IRON GARNET

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Vortex optical beams carrying orbital angular momentum (OAM) of light [1] have attracted great attention due to their unique properties and potential applications in high-capacity communications and optical manipulation. At the same time, magneto-optics traditionally deals with polarization state changes of light passing through magnetized media. The question of whether magnetization can affect not only polarization [2] but also the OAM mode composition of a vortex beam remains open.

In this work, we experimentally investigate the transmission of Laguerre–Gaussian vortex beams through a 10 μm thick film of bismuth-substituted yttrium iron garnet (Bi:YIG), which exhibits strong magneto-optical activity. A spatial light modulator (SLM) with a split screen is used. The left half of the SLM generates an incident vortex beam with topological charge l_{in} = –2, –1, 0, +1, +2 using a forked diffraction grating. After passing through the film magnetized in the polar system (magnetization ±*M*), the beam reflects onto the right half of the same SLM, which displays a crossed forked grating optimized by the Gerchberg–Saxton algorithm to distribute energy evenly over nine diffraction orders [3]. The resulting diffraction pattern is recorded by a CMOS camera, allowing changes in the OAM mode content of the transmitted beam to be analyzed [4].

An ideal vortex beam with a nonzero resulting topological charge has a phase singularity on the beam axis; therefore, its intensity in the beam center is close to zero and a dark spot is observed. If other OAM components are admixed to this vortex mode, the phase singularity is partially destroyed and the beam center becomes brighter. Therefore, the appearance or increase of intensity in the beam center can be used as an indicator of admixture of other OAM modes into the analyzed vortex order.

For incident beams with l_{in} = +1 and l_{in} = –1 no pronounced change in the beam-center intensity was observed. In contrast, for l_{in} = –2 a clear increase of the intensity in the beam center was found in the diffraction orders (0,-1) and (-1,0) of the crossed fork grating. This central filling can be interpreted as a magnetically induced conversion into an OAM component with l = +1, with an estimated conversion efficiency of about ~10^{-4} of the beam power. Within the experimental accuracy, this effect does not depend on the sign of the magnetization, while the radii of the bright rings remain unchanged. This confirms that the observed central brightening is not caused by defocusing, but is associated with a change in the OAM mode composition of the transmitted beam.

This work was supported by the Russian Science Foundation (project No. 24 12 00210).

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STRUCTURAL AND OPTICAL PROPERTIES OF POROUS SILICON LAYERS SYNTHESIZED BY ELECTROCHEMICAL ANODIZATION OF N-SI (100) SUBSTRATES

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In this work, layers of porous silicon with pronounced nanostructural properties were successfully formed on n-Si (100) substrates by the method of electrochemical anodic etching at current densities J = 50 mA/cm² and 150 mA/cm² and anodization times t = 20, 40, 60 min (see Fig. 1).

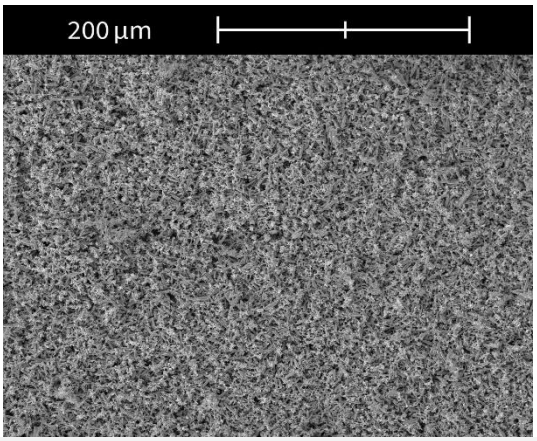

Fig. 1. SEM image of the surface of an etched n-Si (100) sample at a current density J = 50 mA/cm²

According to Raman spectroscopy data, the main phonon peak is localized at 514.15 cm^{-1} (relative to the reference value for bulk silicon of 520.8 cm^{-1}). The formed layers retain a high degree of crystallinity. The observed low-frequency shift confirms the manifestation of the phonon spatial confinement effect in the elements of the silicon skeleton. It was established that variation of the anodization time (20, 40, 60 min) does not have a significant effect on the position of the Raman peak, which indicates high reproducibility of the geometric and morphological parameters of the pores throughout the depth of the layer.

It was found that the synthesized samples exhibit intense and stable photoluminescence in the visible range of 640–700 nm. The position of the PL maxima (668–674 nm) and their systematic shift with increasing anodization time are due to quantum-size effects in the nanocrystalline phase with a characteristic crystallite size of 3–5 nm. The relatively symmetric shape of the dominant bands indicates the dominant role of interband recombination in quantum-confined objects and the insignificant contribution of non-radiative or deep defect states to radiative recombination immediately after synthesis.

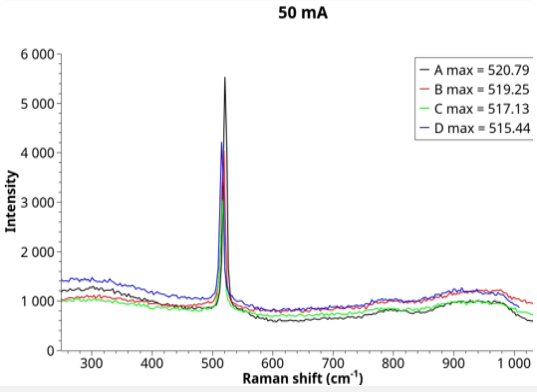

Fig. 2. Raman spectra of an etched n-Si (100) sample at a current density J = 50 mA/cm²

The obtained results demonstrate the high efficiency of the selected electrochemical etching regimes for the precise creation of functional silicon-based nanostructures with controllable optical properties, promising for integration as active elements in silicon photonics, light-emitting devices, and sensor systems.

EFFECT OF NEODYMIUM IMPURITY ON THE ACOUSTO-OPTICAL PROPERTIES OF LEAD MOLYBDATE CRYSTALS

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The effect of neodymium impurity on the effective photoelastic constant and acousto-optic figure of merit M_2 in lead molybdate crystals, which are widely used as active media in acousto-optic modulators and deflectors [1], has been studied. Neodymium-doped lead molybdate crystals ($PbMoO_4$:0.2Nd) exhibit paramagnetic properties because the ground state of the Nd^{3+} ion has a 4f electron shell with uncompensated spin and orbital angular momentum, making it a typical paramagnetic center. Therefore, such crystals can be used as active media for solid-state lasers and EPR spectroscopy.

PbMoO4 samples doped with neodymium (0.2 mol.%) were oriented along the [100] and [001] directions. The measurements were performed by the Bragg diffraction of light (λ_0=632.8 nm) on longitudinal acoustic waves with frequencies of 0.4–1.2 GHz, which were excited by X-cut quartz piezoelectric transducers. A modified Dixon-Cohen method was used to determine the effective photoelastic constants p_{eff} and acousto-optic figure of merit M_2:

$$M_2 = \frac{n_1\, n_2\, p_{eff}^2}{\rho V^3}, \qquad (1)$$

where n_1 and n_2 are the refractive indices of incident and diffracted light, ρ is the density, V is the velocity of the acoustic wave. A fused quartz sample was used as a standard. The acoustic wave velocities were determined from the Bragg diffraction angle of light on these waves with an accuracy of approximately 0.2% [1]. The accuracy of determining the M_2 value was ~20%.

The results of the study showed that in $PbMoO_4$:0.2Nd crystals, a strong dependence of the effective photoelastic constant and the acousto-optic quality factor on the direction of light propagation and polarization is observed. It is shown that the dependence of the effective photoelastic constant on the direction of polarization of light incident on a PbMoO4:0.2Nd sample along the [010] crystallographic axis, which is well described by the expression:

$$p_{eff}^2 = p_{11}^2\, cos^2\, \psi + p_{31}^2\, sin^2\, \psi, \qquad (2)$$

where Ψ is the angle between the light polarization vector and the [100] axis in the (010) plane. It can be seen that by changing the direction of polarization of the incident light, the efficiency of Bragg diffraction of light can be controlled.

Neodymium ions introduced into the lead molybdate crystal lattice occupy interstitial sites and vacancies, predominantly aligning or shifting along the [001] crystallographic axis. The disruption of the ideal lattice symmetry by paramagnetic Nd ions changes the local polarization characteristics of the medium under the influence of elastic deformations. As a result, photoelasticity becomes highly dependent on the direction of acoustic wave propagation and the direction of light polarization.

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STUDY OF Cu_2S NANOSTRUCTURES IN SILICON USING COREAFM

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Semiconductor heterostructures and multilayer systems obtained by depositing two or more materials on a semiconductor substrate are widely used in modern electronic and optoelectronic devices. Recently, a new direction of nanotechnology based on the formation of ordered nanostructures on semiconductor surfaces has been actively developing. Investigation of the topology and morphology of such structures is important for understanding their physical properties and technological applications.

In the present work, Cu_2S nanostructures formed in silicon crystals were investigated using atomic force microscopy (CoreAFM). As an initial material, Cz-grown KDB-10 silicon single crystals were used. Sulfur was first introduced into silicon from the gas phase at 1250°C. Subsequently, copper was deposited onto the surface under vacuum conditions (~10^{-4} mm Hg) and diffused into the crystal at 1250°C. The obtained samples were subjected to additional thermal treatment in the temperature range of 800–960°C. Previous studies have shown that at approximately 920°C the electrical parameters of the samples return to those of the initial silicon crystal, indicating an effective interaction temperature between sulfur and copper impurities [1].

To clarify the nature and formation mechanism of impurity complexes, the sample surfaces were chemically cleaned and examined by atomic force microscopy. Surface topography images were obtained in static scanning mode over an area of 1×1 μm². The AFM analysis revealed the presence of nanoscale objects on the sample surfaces. The heights of the observed surface features were found to be approximately 44.3 nm and 11.4 nm for different samples. According to literature data, sulfur atoms mainly occupy substitutional lattice sites in silicon, whereas copper atoms tend to be located in interstitial positions or form clusters near dislocations [2,3].

The obtained results indicate that sulfur atoms interact with copper atoms, leading to the formation of chemically bonded Cu_2S-related nanostructures. Such interactions contribute to a more uniform distribution of atoms across the crystal surface and significantly affect the morphology of the silicon substrate. The AFM observations support the assumption that sulfur atoms can bind neighboring copper atoms, resulting in the formation of stable impurity complexes within the silicon matrix.

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INVESTIGATION OF THE ATMOSPHERIC OZONE LAYER USING THERMAL RADIATION SPECTRA

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This work is devoted to the study of atmospheric ozone by means of ground-based observations using thermal radiation spectra, the photochemical theory of ozone, the results of observations of its vertical distribution and total amount, the dependence of atmospheric ozone on geographical conditions, climate, and season, the processes of its transport and their analytical theory, which makes it possible to diagnose a number of important features of the general circulation of the atmosphere, and finally, calculations of atmospheric heating caused by ozone and the corresponding temperature changes.

Ozone, being a minor gaseous component of the atmosphere, absorbs harmful ultraviolet radiation and protects all living organisms on Earth from the destructive part of solar radiation. The highest ozone density is observed at altitudes of about 18–24 km, while the largest portion of ozone in the total atmospheric volume is found at an altitude of about 42 km. The chemical properties of ozone determine its strong oxidizing ability; therefore, in the troposphere ozone acts as an air pollutant, exerting toxic effects on human health and ecosystems. At ordinary temperatures, ozone oxidizes all metals except gold and platinum-group metals. Monitoring of ground-level ozone concentrations is carried out in order to prevent an increase in its content, since this may lead to deterioration of air quality.

The nearly century-long history of studies of the Earth’s ozone layer includes two main directions: monitoring of its stratospheric and tropospheric content through remote and in situ measurements, as well as theoretical investigations of the processes influencing ozone formation and destruction. Monitoring of ozone content must be carried out with high spatial and temporal resolution in order to accurately understand changes in the planet’s ozone layer and their effects on ultraviolet radiation levels, air quality, and climate. Theoretical studies of atmospheric ozone variability are mainly conducted through the development of numerical models describing physical and chemical processes in the troposphere and stratosphere.

POSTER SESSION

Spintronics and Magnetotransport II Magnetophotonics

Wednesday, 19 August, 17:00 - 19:00

MANIPULATION OF SKYRMIONS VIA STRAIN GRADIENT

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Strain engineering provides a powerful means to control magnetism, offering promising pathways for flexible sensing technologies in applications such as extended reality and humanoid robotics [1,2]. Understanding how mechanical stress influences magnetic properties is essential for high-performance flexible and wearable magnetoelectronic devices [3–5]. However, the complex strain distributions in flexible systems make their regulatory effects on magnetic behavior difficult to reveal. Here, we unveil the modulation of magnetic domain structures in multilayers via localized strain gradients [6]. By fabricating microscale periodic wrinkles in flexible Pt/Co/Ta multilayers, we introduce strain gradients with tunable magnitudes and directions. Magnetic force microscopy reveals that both the density and size of skyrmions are synchronously modulated by the in-plane strain gradient profile, enabling significantly broader tunability than achievable with uniform strain. This approach is reversible, cyclable, and transferable across different magnetic multilayer systems. The observed behavior is attributed to strain- and strain-gradient-mediated modulations of the Dzyaloshinskii–Moriya interaction and magnetic anisotropy, as supported by micromagnetic simulations.

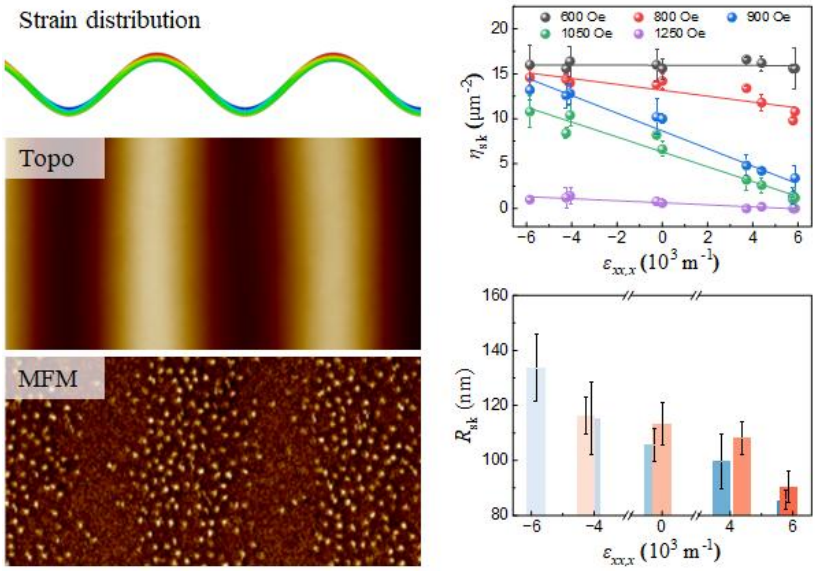

Fig. 1. The topology and corresponding MFM image of the wrinkled Pt/Co/Ta multilayers, in which strain gradient modulates the density and size of skyrmions simultaneously.

Support by NSFC is acknowledged.

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FLUXGATE-TYPE SECOND-HARMONIC READOUT IN EXCHANGE-BIASED NIFE/CU/IRMN PLANAR HALL MAGNETORESISTIVE SENSORS

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Planar Hall magnetoresistive (PHMR) sensors are promising for compact in-plane magneticfield detection because they combine thin-film geometry, magnetotransport-based electrical readout, and microfabrication compatibility. However, direct PHMR readout is usually carried out in the dc or low-frequency range, where dc offset, thermal baseline drift, and low-frequency 1/f noise can limit weak-field measurements. Here, we present a fluxgate-type second-harmonic readout approach for exchange-biased PHMR sensors based on a NiFe/Cu/IrMn multilayer thin film.

The sensor was based on an exchange-biased NiFe/Cu/IrMn magnetic stack patterned into a planar Hall geometry. The Cu interlayer was introduced to modify the coupling at the ferromagnet/antiferromagnet interface. An external AC magnetic modulation field was applied perpendicular to the exchange-bias/current direction, and the transverse output was measured using phase-sensitive second-harmonic detection. This shifts the field-dependent magnetotransport signal from the dc channel into a harmonic detection band.

A representative NiFe/Cu (0.5 nm)/IrMn planar Hall sensor showed a clear modulation dependent second-harmonic voltage response. As the AC modulation field increased from 0.2 to 3.0 mT, the peak-to-peak V_{2f}output increased from approximately 28 μV to 2.75 mV over a dc field sweep of −5 to +5 mT. The field-to-harmonic transfer slope around ±1 mT increased from approximately 0.0070 to 0.719 V/T, corresponding to about a 100-fold enhancement. Noise measurements showed that the AC-modulated 2f readout reduced the output noise spectral density from 19.38 to 12.35 nV/√Hz at 0.01 Hz and from 7.41 to 1.76 nV/√Hz at 1 Hz compared with direct PHMR readout. The response changed sign around zero field and showed an approximately antisymmetric field dependence, indicating that the harmonic output originates from the nonlinear magnetic-field response of the exchange-biased planar Hall sensor.

These results show that fluxgate-type AC magnetic excitation can convert the nonlinear PHMR response into a measurable harmonic magnetotransport signal while suppressing low frequency output noise. The approach provides a compact, core-free readout route for exchange biased PHMR sensors and supports the development of low-noise, high-sensitivity weak-field magnetic sensing platforms.

RESONANT FREQUENCY OF THE EQUIVALENT OSCILLATORY SYSTEM OF A SPINTRONIC OSCILLATOR

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Spintronic nano-oscillators are compact microwave sources with frequency tuning by current and external magnetic field. For circuit-level design, their magnetization dynamics should be expressed through engineering parameters. This work summarizes a small-signal equivalent LC model of an easy-plane spintronic oscillator, where precession of the free ferromagnetic layer is described by effective inductance and capacitance [1].

The resonant frequency is found from the standard relation for a linear oscillatory circuit. In the considered regime the effective capacitance is determined by the hard-axis anisotropy field and is nearly current-independent, so the frequency-current behavior is governed mainly by the inductive characteristic obtained previously for the same equivalent model [2].

Varying the external-field components $B_{e,x}$ and $B_{e,y}$ shows that increasing the internal current IL decreases the effective inductance and therefore monotonically increases the resonant frequency. A larger transverse component $B_{e,y}$ makes the dependence steeper, whereas predominance of the longitudinal component $B_{e,x}$ flattens the characteristic.

Variation of internal parameters was analyzed through the product M_sV_s. A smaller product gives higher resonant frequencies and stronger current sensitivity; increasing saturation magnetization and free-layer volume shifts the frequency downward and reduces the slope. The corresponding dependence is shown in Fig. 1.

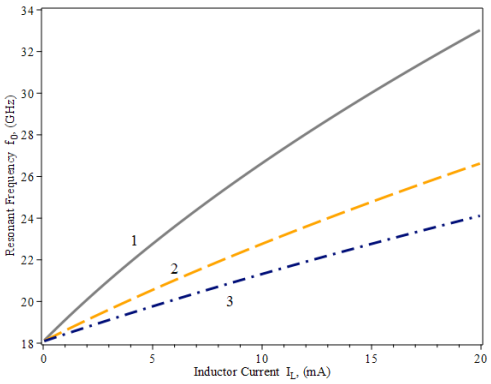

Fig. 1. Dependence of the resonant frequency of the oscillatory circuit on the current flowing through the coil for different values of the internal parameters of the SO. 1 – M_s = 398 kA/m, $V_s = 2.78\times10^{-24}$ m^3; 2 – M_s = 796 kA/m, $V_s = 5.56\times10^{-24}$ m^3; 3 – M_s = 1194 kA/m, $V_s = 8.34\times10^{-24}$ m^3.

The model is limited to small azimuthal deviations, assumes a macrospin free layer, and neglects defects, inhomogeneity, and thermal fluctuations. Within this domain it gives a deterministic circuit representation directly linked to the physical parameters of the magnetic system.

The results show that the resonant frequency of the equivalent circuit can be predictably controlled by external field, current, and structural parameters, with values consistent with ferromagnetic-resonance frequencies for related structures [3]. This supports physics-based SPICE-compatible modeling without time-domain solution of the Landau-Lifshitz-Gilbert equation.

This work was supported by the Russian Science Foundation, Grant No. 25-79-20053.

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INFLUENCE OF 2D SEMICONDUCTOR BANDGAP ON EXCHANGE INTERACTION AND THZ EMISSION IN AFM-BASED SPINTRONIC EMITTERS

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Generation and control of spin currents in antiferromagnet-based (AFM) heterostructures represent one of the most promising directions in modern terahertz spintronics. Unlike ferromagnets, AFM materials exhibit intrinsic magnetic resonances in the terahertz frequency range due to strong exchange interactions, while also possessing zero net magnetic moment and high stability against external magnetic fields [1]. Interest in such systems is largely driven by ultrafast spin–phonon interactions, which enable the excitation of coherent magnon modes on picosecond timescales [2]. One of the key challenges remains the control of spin transport efficiency and interfacial exchange interactions in multilayer heterostructures, which determine the characteristics of the THz response [3].

In this work, monolayers of two-dimensional (2D) semiconductors with different band gaps are incorporated into 2D/FM/AFM heterostructures to control spin transport properties. These interlayers modify the interfacial electronic structure and tune the potential barrier, thereby affecting the transport of nonequilibrium spin-polarized carriers and the efficiency of interfacial spin transfer. This configuration also allows control over the exchange interaction between the ferromagnetic and antiferromagnetic layers.

To investigate these mechanisms, a series of optimized spintronic THz emitters with varying 2D monolayers was experimentally studied. Their magnetic and emission properties were characterized using time-resolved terahertz emission spectroscopy (TES) and terahertz magnetometry (TSM). The results show that adjusting the 2D layer parameters alters the exchange coupling, leading to corresponding changes in the exchange bias field Heb, coercive field Hc, and the THz emission amplitude.

The main focus is on the correlation between the 2D band gap, exchange bias, and THz emission characteristics. Modifying the exchange anisotropy via interlayer selection influences both the amplitude and polarization of the THz pulse, demonstrating that 2D semiconductor interlayers provide an effective route for designing high-performance THz spintronic emitters with tailored properties.

This work was supported by the Russian Science Foundation (Grant No. 24-79-10302)

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ENHANCEMENT OF SPIN ORBIT TORQUE IN HETEROSTRUCTURES BASED ON PLATINUM AND MOLYBDENUM DITELLURIDES

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The development of modern nanoelectronics and energy-efficient magnetic random-access memory (MRAM) devices requires a transition to current-induced magnetization switching via the spin-orbit torque (SOT) mechanism. Since traditional heavy metals exhibit moderate charge-to-spin conversion efficiency, a promising solution is the use of topological materials, specifically transition metal dichalcogenides such as platinum ditelluride ($PtTe_2$) and molybdenum ditelluride ($MoTe_2$). The combination of these materials allows for the utilization of the high spin conductivity of $PtTe_2$ and the ability of $MoTe_2$ to generate spin currents with out-of-plane polarization, which is critically important for the deterministic switching of perpendicularly magnetized layers.

In this work, magnetic heterostructures based on transition metal dichalcogenides (Al_2O_3/$MoTe_2$/Pt/Co/Mo/Si, Al_2O_3/$PtTe_2$/Pt/Co/Mo/Si, and Al_2O_3/$PtTe_2$/$MoTe_2$/Pt/Co/Mo/Si) were synthesized and investigated to quantitatively evaluate the SOT generation efficiency. The spin-torque ferromagnetic resonance (ST-FMR) technique was employed to analyze the spin current parameters [1, 2]. This method is based on the excitation of magnetization precession in the ferromagnetic layer under the influence of a radio-frequency current, enabling the direct determination of the spin Hall angle through the analysis of the symmetric and antisymmetric components of the resonance signal [3].

The research results demonstrated that ultrathin $MoTe_2$ films exhibit a non-zero spin Hall angle comparable to that of conventional heavy metals. A negative spin Hall angle was observed in the heterostructure combining $PtTe_2$ and Pt layers. Considering that this parameter is positive for pure platinum, it can be concluded that the contribution of $PtTe_2$ has an opposite sign and exceeds the contribution of platinum in absolute magnitude.

The key result of this work is the demonstration that the combination of the topological materials $PtTe_2$ and $MoTe_2$ leads to a significant enhancement of the spin-orbit torque. The magnitude of the spin Hall angle in such a heterostructure exceeds the values for bulk platinum by more than a factor of 5 and is an order of magnitude greater than the values for an isolated thin $MoTe_2$ layer. This indicates the bulk nature of the effect. Furthermore, the interface with $PtTe_2$ plays a significant role, providing a substantial additional contribution to the overall efficiency of spin-orbit torque generation.

This work was supported by Russian Scientific Foundation project № 26-72-31015.

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INVESTIGATION OF COMPETING TERAHERTZ GENERATION MECHANISMS IN Co/Mo AND Co/Mo/Pt SPINTRONIC EMITTERS

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Spintronic terahertz (THz) emitters have attracted considerable attention from the scientific community due to the possibility of creating broadband emission and flexible control over its polarization [1]. Traditionally, the primary generation mechanism in such structures (e.g., Co/Pt) is the inverse spin Hall effect (ISHE) [2]. However, interface engineering provides access to additional nonlinear optical effects. In this work, we investigate anisotropic THz generation in Co/Mo heterostructures and Co/Mo/Pt multilayer systems.

Recent studies [3] of a Co(3 nm)/Mo(3 nm) bilayer system demonstrated unconventional, polarization-dependent anisotropic THz emission. Generation in this structure occurs due to the combined action of the ISHE in the molybdenum layer and second-order nonlinear processes, such as optical rectification. It was established that approximately 70% of the signal amplitude is an odd-in-magnetic-field contribution from the ISHE, whereas the remaining 30% accounts for even-in-field components. The emergence of this nonlinear contribution is attributed to the breaking of inversion symmetry at the Co/Mo interface.

To further study the influence of interfaces and spin current transport, three-layer structures with a platinum (Pt) layer were synthesized and studied. In a series of samples with a thin Mo interlayer (Co (3 nm)/Mo (0.5–1.5 nm)/Pt (1.5–2 nm)), no nonlinear generation effects were observed. However, decreasing the Mo layer thickness led to a significant increase in the overall THz signal amplitude. This behavior is explained by the fact that the spin current efficiently tunnels (is injected) through the ultrathin molybdenum layer directly into the platinum, with high efficiency of spin current conversion to charge current. The strong THz signal from the ISHE in the Pt layer dominates the nonlinear effects arising at the Co/Mo interface.

To isolate the nonlinear contribution, a new architecture of Pt(0.5-1.5 nm)/Mo(2-3 nm)/Co(3 nm) structures was developed with variable platinum thickness while maintaining an optimal molybdenum thickness. Controlled reduction of the Pt layer thickness will proportionally reduce the dominant contribution of the inverse Hall effect (ISHE). This will allow for a more precise identification and detailed study of the nonlinear optical properties of the generated THz signal at the Co/Mo interface.

This work was supported the Ministry of Science and Higher Education (Contract No. FSFZ-2025-0002).

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ANISOTROPY OF MAGNETORESISTANCE ALONG EQUIVALENT CRYSTAL AXES IN GAMNAS WITH DIFFERENT MN CONCENTRATION

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Nowadays, GaMnAs is considered as a model system for studying ferromagnetic ordering in dilute magnetic semiconductors. The concentration of magnetic impurities is one of the most important factors affecting ferromagnetic order in this class of materials [1]. This fact motivates interest in studying the influence of Mn concentration on the magnetic properties of GaMnAs. The existence of a correlation between the magnetic and transport properties of GaMnAs makes it possible to study magnetic properties using magnetotransport measurements. This work presents the results of studies of the dependence of magnetoresistance (MR) on the Mn concentration in the GaMnAs epitaxial layer.

The GaMnAs epilayers were grown by low-temperature molecular beam epitaxy on semi-insulating (001) GaAs substrate. Mn concentration was 1.41, 2.42 and 2.93 at.% for A1, A2, A3 samples, respectively. The technology of the epitaxial growth in general corresponded to that described in [2]. The MR values were measured under magnetic field applied along the current at T = 20 K. For comparison of the results obtained for different samples MR values was determined as $R_H = (R(H) - R(0))/R(0)$, where $R(H)$ and $R(0)$ are the resistances measured at a given value of H and at zero field, respectively.

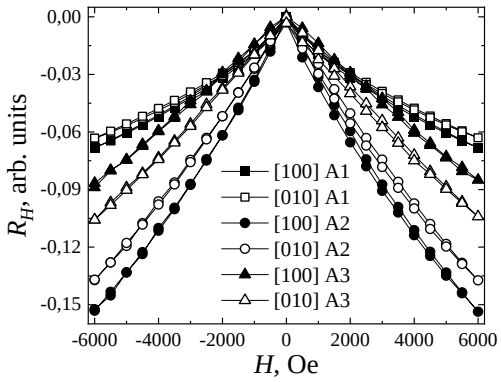

Fig. 1. MR of GaMnAs with different Mn concentrations, measured at 20 K along equivalent crystallographic axes

Fig 1 shows MR data measured along [100] and [010] axes. One can see that the differences in the MR values measured along equivalent axes increase with increasing Mn concentration: in the case of sample A1, the differences are practically negligible, whereas for A2 and A3 samples, the difference in R_H value at $H = 6000$ Oe reaches 11% and 21%, respectively. This result can be associated with spatially oriented structures related with the non-uniform distribution of the Mn impurity. It was shown [3] that such structures are oriented along the <110> direction and cause anisotropy of MR in this direction. The fact that increasing of Mn concentration leads to anisotropy along the <100> directions can be explained as follows. The increase in Mn concentration saturates the growth of spatially oriented structures along the [110] direction while excess Mn atoms contribute to the formation of inhomogeneities along the <100> directions.

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ANGULAR DEPENDENCE OF THZ EMISSION FROM SPINTRONIC W/COFEB/PT HETEROSTRUCTURES INTEGRATED WITH BRAGG MIRRORS

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Spintronic terahertz (THz) emitters based on the generation of ultrafast spin currents and their conversion into charge currents via the inverse spin Hall effect (ISHE) in ferromagnet/heavy metal heterostructures are considered promising compact broadband THz radiation sources [1,2]. Despite the high efficiency of modern spintronic emitters, the problem of controlling and enhancing THz generation using photonic and interference effects remains insufficiently studied. One of the promising approaches is the integration of spintronic heterostructures with dielectric periodic structures capable of modifying the electromagnetic field distribution in the active region [3,4].

In this work, the angular dependence of THz emission from a spintronic heterostructure integrated with a dielectric Bragg mirror (BM) was investigated. The studied structure had the following architecture: SiO_2 / dielectric Bragg mirror/ Ta_2O_5 / W (2 nm) / CoFeB (2 nm) / Pt (2 nm). The dielectric BM films were fabricated by chemical vapor deposition (CVD) by a commercial manufacturer, while the metallic layers of the spintronic emitter were deposited by magnetron sputtering under an in-plane external magnetic field of 1 kOe. THz generation in the structure is associated with ultrafast spin current generation and its conversion into charge current via ISHE.

THz generation was investigated using terahertz time-domain spectroscopy (THz-TDS) under excitation by 800 nm femtosecond laser pulses. The influence of the sample rotation angle with respect to the direction of the incident optical pump on the THz signal amplitude was studied.

The BM was designed for a wavelength of 835 nm. It was experimentally established that the maximum reflectance of the BM was achieved at an angle of approximately 32° between the sample surface normal and the direction of the incident optical pump. Under these conditions, the radiation reflected from the BM was most efficiently absorbed in the region of the spintronic THz emitter, resulting in an increase in the generated THz signal amplitude. In contrast, no pronounced angular dependence of the THz signal was observed for the W (2 nm) / Co (2 nm)/Pt (2 nm) structure. The obtained results indicate a significant influence of interference effects and electromagnetic field redistribution in the multilayer structure on the efficiency of THz generation.

The obtained results demonstrate the prospects of using dielectric Bragg mirrors for enhancing the efficiency of spintronic THz emitters and controlling the characteristics of the generated THz radiation.

This work was supported by the Russian Science Foundation (Grant No. 23-19-00849-П).

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THZ GENERATION IN HYBRID SPINTRONIC STRUCTURES BASED ON TWO-DIMENSIONAL MATERIALS

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Spintronic terahertz (THz) emitters represent a fundamentally different approach to converting optical energy into electromagnetic radiation compared to conventional sources. The key mechanism underlying their operation is the conversion of a spin current into a charge current via the inverse spin Hall effect or the inverse Rashba–Edelstein effect. However, the development of this field faces two fundamental limitations. First, the optical-to-terahertz conversion efficiency remains critically low (~0.01%), preventing competition with crystalline sources. Second, current designs are restricted to a limited set of materials with strong spin–orbit coupling, with platinum being the most efficient spin-to-charge converter.

In this context, two-dimensional transition metal dichalcogenides (TMDs) are considered a new class of materials that can replace the nonmagnetic metal layer. For example, the integration of MoS2 or WSe2 into spintronic THz emitters has demonstrated the feasibility of using TMDs as active layers; however, the efficiency does not exceed ~4% even relative to conventional Co/Pt structures.

In this work, a series of spintronic THz emitters was fabricated by depositing a 3-nm cobalt layer onto two-dimensional WSe2, WS2, WSe2/graphene, and WS2/graphene layers grown by CVD on sapphire substrates. In addition, to investigate threshold effects in THz generation, a series of Co/Pt structures with varying ferromagnetic layer thicknesses in the range of 0.5–1.5 nm was prepared. Terahertz spectroscopy was used to characterize the emitted THz radiation and to evaluate the contribution of the TMD bandgap to the THz pulse amplitude. The obtained results support the hypothesis that the bandgap in TMDs acts as an energy filter for photoexcited electrons in the cobalt layer. Structures incorporating WSe2/graphene and WS2/graphene enabled analysis of the contribution of enhanced spin–orbit interaction to the THz emission amplitude. Threshold effects were also identified, and the role of the Co ferromagnetic layer thickness in the range of 0.5–3 nm in determining the THz emission amplitude was demonstrated.

This work was supported the Ministry of Science and Higher Education (Contract No. FSFZ-2025-0002)

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LASER-GENERATED GHZ SURFACE ACOUSTIC WAVES DURING MAGNETOSTRUCTURAL PHASE TRANSITION IN FERH

Mogunov Ia.A.[1], *Klokov A.Yu.*[2], *Frolov N.Yu.*[2], *Sharkov A.I.*[2], *Protasov A.V.*[3], *Zhezlyaev G.E.*[3], *Devyaterikov D.I.*[3], *Gimaev R.R.*[4], *Zverev V.I.*[5], *Kalashnikova A.M.*[1]

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In spintronics, surface acoustic waves (SAWs) are used for efficient magnon manipulation due to the matching range of dispersions [1]. High-frequency broadband SAWs and spin waves can be generated by fs lasers, enabling diverse magnetoacoustic regimes [1,2]. Near-equiatomic FeRh is widely used in spintronics owing to its first-order metamagnetic phase transition (PT) from antiferromagnetic to ferromagnetic states, accompanied by a 1% lattice change [3]. This PT can be triggered by heating above T_{PT}~370 K or by fs laser pulses with above-threshold fluence [3]. Here, we explore the laser generation of SAWs in FeRh and their propagation considering temperatures and pump fluences both below and above the PT.

We used a single-crystalline 60-nm $Fe_{49}Rh_{51}$ film epitaxially grown on MgO(001) substrate – a system with the best film quality. We performed fs pump-probe scanning microscopy experiments with sub-micron resolution. Pump pulses were able to excite both PT and quasi-Rayleigh SAW pulses (central wavenumber 1-4 rad/μm, frequency 1-3 GHz). SAWs were detected either by strain-induced reflectivity change (photoelastic effect), or surface displacement via interferometry.

Firstly, we investigated the laser generation of SAWs in FeRh (details in [4]). Below T_{PT}, the laser-induced PT contributes dominantly (80%) to the SAW strain, leading to nonlinear fluence dependence. When FeRh is heated within the AFM phase, this contribution activates at lower fluences yielding higher SAW amplitudes. When FeRh is heated into the FM phase, the detected SAW amplitude drops sharply as the PT contribution 'switches off'. The drop differs between photoelastic and interferometric measurements, suggesting a change in photoelastic constants across the PT. The demonstrated level of control over SAW amplitudes allows acoustical cross-talk between logical elements in a hypothetical magnetoacoustic FeRh-based device.

Secondly, we examined the propagation of laser-generated SAWs in FeRh/MgO(001) system (details in [5]). We investigated SAW amplitudes, spectra, phase and group velocities, their dispersions and anisotropies with varying temperature and pump fluence. We find that the laser-generated SAW is primarily localized in the MgO substrate, so its propagation is only marginally affected by the PT in FeRh film. Nonetheless, dispersion (manifested as chirping), group velocity values, and measurable changes in velocity anisotropy are important for designing devices based on FeRh/MgO(001). Finally, we tracked SAWs over distances exceeding 160 μm, confirming their applicability for realistic devices.

Support by RSF grant № 24-72-00111 is acknowledged.

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Plenary

Thursday, 20 August, 09:00 - 10:30

SUPERCONDUCTOR–MAGNET HYBRID STRUCTURES: RECENT PROGRESS AND NEW DIRECTIONS

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HSE University, 101000 Moscow, Russia

Recent years have witnessed rapid progress in hybrid structures combining superconductors with ferro- and antiferromagnetic materials, driven both by fundamental interest in competing quantum orders and by prospects for superconducting spintronics, cryogenic memory, and low dissipation information technologies. In these systems, superconducting correlations acquire complex spin structure due to magnetic proximity effects, leading to a rich variety of phenomena including spin-triplet pairing, π- and φ-Josephson junctions, superconducting spin valves, spin-polarized supercurrents, nonequilibrium spin transport, and magnetization dynamics controlled by superconductivity. Antiferromagnets have recently emerged as especially promising components of superconducting hybrid devices because of the absence of stray fields, ultrafast dynamics, and compatibility with nanoscale integration.

This talk presents an overview of recent theoretical and experimental developments in superconductor/ferromagnet and superconductor/antiferromagnet heterostructures, with particular emphasis on proximity-induced triplet correlations and their role in superconducting spintronics. Special attention is devoted to the emergence of Néel triplet superconducting correlations in compensated superconductor/antiferromagnet structures, their interplay with spin–orbit coupling, and the resulting anisotropic superconducting properties.

Recent advances in Josephson hybrid structures, nonequilibrium and dynamical proximity effects, superconducting spin transport, and hybrid collective excitations in magnetic superconducting systems will also be discussed. Particular emphasis will be placed on emerging two-dimensional and van der Waals superconducting heterostructures combining Ising superconductors and antiferromagnets. In particular, we will discuss the prediction of proximity induced orbital antiferromagnetism in $NbSe_2/MnPS_3$ heterostructures, where spin–orbit coupling and staggered magnetic order generate atomic-scale loop supercurrents and phase-modulated superconducting states.

Finally, perspectives for future superconducting electronics, antiferromagnetic superconducting spintronics, and quantum technologies will be outlined.

QUANTUM MAGNONICS: CONTROLLING A SINGLE MAGNON AND QUANTUM SQUEEZING

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Quantum magnonics has emerged as a new research frontier bridging quantum physics and condensed matter physics. This talk outlines the background of this field and highlights recent progress in my research group. First, I present the quantum control of a single magnon, including the deterministic generation of a single-magnon state and its coherent superposition with the vacuum (zero-magnon state) [1]. Second, I report magnon squeezing achieved in the quantum regime, demonstrating this key phenomenon in quantum nonlinear magnonics [2]. By further enhancing the magnon blockade effect, we demonstrate that the system functions as a coherent magnonic qubit, showcasing its potential for quantum information applications.

Support by the National Natural Science Foundation of China is acknowledged.

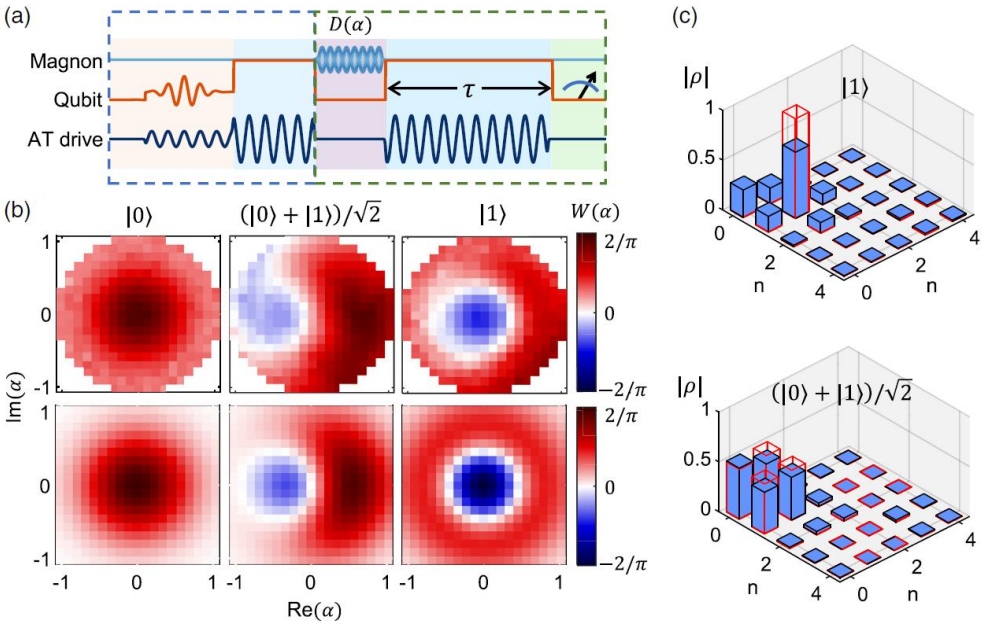

Fig. 1. Quantum tomography data and reconstructed density matrices for the generated magnon states.

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ORAL SESSION

Spintronics and Magnetotransport

Thursday, 20 August, 11:00 - 13:15

HIGHLY ANISOTROPIC SPIN TRANSPORT IN ALTERMAGNETS

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The altermagnet exhibits the nonrelativistic spin splitting that enables all-electrical generation of spinpolarized currents beyond the SOC. Here, we report on a study on the anisotropic spin polarization and charge-to-spin conversion in altermagnets. Based on the general spin-group analysis, we identify the spin point groups sustaining the finite spin polarization and charge-to-spin conversion. We show that the spin polarization and charge-to-spin conversion vanish along any direction for the g-wave and i-wave altermagnets while the spin polarization and charge-to-spin conversion are significantly anisotropic for the d-wave altermagnet. We further derive the analytical expressions for the anisotropic spin polarization and anisotropic conversion ratio for the d-wave altermagnets. Then, we exemplify those phenomena in several representative altermagnets based on the density functional theory calculations. The highly anisotropic charge-to-spin conversion efficiency, varying from zero to several tens of percent, was demonstrated. Our work shines more light on the exploration of the nonrelativistic generation of spin currents in altermagnets.

The research was supported by the National Natural Science Foundation of China (Grant No. 12274102).

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MAGNON CURRENT GENERATION AND MAGNON TORQUE-DRIVEN MAGNETIZATION SWITCHING

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Beyond electron charge, information can also be carried by electron spin, orbital, and magnon degrees of freedom, leading to the development of spintronics, orbitronics, and magnonics. These innovations hold potential for next-generation nanoelectronic devices for data processing and storage. However, the main challenges include efficient interconversion among these degrees of freedom and robust binary state switching, as illustrated in Fig. 1.

Historically, charge-to-spin conversion (Fig. 1a) enabled the discovery of spin-transfer torque (STT) and spin-orbital torque (SOT). This has opened the era for electrically controlled spintronic device applications, such as STT- or SOT-based magnetic random access memories (MRAMs). Meanwhile, electron spin-to-magnon conversion (Figs. 1a and 1b) is a key mechanism for generating magnon currents

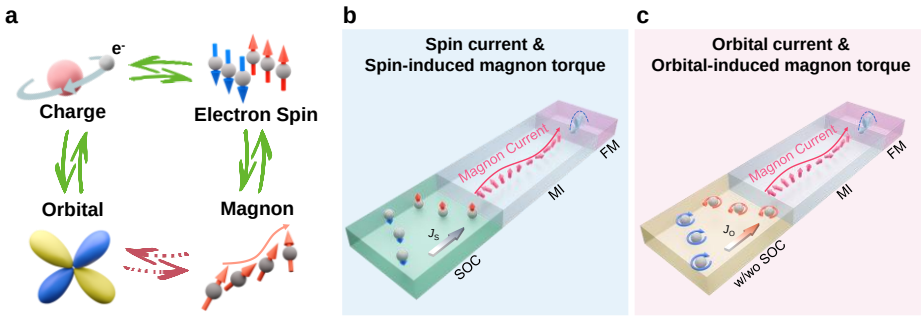

Fig. 1. Orbital angular momentum-to-magnon (*L-M*) conversion and orbit-induced magnon torque. a, The conversion between different degrees of freedom. Here, the conversion between orbitals and magnons remains elusive. b, A schematic illustration showing the conversion between electron spins and magnons in magnetic insulators (MIs) and the spin-induced magnon torque effect. c, A schematic illustration depicting the conversion between orbitals and magnons in MIs and the orbital-induced magnon torque effect.

[1-2], enabling heat-free, long-distance transfer of spin information in magnetic insulators, and the magnon-torque-driven magnetization switching [1-2] (Fig. 1b). Orbital angular momentum has recently gained much attention for generating large orbital torque via charge-to-orbital and orbital-to-electron spin conversions (Fig. 1a).

It is of great interest to ask whether orbitals can effectively excite magnons and thereby mediate efficient magnetization switching, as depicted in Fig. 1c. We exprimentally demonstrate the giant orbita-to-magnon conversion and successfully achieved the first perpendicular magnetization switching driven by this new mechanism at room temperature using an orbital metal Ti/antiferromagnetic insulator NiO bilayer [3]. This work would connect the fields of orbitronics and magnonics.

The work is supported by the National Natural Science Foundation of China (T2495211, 12261131506, 12074052). Guangdong Provincial Quantum Science Strategic Initiative (GDZX2401002). The Natural Science Foundation of Liaoning Province of China (2021-YQ-06). The Open Fund of the State Key Laboratory of Spintronics Devices and Technologies (SPL-2410).

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ULTRAFAST SPIN DYNAMICS AND THZ EMISSION IN FERROMAGNETIC FILMS

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Understanding spin dynamics over wide timescales and wide temperatures is a basis for developing spin-based logic devices. There have been various ultrafast spin dynamics phenomena such as ultrafast magnetic cooling, ultrafast exchange stiffness modification, and role of non-thermal electrons. Recently, spin-charge conversion mechanisms have attracted much attention due to applications for high-speed spintronic devices, where optically generated spin current is converted to charge current, generating THz wave emission in magnetic multilayers. Experimental investigation on quantitative and comparative analysis of THz emission originated from spin-charge conversion mechanisms such as inverse spin Hall effect, inverse RashbaEdelstein effect, and inverse spin-orbit torque are measured and quantitatively separated [1]. The separation of such mechanisms is proved to be possible by direct and straightforward nondestructive measurement of THz emission at various ferromagnetic multilayers. Polarization analysis of both optical pump and THz emission reveals the THz emission properties of spincharge conversion on an ultrafast timescale. Interface exchange interaction breaking and recovery on an ultrafast time scale is also probed by the optical pump and THz emission technique, where exchange-biased NiFe/IrMn ferromagnetic/antiferromagnetic layers exhibit exchange bias breaking by the femtosecond laser pulse [2]. These results allow fundamental understanding of various spin-charge conversion phenomena, which could be a key basis for future quantum and spintronic devices based on ultrafast spin dynamics system.

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TWO-DIMENSIONAL VALLEYTRONIC MATERIALS: FROM PRINCIPLES TO DEVICE APPLICATIONS

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In recent years, with the successful experimental preparation of two-dimensional (2D) materials, such as monolayer graphene, group-VI transition-metal dichalcogenides (MoS_2, $MoSe_2$, WS_2 and WSe_2), and so on, the valley degree of freedom (local maximum/minimum on the valence/conduction band) has attracted wide attention from researchers. Valleytronics based on 2D materials [1] is a brand-new field which considered the heart of next-generation semiconductor technology. It proposes to use the valley degree of freedom as an information carrier. By manipulating and controlling these valleys, researchers are opening up new avenues for developing faster, more efficient, and more versatile electronic and optoelectronic devices. The potential applications span from high-speed data processing to innovative light-emitting diodes, making valleytronics a pivotal area of research in modern technology.

This work [2] is structured to guide the reader through both the theoretical underpinnings and practical applications of 2D valleytronic materials. We start with an in-depth introduction to the basics of 2D materials and principles of valleytronics. This foundational knowledge is crucial for understanding the subsequent discussions on device applications and technology integration. Then, we progress to explore the approaches in various disciplines to manipulate and utilize valley degree of freedom in a logical journey, such as geometric structures, intrinsic electronic properties, electrical techniques, magnetic techniques, thermal techniques, optical methods, heterostructures, etc. We also inspect the interplay between these approaches.

As we explore the intricate principles and cutting-edge applications of valleytronics, we invite you to join us in this exploration and envision the possibilities that lie ahead. The field of valleytronics is rapidly evolving, and the insights presented in this work are intended to contribute to its continued growth and innovation.

This work was supported by the National Natural Science Foundation of China (No. 12264059), the Natural Science Foundation of Jiangsu (No. BK20211002) and Shandong Province of China (No. ZR2023MA027), the China Scholarship Council (No. 201908320001) and Qinglan Project of Jiangsu Province of China.

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ROLE OF MAGNON-MAGNON INTERACTION IN OPTICAL EXCITATION OF COHERENT TWO-MAGNON MODES

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Modern information technologies demand faster data processing, higher storage densities, and greater energy efficiency. High-frequency coherent magnetic excitations are considered a promising platform for acheiving these goals [1]. In this context, two-magnon modes in antiferromagnets are of particular interest. Two-magnon modes are terahertz-frequency magnetic excitations in antiferromagnets, governed by exchange interactions, involving magnons from the entire Brillouin zone and dominated by zone-edge magnons.They couple directly to light via inelastic scattering [2], and therefore can be excited by femtosecond laser pulses in a coherent manner. However, the role of magnon-magnon interactions in their coherent, time-domain excitation has remained an open question.

In our work, we combine time-domain impulsive stimulated Raman scattering and frequency-domain spontaneous Raman scattering to study coherent and incoherent two-magnon modes in the cubic antiferromagnet $RbMnF_3$. This is a Heisenberg antiferromagnet with spin S = 5/2, a Néel temperature T_N = 83 K [2], and very weak magnetic anisotropy. We report [3] the direct experimental observation of how magnon-magnon interactions affect the optically driven coherent two-magnon modes, revealing a nontrivial evolution of the magnetic dynamics and the corresponding spectrum. By extending the spin-correlations-based theory [4], we provide a unified framework that describes the spectral signatures of two-magnon modes in both experiments, highlighting the role of magnon-magnon interactions.

Our results show that magnon-magnon interactions similarly redistribute spectral amplitude to lower energies in both regimes, but the spectrum of coherent two-magnon modes is additionally shaped by the phases, which are inaccessible in spontaneous Raman scattering. We further demonstrate that the distinct features between coherent and incoherent spectra persist over a broad temperature range below the Néel temperature, and that the pump pulse duration impacts the coherent two-magnon mode spectrum by modifying its overall magnitude and the relation between different spectral features. These findings establish a comprehensive understanding of coherent two-magnon mode dynamics and provide essential insights for future experiments on the coherent optical control of magnetic states in antiferromagnets.

The work is partially supported by RSF grant No. 26-12-00401.

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ASYMMETRIC ENERGY LANDSCAPE AS UNIVERSAL SOURCE OF THRESHOLDLESS NONLINEAR PRECESSION AND SPIN WAVES

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Conventional nonlinear magnetization dynamics (e.g., type-I Suhl) requires large precession amplitudes and exhibits a threshold [1]. Here we demonstrate a thresholdless mechanism emerging when an external magnetic field is applied close to the hard magnetic anisotropy axis with magnitude comparable to the anisotropy field. The magnetic free energy then becomes asymmetric and non-parabolic, leading to three effects: anharmonic magnetization precession, generation of higher harmonics, and dynamical rectification – a shift of the time-averaged magnetization from the energy minimum that produces an amplitude-dependent frequency shift even for sub-degree deviations [2].

Using femtosecond all-optical pump-probe with temporal and spatial resolution on a 20 nm epitaxial Fe(001) film, we first study uniform precession. We directly observe the amplitude-dependent frequency shift together with higher harmonics (up to 4th order), confirming intrinsic thresholdless nonlinearity. We then launch propagating magnetostatic spin-wave packets. The same asymmetric potential – realized either in the laser-heated region (for precession) or in the cold area (for waves) – governs both cases. Detection of a second harmonic of a surface magnetostatic wave packet propagating with the same group velocity as the fundamental wave directly evidences nonlinear wave-wave interaction at ultra-low power. Full (non-linearized) Landau-Lifshitz-Gilbert calculations and micromagnetic simulations confirm the intrinsic nature of this effect.

The same amplitude-dependent frequency shift creates a spurious damping anomaly near the spin-orientation transition [3]. A finite pump spot produces a spatial distribution of temperature and thus of precession frequency. Interference of signals from different parts of the excited area artificially accelerates envelope decay, mimicking enhanced damping. This interference is amplified by the thresholdless nonlinearity itself, which operates even without heating. Choosing field directions where the frequency is temperature-independent allows recovery of the true Gilbert damping.

Thus, tailoring the energy landscape asymmetry provides a universal, thresholdless route to nonlinear spin dynamics – from harmonic generation and wave mixing to correct interpretation of damping measurements. Our findings enable low-power magnonic devices and highlight the need to account for spatial inhomogeneities when extracting intrinsic parameters.

The work supported by the grant of the RSF No. 26-12-00401.

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MODELING AND MODULATION OF ANOMALOUS HALL ANGLE IN MAGNETIC MATERIALS

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As an essential parameter of the anomalous Hall effect, the anomalous Hall angle (AHA) represents the conversion efficiency of the longitudinal electric current density to the anomalous Hall current density. It is expected that materials with a large AHA can improve the efficiency of spin current source for spin transfer torque and the sensitivity of magnetic field detection for anomalous Hall sensors. Compared with conventional magnetic materials, topological magnets with Weyl fermions and strong Berry curvature can exhibit large AHA [1-3].

In this talk, I will report our efforts on the improvement of AHA based on magnetic topological materials. I will show that the AHA can be formulated as a function of the product of electrical resistivity and anomalous Hall conductivity. We can use this scheme to demonstrate the modulation of AHA. Finally, we obtain the large AHA up to a magnitude of 0.46, corresponding to an angle of around 25°. We further fabricate anomalous Hall devices using Fe-doped $Co_3Sn_2S_2$ single-crystalline nanoflakes and demonstrate a Hall sensitivity of $7{,}028 \pm 341\ \mu\Omega\,\mathrm{cm\,T^{-1}}$ and a magnetic field detectability of $23.5 \pm 1.7\ \mathrm{nT\,Hz^{-0.5}}$ at 1 Hz. Our approach could help in the development of devices based on emerging topological materials for applications in magneto-electronics and spintronics [4].

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ORAL SESSION

Magnetic Nanostructures and Low Dimensional Magnetism

Thursday, 20 August, 11:00 - 13:00

MAGNETIZATION REVERSAL VERSUS SPIN FREEZING IN 2D CRSBR SEMICONDUCTOR

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Changes in the dynamics of CrSBr domain walls between 40 K and 100 K are accompanied by spin fluctuation slowing and a magnetic dimensionality crossover. At low temperatures (T < 40 K), magnetization reversal is realized by the generation of nuclei, while at elevated temperatures (T > 100 K the macroscopic expansion of domain walls controls magnetization dynamics. Longitudinal MOKE microscopy at 80-140 K directly visualizes this continuous domain propagation. Fatuzzo-Labrune kinetic model confirms the transition from domain expansion to nucleation-dominated reversal mode below 90 K.

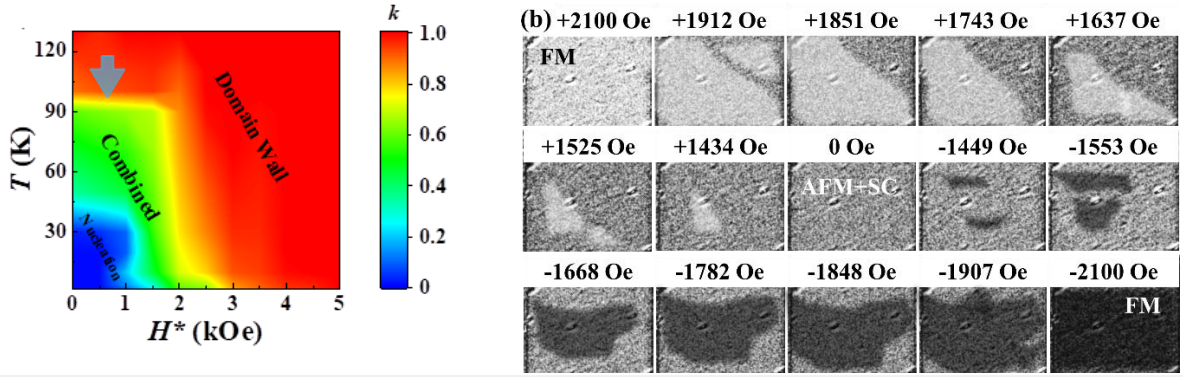

FIG. 1. (a) Distribution map of dimensionless coefficient *k* corresponding to contribution of domain wall motion to magnetization reversal. At *k* = 1 domain motion dominates, at *k* = 0. generation of magnetization nuclei dominates. The arrow marks border separating magnetization reversal modes. (b) Domain structure at different fields at 120 K.

Furthermore, Cole-Cole diagrams of the alternating magnetic susceptibility demonstrate a transition from the Debye relaxation of pinned domain walls at T < 40 K to thermally activated creep and sliding regimes at T > 100 K in strong fields. The observed broadening of relaxation times during creep reflects a complex energy landscape of domain obstacles. Participation of the spin-canted phase in magnetization reversal is discussed. Finally, time-dependent magnetization tracking reveals a transition to highly stretched relaxation dynamics. This suggests a magnetic field-induced shift in the spin noise spectrum from white to pink color, accompanying the macroscopic changes in magnetic viscosity, domain mobility, and magnetization reversal sources.

DEFECT-ENGINEERED EMERGENT MAGNETIC ORDER IN THE VAN DER WAALS SEMICONDUCTOR CRSBR

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The controlled emergence of unconventional order in low-dimensional quantum materials is a central theme in current condensed-matter research. In this context, the air-stable van der Waals magnetic semiconductor CrSBr provides an attractive platform, combining anisotropic electronic properties with layered magnetism. Below its Néel temperature of 132 K, CrSBr exhibits A-type antiferromagnetic order, consisting of ferromagnetic layers coupled antiferromagnetically along the stacking direction [1, 2].

In this contribution, I will show how ion irradiation can be used as a tuning knob to drive and control magnetic phase transitions in CrSBr. We observe the emergence of a ferromagnetic phase from the antiferromagnetic ground state at moderate irradiation fluences, followed by its gradual suppression as disorder increases further [3, 4]. By combining structural analysis with density-functional-theory calculations, we identify irradiation-induced interstitial defects as the microscopic origin of the enhanced ferromagnetic interlayer coupling. The evolution of the Curie temperature with fluence further reveals the competition between defect-induced magnetic reconstruction and crystalline degradation. Remarkably, at even higher fluences, CrSBr does not simply amorphize, but undergoes a transition into a new crystalline phase [5].

These results establish defect engineering as a powerful route to manipulate symmetry-broken magnetic states in a layered quantum material. More broadly, the results demonstrate how controlled defect landscapes can be exploited to access and spatially pattern emergent magnetic phases in van der Waals quantum materials.

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ADVANCED MAGNETIC NANOCOMPOSITES FOR EMERGING POLLUTANT REMOVAL IN WATER TREATMENT

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Contaminants of Emerging Concern (CECs), including pharmaceuticals, pesticides, and personal care products, pose significant risks to human health and ecosystems. Although historically unregulated, the recently approved EU Urban Wastewater Treatment Directive (2024) now mandates quaternary treatments for their removal. Among the available technologies, advanced oxidation processes (such as photocatalysis) and adsorption stand out. In this context, magnetic nanocomposites offer a highly promising solution, as they can be efficiently separated from treated water using an external magnetic field, thereby preventing secondary contamination.

In this work, magnetic carbon nanocomposites (Fe@C) have been employed as base materials for pollutant degradation. These nanocomposites were synthesized via the thermal decomposition (pyrolysis) of fructose, which acts as the carbon source and reducing agent, and an Fe^{3+} salt as the iron precursor [1]. Systematic structural characterization (X-ray diffraction, transmission electron microscopy, FTIR, and Raman spectroscopy) showed that the microstructure is composed of α-Fe and cementite (Fe_3C) nanoparticles in a carbon (graphite) matrix. Different Fe@C composites were synthesized by varying the Fe content in order to obtain the composite with the optimal properties. The composite prepared with 10 wt.% Fe turned out to be the sample with the most outstanding adsorption properties, combining optimal structural (highest surface area) and magnetic characteristics. In a second step, anatase TiO_2 nanoparticles were deposited on the surface of the 10 wt.% Fe composite via a hydrothermal method using TBOT as the precursor and CTAB as the stabilizing agent.

Evaluation of the adsorption capacity was initially performed using methylene blue (MB) and phenol as model organic pollutants. The selected Fe@C composite exhibited high effectiveness for MB adsorption, removing practically all the pollutant from the aqueous medium after 90 min, whereas only approximately 34% of phenol was removed within the same timeframe. The effect of an external magnetic field generated by permanent magnets on the adsorption process was specifically analyzed. Although a net positive effect (increase in the adsorption kinetics) was found for the removal of MB, no clear effect was observed for phenol. These results are interpreted considering the different electrostatic and magnetic nature of MB and phenol, taking into account phenomena such as Lorentz and Kelvin forces on the adsorption process.

Regarding photocatalytic degradation, efficient photocatalytic Fe@C@TiO_2 composites were employed, placing special emphasis on the antibiotic enrofloxacin as a persistent pollutant. Comprehensive structural, optical, and magnetic characterizations were performed to optimize the composite design. Notably, the optimized photocatalyst achieved 100% removal of enrofloxacin after just 2 hours of UV-Vis irradiation, significantly outperforming the degradation rate obtained for phenol (83% after 5 hours).

Grant PID2023-150078OB-I00 funded by MICIU/AEI/10.13039/501100011033 and by ERDF/EU is acknowledged.

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INFLUENCE OF CERIUM DOPING ON THE ELECTROCHEMICAL, COLLOIDAL, AND MAGNETIC PROPERTIES OF NICKEL FERRITE NANOPARTICLES

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The electrochemical, colloidal, and magnetic characteristics of nickel ferrite nanoparticles doped with cerium were studied by synthesising them using the sol-gel auto-combustion method. The nanoparticles had a composition of NiCexFe2-xO4 (x = 0.1, 0.3, 0.5, 0.7). The pseudocapacitive behavior of all samples was confirmed by cyclic voltammetry (CV) measurements taken at scan rates ranging from 25 to 100 mV s^{-1}, which showed clear redox peaks associated with the Fe2+/Fe3+ and Ni2+/Ni3+ couples. For NiCe0.5Fe1.5O4, the specific capacitance peaked at 0.539 F g-1 at 25 mV s-1, compared to 0.508, 0.527, and 0.526 F g-1 for x=0.1, 0.3, and 0.7, respectively, as the Ce content increased. Increases in cerium concentration were found to improve colloidal stability, as seen by zeta potential tests, which showed a shift from -7.38 mV (x=0.1) to -28.8 mV (x=0.5), suggesting less agglomeration and an improved surface charge. The specific saturation magnetization (σs) decreased from 40.38 to 22.68 emu g-1 as the Ce concentration increased, according to the magnetic studies. In terms of magnetic hardness, NiCe0.3Fe1.7O4 had the highest remanence (σr=26.2 emu g1) and coercivity (Hc=2637.27 Oe), while NiCe0.1Fe1.9O4 displayed the highest saturation magnetization (40.38 emu g-1). Supercapacitors, magnetic storage, and multifunctional electrochemical devices are just a few of the possible uses for cerium-doped nickel ferrite nanoparticles, which are optimally suited for electrochemical stability and magnetic properties.

Keywords- Sol-gel auto-combustion; Cyclic voltammetry; Zeta potential; Magnetization; Supercapacitors.

NON-EQUILIBRIUM PHASE TRANSITION IN VAN DER WAALS ANTIFERROMAGNETS

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Phase transitions in condensed matter give rise to emergent collective behavior driven by interactions among many particles and their internal degrees of freedom. They constitute a central concept in condensed matter physics, with fundamental importance as well as a wide range of applications. In equilibrium, phase transitions are often well understood in terms of an order parameter and its fluctuations, which near criticality lead to universal behavior characterized by critical exponents.

In recent years, there has been a surge of interest in non-equilibrium condensed matter physics, both theoretically and experimentally. Key questions include how rapidly phase transitions can be driven from a non-equilibrium state, whether novel phases without thermal equilibrium counterparts can be realized, and to what extent non-equilibrium phase transitions exhibit universality. Significant progress has been made in addressing these questions, including the ultrafast control of magnetic order, optically induced superconductivity, and universal scaling behavior such as that described by the Kibble–Zurek mechanism in driven phase transitions.

The present work discusses two examples of non-equilibrium phase transitions. The first concerns the suppression of antiferromagnetic order in the proximate Kitaev material α-$RuCl_3$. Here, non-equilibrium holon–doublon excitations decay into magnon excitations, while holon hopping further destabilizes magnetic order. Together, these processes suppress the antiferromagnetic order parameter and drive the system toward a quantum-disordered state. The second example addresses the antiferromagnetic phase transition in $FePSe_3$ under non-equilibrium conditions, where strong non-equilibrium fluctuations lead to significant modifications of the order-parameter dynamics near the transition.

Support by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) through Project No. 277146847 – CRC 1238 (project B05) is gratefully acknowledged.

ORAL SESSION

Magnetism in Biology and Medicine

Thursday, 20 August, 11:00 - 13:00

WATER-BASED MAGNETIC FLUIDS BASED ON MAGNETITE AND COBALT FERRITE FOR BIOMEDICAL APPLICATIONS

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Magnetic nanoparticles are the object of numerous studies during recent decades. Their properties enable diverse applications, including therapy and drug delivery, biocomputing and theranostics (which could be of particular interest in the context of recent studies in these fields, analytical assays based on non-linear magnetization detection and others. The development of new methodologies for obtaining highly pure and stable sols is an on-going challenge in materials science. The common strategy for improving synthetic conditions has been to modify the chemical conditions, while modifying the physical aspects of the synthesis has been less explored.

We have developed a new synthetic strategy for synthesis of magnetic colloids, namely ultrasonic-assisted precipitation from non-stochiometric ratio of reagents. This strategy was used for the synthesis of a new class of magnetic systems: stable hydrosols of magnetic nanoparticles without additional surfactants and at neutral pH level. The procedure is cheap, scalable and convenient, the produced magnetic colloids are free of any additional molecules and can be used in various ways.

By using this strategy we have synthesized two different materials, namely magnetite and cobalt ferrite[1], [2]. Synthesized systems showed excellent colloidal stability and behaved as magnetic fluids. Surface of the synthesized material were enriched with iron (II) and cobalt (II) and hydroxyl groups, resulting in high zeta potential at neutral pH level and electrostatic stabilization of the systems. Due to absence of any additional molecules and pristine surface of nanoparticles the obtained systems can be easily modified in a variety of ways with various molecules, including proteins, polymers or oligonucleotides and demonstrate excellent biocompatibility. Moreover, they can undergo sol-gel transition to form inorganic hydrogels or ceramic xerogels, which can be used as sorbents or to entrap proteins and enzymes[3]. It was demonstrated that protein molecules, entrapped into magnetic xerogels showed enhanced temperature of denaturation, excellent thermal stability retaining their enzymatic activity.

The produced systems can be used for various biomedical applications and development of advanced bioactive systems.

This work was supported by Russian Science Foundation project № 24-13-20032.

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MODELING THE COLLECTIVE DYNAMICS OF MAGNETICALLY CONTROLLED MICROROBOTS

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Magnetorheological materials are composite systems consisting of magnetic particles dispersed in an elastic or liquid matrix. Due to their ability to change mechanical properties under the influence of external magnetic fields, such materials are a promising basis for creating magnetoactive microrobots capable of remotely controlled motion in liquid media. One possible design for such microdevices involves microrobots based on a polymer matrix that functions as an elastic tail and embedded magnetic particles that form a controllable head. Studies have shown that the motion of magnetoactive microrobots under the influence of magnetic fields is particularly effective in environments with a low Reynolds number, characteristic of biological fluids [1].

In this work, numerical simulations of the dynamics of a collective of magnetic microrobots in various media under the influence of a constant linear gradient magnetic field were performed in the open-source ESPResSo software environment [2]. Two models of the motion of a three-dimensional ensemble of microrobots were considered: in viscous (Fig. 1) and viscoelastic media. The flexible tail of the microrobots was modeled in two variants: a passive one, containing no magnetic particles, and an active one, incorporating magnetic particles. It was established that the displacement of the ensemble in a viscous medium is linearly dependent on the magnetic field gradient and inversely proportional to the viscosity of the medium. Dependencies of the efficiency of the microrobot ensemble's motion on the dipolar interaction parameter λ and the elasticity coefficient of the microdevice tails during motion in viscous and viscoelastic media were obtained. Two types of magnetic particles were used in the simulations: spherical and ellipsoidal.

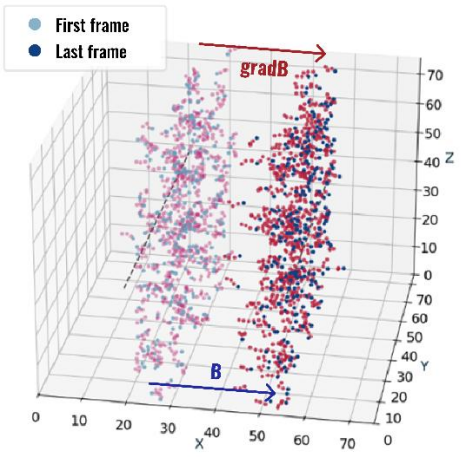

Fig. 1. Displacement of microrobots under the influence of a gradient magnetic field.

The results obtained allow us to identify key principles for the design of flexible magnetic microrobots. The developed numerical model integrates a wide range of parameters and reproduces the behavior of microrobots under conditions close to real operating environments.

Support from the RSF project No. 25-22-00563 is acknowledged.

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REMOTE-CONTROLLED MOLECULES: HOW MAGNETIC NANOPARTICLES GOVERN INTERMOLECULAR INTERACTIONS IN MAGNETOMECHANICAL APPROACH

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Accurate structural control of nanoscale molecular systems is fundamentally and practically crucial for biophysics, chemistry, biology, and medicine. Currently, remote activation and control of nanosystems rely on external energy sources, including light, heat, chemical reactions, or ultrasound. Over the past decade, magnetomechanics has gained significant traction. This approach leverages ultralow-frequency (<100 Hz) non-heating magnetic fields to convert magnetic energy into mechanical force via magnetic nanoparticles (MNPs) with sizes comparable to proteins and intracellular compartments. While biomolecules are inherently unresponsive to low-frequency fields, conjugating them with MNPs enables controlled molecular deformations, thereby allowing localized regulation of their catalytic and biological activity. A major unresolved challenge, however, has been identifying the precise nanoparticle parameters and magnetic field characteristics required to achieve specific biological effects.

To address this, we developed a specialized technology based on fluorescent oligonucleotide microarrays to experimentally demonstrate magnetomechanical effects mediated by various nanoparticles in alternating magnetic fields [1]. It was found that the magnetomechanical effect is not a monotonic function of the size of the nanoparticle core, as previously thought in theoretical works. Important parameters affecting the effectiveness of the magnetomechanical approach are the superparamagnetic state of magnetic nanoparticles, the magnitude of their magnetic dipole interaction, the morphology of nanoparticles and the type of the dynamic magnetic field [2,3]. It was experimentally shown that the maximum magnetomechanical effect can be achieved for nanoparticles with a coating thickness of a non-magnetic shell comparable to the size of their magnetic core. Concurrently, 10 nm magnetite nanoparticles can transfer ~90 kcal/mol of energy to their conjugated molecules via Brownian relaxation under an external magnetic field. Furthermore, we demonstrated that even the biotin-streptavidin complex, which is considered as the gold standard for high-affinity molecular recognition, typically considered practically irreversible, dissociates under quasi-static magnetomechanical loading even in the absence of external magnetic fields. By engineering a series of nanoparticles with identical magnetic cores and tunable non-magnetic shell thicknesses bound to biotin, we isolate the effect of mechanical leverage on the stability of the biotin-streptavidin complex at low loading rates (< 10 $pN \cdot s^{-1}$). Under these conditions, the complex dissociates spontaneously at forces below 2 pN, which is several orders of magnitude lower than the rupture forces typically reported in dynamic force spectroscopy studies. While thin shells provide insufficient mechanical leverage for complex dissociation, thicker shells act as "thermal sails" dominated by stochastic Brownian torque, masking the magnetic effect. These findings uncover a hidden mechanical vulnerability in nature's strongest non-covalent bond, opening transformative pathways for the remote, non-thermal control of biomolecular interactions. The data obtained made it possible to evaluate the effectiveness of the magnetomechanical therapy *in vitro*, the results of which, as was subsequently found, are fully consistent with the data obtained using the developed model system. We believe that our observed results shed light on the "black box" of fine-tuning the properties of magnetic nanoparticles for addressing specific magnetomechanical tasks.

The work was funded by Russian Science Foundation, grant number 25-73-00100.

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MXENE-BASED FUNCTIONAL PLATFORMS FOR PHOTOTHERMAL TUMOR CELL THERAPY

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Here, we demonstrate the potential of $Ti_3C_2T_x$ MXenes, a prospective class of 2D materials as photothermal agents for the elimination of human hepatocarcinoma cells (Huh7) *in vitro*. MXenes were synthesized from Ti_3AlC_2 MAX-phase (Sanno, China) using the HF/HCl etching method. The synthesized MXenes were characterized by XRD, FTIR, dynamic and electrophoretic light scattering (DLS/ELS), and photothermal analysis. FTIR confirmed successful synthesis and surface functionalization with citric acid. Photothermal analysis revealed a photothermal conversion efficiency of 67 ± 2% and a specific absorption rate of 2263 W/g. Cytotoxicity was evaluated using the CCK-8 cell viability assay. Results demonstrate (Fig.1) that photothermal treatment utilizing MXenes (at concentration 50 µg/mL) and laser exposure with 20 min exposition induce death of 48% cells in comparison to control (untreated cells). Viability of cells treated with MXenes (w/o laser irradiation) was decreased to 83%.

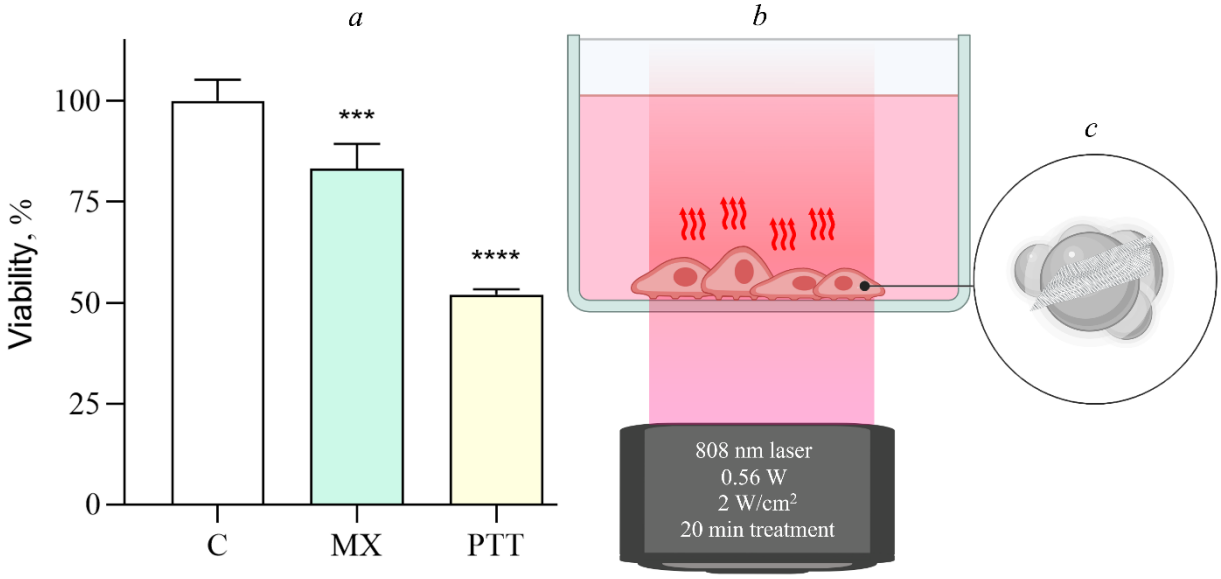

Fig. 1. Photothermal treatment (PTT) with MXenes reduces viability of human hepatocarcinoma (Huh7) cells. (*a*) Cell viability after PTT was significantly decreased in comparison to untreated cells (C) and cells incubated with MXenes (50 µg/mL) without laser treatment. (*b*) Schematic illustration of photothermal exposure. (*c*) Schematic illustration of MXenes' localization. Statistical significance between control and treatment groups is showed by asterisks («***» $P < 0.001$, «****» $P < 0.0001$).

These findings highlight the potential of $Ti_3C_2T_x$ MXenes as efficient photothermal agents for hepatocellular carcinoma therapy.

This research was funded by the Russian Science Foundation, project № 25-22-00433 (https://rscf.ru/en/project/25-22-00433/).

LAYERED MAGNETIC MICRODISKS AS AN AGENT FOR COMBINED PHOTOTHERMAL AND MAGNETOMECHANICAL THERAPY

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One of the most promising directions in modern anti-cancer therapeutics is the development of treatment modalities with reduced invasiveness and diminished adverse effects relative to conventional approaches, including chemotherapy, surgical intervention, and radiotherapy [1]. Among such emerging strategies are photothermal therapy (PTT) and magnetomechanical therapy (MMT). In PTT, laser irradiation directed at tumour sites preloaded with noble metal nanoparticles (NPs) induces localised hyperthermia exceeding the thermal threshold for cellular damage, thereby causing structural disruption of cellular constituents and subsequent thermal ablation of tumour cells [1]. Given the complexity of neoplastic diseases, PTT is generally implemented as a component of combination therapeutic regimens rather than as a standalone curative modality. The present study advances the hypothesis that the combination of simultaneous PTT with MMT may achieve enhanced therapeutic efficacy against cancer cells. MMT exerts its effect through the mechanical perturbation of the cell membrane via the displacement of magnetic NPs within a low-frequency alternating magnetic field (approximately 1–10 Hz), a process capable of initiating cell death pathways.

Here microdisks composed of gold and iron layers were employed as dual-functional agents. Relative to their spherical counterparts, microdisks possess a superior mechanical moment, rendering them particularly suitable for the concurrent application of MMT and PTT. The fabrication of the layered microdisks was accomplished using electron-beam lithography combined with magnetron sputtering. Two types of microdiscs were considered: iron–gold–iron (FAF) and gold–iron–gold (AFA).

This study investigates the effects of the microdisks on human hepatocarcinoma cells (Huh7) both prior to and following PTT and/or MMT treatment. Cell viability was assessed using the WST-1 assay. Following 24 hours of exposure to AFA and FAF microdisks at the maximum tested concentration of 100 μg/mL, the relative viability of Huh7 cells decreased by 7% and 10%, respectively. Notably, the combination of PTT and MMT consistently at the identical concentration resulted in a stronger reduction by 30% in culture viability compared to the control group. Moreover, the simultaneous PTT with MMT resulted in a halving of Huh7 viability.

The present study was supported by the Russian Science Foundation, grant № 21-72-20158-П.

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THE INFLUENCE OF THE TEXTURE OF THE EASY AXES ON THE DYNAMIC SUSCEPTIBILITY OF AN ENSEMBLE OF IMMOBILIZED MAGNETIC NANOPARTICLES

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This work is devoted to computer simulation of the dynamic properties of an immobilized ensemble of non-interacting magnetic nanoparticles with orientational texturing of the easy axes. Computer simulation was performed using the molecular dynamics method in the ESPResSo software package [1]. In the first stage of simulation, the magnetic nanoparticles were located inside a simulation cell and were free to move and rotate. Each particle is assigned its own magnetic moment and easy axis. Under the action of a static magnetic field α^p, which is directed parallel to the O_z axis, the easy axes of the particles are aligned both along the field and in the opposite direction. By varying the field strength α^p and the magnetic anisotropy parameter σ, it is possible to vary the measure of alignment of the easy axes. In the second stage of the simulation, the particle positions and the easy axes directions are fixed in the system. An alternating magnetic field α^{ac} of varying strength, directed at different angles to α^p, acts on the immobilized particles with the formed easy axes texture.

The dynamic susceptibility of the system was then calculated, and the behaviour of it's real and imaginary parts was analysed as a function of the rotation angle of the alternating field relative to the static field, the magnetic anisotropy parameter, and the strength of both the alternating field and the polymerization field.

Fig. 1 shows graphs of the real and imaginary parts of the dynamic susceptibility as a function of the dimensionless frequency $\omega\tau_0$, where τ_0 is the characteristic precession time of the magnetic moment. The fig.1 shows that in the low-frequency region, the real part of the dynamic susceptibility decreases with increasing alternating field amplitude α^{ac}, fig. 1. The maximum of the imaginary part decreases with increasing α^{ac} and shifts toward higher frequencies, fig. 1.

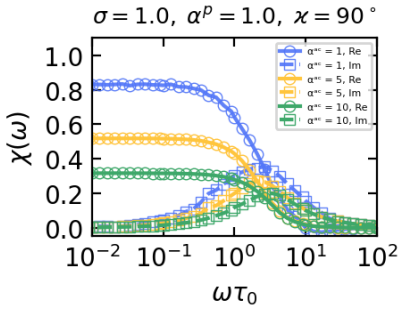

Fig. 1. Graphs of the dynamic susceptibility of an ensemble of immobilized magnetic nanoparticles depending on the dimensionless frequency $\omega\tau_0$. The magnetic anisotropy parameter $\sigma = 1.0$, the polymerization field $\alpha^p = 5$, the value of the variable α^{ac} is indicated in the graph legend. Field $\alpha^p \perp \alpha^{ac}$.

The research was supported by the Russian Science Foundation, Grant No. 23-12-00039-П, https://rscf.ru/project/23-12-00039-П/

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ORAL SESSION

Magnetic Materials

Thursday, 20 August, 11:00 - 13:00

COMPENSATED FERRIMAGNETS OF (Cr,Fe)*Z* (*Z* = S AND Se) CHALCOGENIDE COMPOUNDS

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Transition metal chalcogenides (TMCs) have attracted significant interest due to their unique physical properties, including superconductivity, altermagnetism, and two-dimensional van der Waals behaviors. Recently, several TMCs have been theoretically predicted as potential candidates for half-metallic (HM) compensated ferrimagnets (CFIMs) [1], yet experimental reports on such materials remain scarce. HM-CFIMs possess distinct advantages, such as zero stray fields and high spin polarization, making them essential for spintronic applications. Previous research has identified (Cr,Fe)S as a promising HM-CFIM [2,3]. To expand the range of candidate materials, we substituted S with Se and successfully synthesized single-phase samples with a NiAs-type structure, similar to (Cr,Fe)S, via a quenching method. This study investigates the magnetic properties of (Cr,Fe)Se compounds and compares their characteristics with those of (Cr,Fe)S to assess their potential as HM-CFIMs.

The chalcogenide compounds (Cr,Fe)*Z* (*Z* = S and Se) were synthesized through a powder-sintering process. High-purity powders of Cr, Fe, S, and Se were weighed in specific proportions, thoroughly mixed, and pressed into pellets. Each pellet was vacuum-sealed in a quartz tube and subsequently sintered at various temperatures for 24 hours in a furnace. The crystal structures of the samples were characterized by X-ray diffraction (XRD) and scanning electron microscopy (SEM). The magnetic and transport properties were measured using a superconducting quantum interference device (SQUID) magnetometer and a physical property measurement system (PPMS).

Experimental results reveal that (Cr,Fe)S exhibits N-type ferrimagnetic behavior, as described by Néel [4], with a compensation temperature (T_{comp}) of approximately 200 K. Magnetic reversal was observed around T_{comp}, and the Curie temperature (T_C) was determined to be approximately 510 K. In contrast, (Cr,Fe)Se exhibits R-type ferrimagnetism; it lacks a magnetization compensation point but displays negative magnetization during field-cooled warming (FCW) and positive magnetization in subsequent field-cooled cooling (FCC) cycles. The T_C of (Cr,Fe)Se is around 300 K.

Transport properties, including magnetoresistance and the Hall coefficient, were investigated using a single crystal of (Cr,Fe)S successfully grown via the chemical vapor transport (CVT) method. Hall measurements reveal an exceptionally large anisotropy field well exceeding 90 kOe. The anomalous Hall effect (AHE) persists across the entire investigated temperature range, characterized by a large coercivity, a distinct sign reversal across T_{comp}, and an anomalous Hall angle of approximately 2–4% [5]. These findings demonstrate that (Cr,Fe)S and related chalcogenide compounds are highly promising candidates for next-generation spintronic devices.

This study was supported by a Grant-in-Aids for Scientific Research (A) (MEXT 22H00287, 26H02191), Japan. The authors express their sincere gratitude to Assoc. Prof. C-L Huang and his member (at National Cheng Kung University) for his invaluable guidance and supervision during the single-crystal growth process.

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MAGNETIC AND TRANSPORT PROPERTIES OF Mn_2FeSn

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Studies of Mn_2YZ (Y is a transition metal, Z is the main group element) inverse Heusler alloys have attracted considerable attention over decade [1]. Contrary to the most of these alloys, which possess cubic symmetry of the crystal lattice, the Mn_2FeSn compound has been reported to crystallize in a hexagonal structure. The specific feature of this compound is a non-collinear spin arrangement which brings about a large topological Hall effect [2,3]. It should be noted, however, that basic magnetic, transport and magnetotransport properties of the stoichiometric Mn_2FeSn have not been studied in details so far.

To study physical properties of the stoichiometric Mn_2FeSn, we prepared polycrystalline ingot by induction melting of chemically pure Mn, Fe, and Sn in an argon atmosphere. The ingot was subjected to homogenizing annealing in a vacuum quartz tube at a temperature of 1073 K for 10 days, followed by quenching in cold water. X-ray diffraction analysis revealed that annealed Mn_2FeSn crystallizes in a hexagonal crystal structure with lattice parameters a = 0.558 nm and c = 0.446 nm.

Results of the magnetic measurements pointed to a number of magnetic phase transitions. Specifically, upon cooling down from high temperatures, Mn_2FeSn transforms to long-range magnetically ordered state at $T_C \approx 300$ K. Upon further cooling, a spin-orientation transition is observed at ≈ 200 K. Below this temperature, a strong bifurcation of zero field cooling (ZFC) and field cooling (FC) magnetization curves is observed in a magnetic field of 100 Oe. Splitting of the ZFC-FC curves is diminished upon application of stronger magnetic fields and disappears almost completely in a magnetic field $\mu_0 H = 2$ T (Fig. 1). Temperature dependence of electrical resistivity ρ is atypical for metallic systems. Specifically, ρ is large, exceeding 300 μΩcm at room temperature, and decreases with increasing temperature. Magnetoresistivity does not exceed 2% in the whole measured temperature interval (4.2 – 300 K).

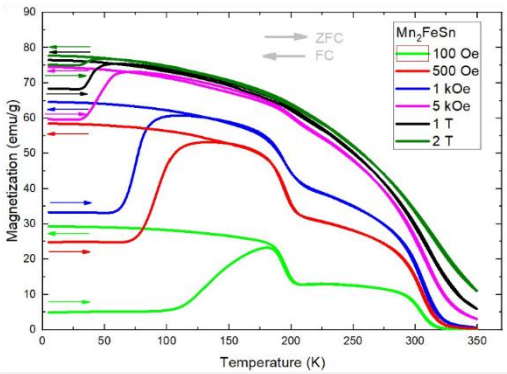

Fig. 1. ZFC-FC curves of Mn_2FeSn measured in external magnetic fields 0.01 – 2 T.

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TECHNOLOGY FEATURES, CRYSTAL STRUCTURE AND MAGNETIC PROPERTIES OF $BAFE_{12}O_{19}$ THICK FILMS FOR MICROWAVE ELECTRONICS AND TERAHERTZ SPECTROSCOPY

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$BaFe_{12}O_{19}$ (BaM) thick magnetic films are promising materials for microwave electronics and terahertz spectroscopy. In this work, thick magnetic BaM films with a thickness of several tens of microns to 1000 microns were obtained and studied by the method of slip casting and screen printing. The starting material is ferritized barium hexaferrite powder synthesized using standard ceramic technology. Al_2O_3 plates with a thickness of 350 microns were used as substrates.

The crystal structure of the obtained films was studied using an Empyrean X–ray diffractometer (PANalytical company) in Co radiation: $\lambda\alpha_1$= 1.789190 Å; $\lambda\alpha_2$= 1.793210 Å. Diffraction peaks from the $BaFe_{12}O_{19}$ film and the Al_2O_3 substrate were observed on the X-ray images according to ICDD cards (98-015-7056) and (98-007-3725), respectively. No impurity phases were detected in the films. The magnetic hysteresis loops of the studied samples were recorded at room temperature using a VM-07 vibration magnetometer.

The obtained results are analyzed. The possibilities of practical application of thick BaM

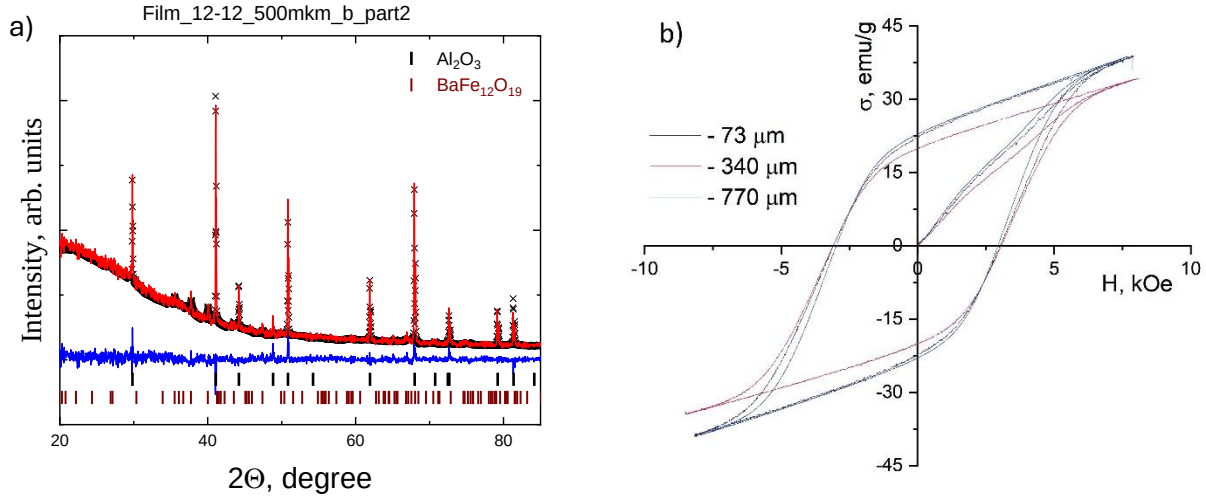

Fig. 1. Characteristics of some samples of the obtained BaM thick films a) X-ray diffraction pattern of a film with a thickness of 500 microns; b) magnetic hysteresis loops of some of the films obtained; magnetic field ⊥ of the film plane.

films in the production of microstrip devices for microwave electronics, magnonic devices and terahertz spectroscopy are discussed. The advantages and disadvantages of each of the used film production methods are discussed.

SIZE-DEPENDENT PHASE TRANSITION TEMPERATURE IN $Co_{83}Fe_7C_1Si_7B_2$ AND $Fe_{45}Co_{30}Si_{10}B_{15}$ MICRO-WIRES

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Thin ferromagnetic metallic glass-coated microwire of compositions Co83Fe7C1Si7B2 and Fe45Co30Si10B15 of different sizes (Table 1) was produced by the Taylor-Ulitovsky method. They demonstrated various types of magnetization reversal behaviors, including bistable, stepwise, and S shape with a highly enhanced coercivity [1]. A system of Co-based microwires with nearly zero magnetostriction coefficient exhibits a step-like hysteresis loop [2]. The hysteresis loops of magnetostrictive microwires show strong sensitivity to the d/D ratio [3]. The influence of post-processing conditions on the magnetic properties of amorphous and nanocrystalline microwires is carefully analyzed, with special attention paid to the influence of magnetoelastic, induced and magnetocrystalline anisotropies on the hysteresis loops of Fe, Ni and Co-rich microwires [4]. The influence of sample geometry (ρ-ratio) on the magnetic anisotropy field is demonstrated previously [5]. Using the EPR equipment (Varian-12, 9.48 GHz), first derivative of microwave absorption spectra was obtained at temperatures up to ~770 K and in magnetic fields up to 10 kOe. The microwire was located vertically in the central part of the cylindrical resonator (TE102), i.e. along the magnetic component of microwaves. The EPR spectrum of microwires has a typical appearance for the EPR spectrum of powder. The spectrum exhibits several lines associated with the g-tensor components (gx, gy, gz) of ferromagnetic resonance. At T > 510 K, the three Co83Fe7C1Si7B2 lines merge into a single line, and the sample transitions from a ferromagnetic to a paramagnetic state (Figure 1). By extrapolating with a similar (power-law) dependence, we approximately estimated the phase transition temperatures of Fe45Co30Si10B15 of various sizes. The size of the microwire is likely a significant factor influencing the size of the ferromagnetic regions and, as noted, the phase transition temperatures.

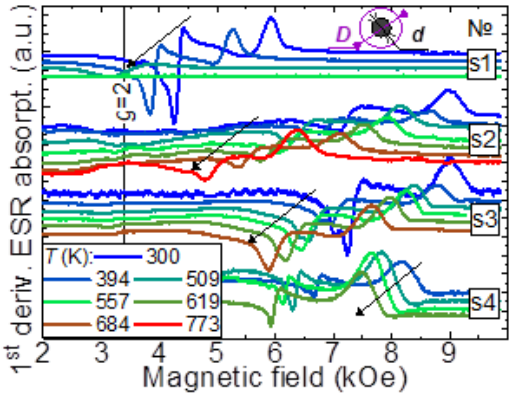

Fig. 1. EPR spectra of samples at different temperatures.

Table 1. Phase transition temperatures for microwires with different ratios of internal and external diameters.

№	Compound	d/D (μm)	$\rho = d/D$	T (10^3·K)
s1	$Co_{83}Fe_7C_1Si_7B_2$	38.0/41.0	0.927	0.51
s2	$Fe_{45}Co_{30}Si_{10}B_{15}$	19.1/26.2	0.729	0.88
s3		16.8/23.2	0.724	0.96
s4		9.7/14.8	0.655	1.35÷1.7

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MAGNETIC PHASE TRANSITIONS IN h-$YbMnO_3$ BY Yb^{3+} SPECTROSCOPY

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Optical *f-f* transitions of the Yb^{3+} Kramers ion in h-$YbMnO_3$ were studied using high-resolution Fourier spectroscopy. At temperatures below T_N = 87 K, splitting of the spectral line related to the optical transition in ytterbium located in the 4b position, Yb(4b), is observed. The temperature dependence of the splitting $\Delta_0(T)$ of the ground Yb(4b) doublet was found. The $\Delta_0(T)$ function is proportional to the temperature dependence of the magnetic moment of manganese (Fig. 1a). This indicates that the ytterbium Yb(4b) subsystem is magnetized in the effective magnetic field generated by the ordered manganese subsystem.

The population of the upper component of the split ground doublet plays a significant role in the low-temperature dynamics of the h-$YbMnO_3$ crystal. Using the $\Delta_0(T)$ function within the ground doublet model, we calculated the temperature behavior of the Yb(4b) magnetic moment: it is in clear agreement with the neutron data [1] (Fig. 1b). The calculated contribution of Yb(4b) to the heat capacity unambiguously explains the origin of the Schottky anomaly in the $C_P(T)$ dependence. A scenario for phase transitions in h-$YbMnO_3$ is proposed, in which the key role is played by the energy gain in the ytterbium system. Within the framework of the proposed scenario, the low-temperature phase transition in h-$YbMnO_3$ at a temperature of 3.5 K is more correctly interpreted as a spin-reorientation transition caused by the energy gain due to the splitting of the Kramers ground doublet of ytterbium in the 2a position. The constructed model explains the experimental temperature behavior of the magnetic moment of Yb(2a) (Fig. 1c).

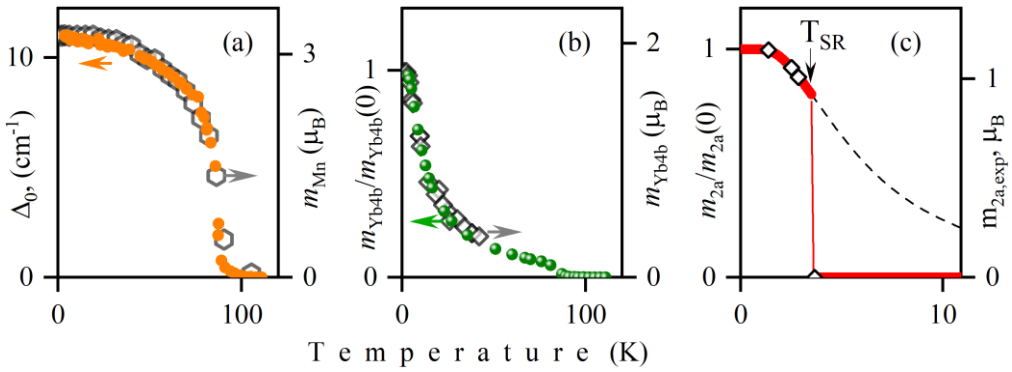

Fig. 1. Comparison of modeled based on spectroscopic and of literature neutron measurements. (a) Splitting of the Yb(4b) ground doublet (orange circles) and the magnetic moment of manganese [1] (open hexagons). (b) Magnetic moment of ytterbium Yb(4b): calculated temperature dependence (dark green balls) and the data from [2] (open diamonds). (c) Magnetic moment of ytterbium Yb(2a): calculated temperature dependence (red solid and black dashed lines) and the data from [2] (open diamonds).

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EPITAXIAL HEAVY METAL TELLURIDES AS PROMISING SOT-MATERIALS

Kozlov A.G.[1], *Silina S.K.*[1], *Bazrov M.A.*[1], *Kuznetsova M.A.*[1], *Prikhodchenko A.V.*[1], *Shestopalov R.A.*[1], *Namsaraev Zh.Zh.*[1], *Feng Y.*[2], *Meng F.*[2], *Wang Y.*[2]

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The basis of all spin-orbitronics devices under development is magnetic heterostructures, whose key properties are determined by phenomena and processes occurring both at interfaces and within the volume of ultrathin layers of magnetic or non-magnetic material. Magnetic heterostructures containing a material with strong spin-orbit coupling at the interface with a ferromagnet can exhibit useful properties such as perpendicular magnetic anisotropy (PMA), the Dzyaloshinsky-Mori chiral exchange interaction (DMI), and spin-orbit torque (SOT). The effect consists in the switching of magnetization during spin transfer to the ferromagnet from a bulk heavy metal. One of the most promising classes of SOT materials are transition metal dichalcogenides [1–3], including WTe_2, $MoTe_2$, MoS_2, etc., due to their topological properties and the peculiarities of their electronic structure, which strongly depends on the crystal structure. A distinctive feature of such materials is their structure—unlike classical SOT materials (crystalline heavy metals—W, Ta, Pt), they have a layered structure in which each layer is connected to its neighbor by weak van der Waals interactions, which allows for the realization of topologically protected states. A promising method for growing such structures is sputtering and epitaxy, as these techniques are compatible with industrial processes. In our work, we focus on the synthesis of heterostructures containing high-quality heavy-metal ditellurides, such as PtTe2 and MoTe2, using molecular beam epitaxy methods, and we also investigated the influence of topological materials on ultrathin Pt/Co magnetic films.

The layers were grown by molecular beam epitaxy on Al_2O_3 substrates. The structural features of the layers and the interface parameters were investigated using X-ray reflectometry. Magnetic hysteresis loops were measured using a VSM. The SOT effect was investigated using spin torque ferromagnetic resonance (ST-FMR) as well as by measuring the shift in the anomalous Hall effect loops. The results of the SOT study based on the AHE loop shift showed a significant decrease in the switching current density and an increase in SOT efficiency up to $\theta_{SHE} \approx 0.82$ in a multilayer film containing $PtTe_2$ + $MoTe_2$ layers. Depending on the order and thickness of the telluride layers, the magnitude and sign of θ_{SHE} could vary over a fairly wide range. A study of spin Hall conductivity for a combination of transition metal dichalcogenide sublayers was also conducted using the ST-FMR method, which also confirmed an increase in the effect.

This work was supported by Russian Scientific Foundation project № 26-72-31015.

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HIGH THROUGHPUT SCREENING OF NEW ALL-D HEUSLER ALLOYS

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Transition metal-based Heusler alloys exhibit a wide range of diverse properties that can be useful across an equally broad spectrum of scientific fields. These properties include ferro-, antiferro-, and ferrimagnetism, half-metallicity, superconductivity, and thermoelectric properties. Heusler alloys also possess magnetic shape memory and magnetostriction effects [1]. Such a variety of potential properties makes Heusler alloys highly promising for the study and design of new materials using first-principles methods.

In the present work, first-principles calculations were carried out for an array of Heusler alloys. The investigations were performed on a dataset consisting of 500 randomly generated compounds, each evaluated in four structural orderings: atomic orderings of the $L2_1$ and XA-types, including the cubic austenitic (space groups 225 and 216) and tetragonal martensitic (space groups 139 and 119) phases for each compound. Additionally, several possible magnetic configurations were constructed for each individual structure. Ground-state characteristics of the generated compounds were obtained via first-principles calculations, and their magnetic properties were investigated to identify alloys with a non-zero magnetic moment for the subsequent calculation of exchange interaction parameters, Curie temperature, and magnetization modeling.

The study was conducted using the high-throughput screening methodology, which is based on constructing a large dataset and rationally filtering out non-relevant compounds in several stages [2]. In this work, the screening was performed based on the structural stability (energetic favorability) of specific phases, formation energies, and types of magnetic ordering.

Ferro- and ferrimagnetic compounds with a non-zero total magnetic moment are required to calculate the Curie temperature. As a result of high-throughput screening, specific compounds were isolated from the initial dataset, for which magnetization modeling and Curie temperature determination were subsequently performed. Fig. 1 shows the dependence of the Curie temperature on the total magnetic moment per formula unit.

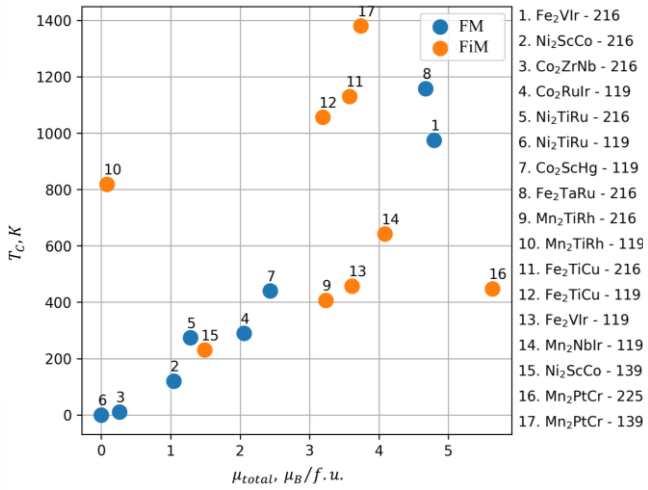

Fig. 1. Curie temperature distribution as a function of the total magnetic moment

The research was supported by the RSF Russian Science Foundation Project No. № 24-12-20016

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ORAL SESSION

Magnetic Soft Matter (magnetic polymers, complex magnetic fluids and suspensions)

Thursday, 20 August, 15:00 - 17:00

MODELLING OF THE DIRECT MAGNETOELECTRIC EFFECT IN POLYMERIC COMPOSITE MULTIFERROICS

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Polymer multiferroics, which are in high demand in sensorics and biomedicine, are the composites whose matrix is filled with fine ferromagnetic particles. These materials are capable of, first place, the direct magnetoelectric (ME) effect that is conversion of the applied magnetic field into electric voltage. As the magnetic field is all-pervading with respect to organic matter and live tissue, a tiny bit of an ME composite embedded in the depth of an object becomes a remotely-controlled biocompatible minuscule electric generator affecting the target site like nerve, muscle, gland, etc. [1]. The same ME effect, accompanied also by mechanical strains, is known to considerably stimulate the development of stem cells seeded on a scaffold made of such a multiferroic [2].

As the electric measurements under these conditions, especially *in vivo*, is an immensely sophisticated task, the corresponding data are utterly sparce if any. A typical situation is that the ingredients are prepared, characterised *per se*, and merged to give an ME composite [1]. The next step that immediate follows, is a biological test. Upon accomplishing it, the quality of the ME material is assessed from comparison of the treated and control specimens, e.g., on advancement of the cell population. However accurately any such trials might be, they give, at most, implicit proofs of the positive influence of the ME effect, and these results are rather qualitative than quantitative. In other words, the physics aspect of the work, viz. the question: what electric fields are really induced and acting inside the test specimen, what are their amplitudes and spatial distributions, lacks a definite answer.

In the absence of experimental data, theoretical modelling cannot resolve this yet existing issue in full. However, if the content of the multiferroic is known, model calculations can produce reasonable estimations of the anticipated ME effect. Moreover, some conclusions might be drawn on the role of particle aggregation that is a ubiquitous is such systems.

In our work—looking at ME films as well as at filaments—we present some examples of mesoscopic modelling of the electric response in polymeric ME composites including both the `classical dyad' (PVDF+cobalt ferrite) [3,4] and more `exotic' structures, e.g., PVDF+a ferrite with next-to-zero magnetostriction [5].

This study was carried out within the framework of Task #126020916888-9 from the Ministry of Science and Higher Education of Russian Federation.

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[3] O.V. Stolbov, Yu.L.Raikher, *Nanomaterials* **15** (2025) Art. no. 487.
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DEMAGNETIZATION DYNAMICS IN IMMOBOLIZED SUPERPARAMAGNETIC NANOPARTICLES: A PART OF INTERPARTICLE INTERACTIONS

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Relaxation dynamics of the magnetization in superparamagnetic nanoparticles is traditionally described on the basis of Landau-Lifshitz-Gilbert equation [1-3] assuming the stochastic fluctuations of the magnetic moment inside a single-domain nanoparticle. Reformulating the problem in terms of the Fokker-Planck-Brown (FPB) equation [1] for the orientational single-particle probability density made it possible to obtain the dependence of the characteristic relaxation time, known as the Néel time, of the remagnetization process of a superparamagnetic nanoparticle on the height of the potential barrier of magnetic anisotropy energy. This approach neglects the interparticle interactions between the nanoparticle magnetic moments, but it was used many times during last several decades in theoretical and experimental studies. The only discussion about the part of interactions has been limited to empirical consideration regarding the possibility of renormalizing the magnetic anisotropy energy and introducing an effective anisotropy constant that takes into account the contribution of interparticle interactions.

Here, we consider the uniaxial superparamagnetic nanoparticles immobilized in a solid matrix under the condition when the easy magnetization axes of all particles are aligned along an external field, which is strong enough to put the sample to magnetically saturated state. Then, we consider that magnetic field is jump-like switched off, and the magnetization of the sample starts to reduce due to temperature fluctuations. We solve numerically the corresponding FPB equation inserting in it the term accounting for the interparticle dipole-dipole interaction within the modified mean-field approach [4].

The time-dependent dynamics is controlled by two characteristic time scales. Initially, the magnetization reduces with the time scale of the precession of single magnetic moment, but longer decay of the magnetization requires the fluctuation overcoming of the magnetic anisotropy energy, that is controlled by the Néel relaxation time. The obtained numerical results demonstrate very accurate coincidence with the known theoretical estimations [2] for noninteracting nanoparticles. Switching on the interaction, we get longer relaxation time, which is monotonically increases with the interaction strength. Finally, we describe quantitatively the interaction dependent relaxation time in terms of effective anisotropy constant.

Support by Russian Science Foundation, project No. 23-12-00039-P, is acknowledged.

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RECLAIMED CARBON FIBER FROM WASTE PRODUCTS MODIFIED WITH COLLOIDAL MAGNETITE PARTICLES: STRUCTURE, PROPERTIES, AND APPLICATIONS

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Interest in waste recycling and material reuse is growing due to environmental and economic reasons. Carbon fibers (CFs)-obtained via high-temperature processing of organic fibers- are valued for their strength, low weight, and chemical resistance. Polyacrylonitrile (PAN) – based CFs are especially promising, offering high microporosity, specific surface area, and mechanical properties useful for supercapacitors, adsorption, aerospace, construction, and medicine. However, the inert surface of CFs limits their use in composites, requiring functionalization via chemical oxidation, thermal treatment, or plasma modification. Since producing virgin CFs (vCFs) is expensive, recycling composite scrap to obtain reclaimed CFs (rCFs) is a cost-effective and environmentally friendly alternative. Key research focuses on optimizing extraction methods to preserve the fiber quality.

Decorating CFs with magnetic nanoparticles (MNPs) [1, 2] enables multifunctional materials combining high strength with controllable magnetic behavior. While vCFs are electrically conductive, MNPs introduce magnetic loss, improving interfacial interactions and electromagnetic compatibility for medical devices.

CF microstructure is complex, spanning nano-, micro-, and meso-scales. This study uses small-angle neutron and X-ray scattering to investigate nanostructural features of vCF, rCF, functionalized CF (fCF), and CFs decorated with magnetite nanoparticles [3, 4]. The methods proved sensitive to structural changes at relevant length scales, revealing key links between fiber microstructure and macroscopic properties – essential for process optimization and performance improvement across applications [5].

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DYNAMIC RESPONSE OF MAGNETIC NANOPARTICLE DISPERSION: APPROXIMATION FORMULAS FOR THE FIRST AND THIRD HARMONICS

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Magnetic nanoparticle dispersions are a promising tool for biomedicine and other applications. One of the key technologies that enables their practical use is magnetic particle imaging (MPI), which focuses on analyzing harmonics of dynamic magnetic susceptibility. These harmonics are defined as the Fourier coefficients of the magnetization.

In this work, we theoretically study first (fundamental) and third (nonlinear) harmonics. Exact analytical expressions for the first and third harmonics are known only in limiting cases. For example, in the case of small amplitudes of the AC field in the single-particle approximation the linear susceptibility is described by the classical Debye theory, while the analytical formula for the third harmonic was proposed in Ref. [1]. Also existing analytical results for the cases weak AC fields with dipole-dipole interactions Ref. [2], and for arbitrary field amplitudes without interactions Ref. [3]. Here, we propose universal expressions for linear and nonlinear harmonics that simultaneously account for both arbitrary amplitudes and dipole-dipole interactions.

Our calculations were performed using two independent approaches: numerical solution of the Fokker-Planck equation and molecular dynamics computer simulations. In the first approach, we considered the single-particle orientation distribution function for magnetic moment orientation and incorporated dipole-dipole interactions via a mean-field approximation that includes terms up to second order in concentration, thus incorporating three-particle correlations. The Fokker-Planck equation was solved numerically using an unconditionally stable finite-difference numerical scheme. In the second approach, all pairwise dipole-dipole interactions and hard spheres repulsion via the Weeks-Chandler-Andersen potential were explicitly evaluated by solving the Langevin equations. By comparing the results, we identified the parameter region in which the numerical solution agrees with the simulations for all field amplitudes and dipole-dipole interaction intensities. For this region, approximate analytical expressions for the first and the third harmonic were derived using the least-squares fitting method, capturing the effects of both arbitrary amplitudes and dipole-dipole interactions. These approximate formulas combine the analytical small amplitude solution of the Fokker-Planck equation with dipole-dipole interactions and correction functions that encode the influence of arbitrary AC field amplitudes. The resulting expressions allow to predict the linear and nonlinear dynamic susceptibility of magnetic nanoparticle dispersions in a parameter range that is inaccessible to existing models. Importantly, approximate formulas correctly reduce to the known analytical limits when interactions are weak or field amplitudes are small.

The research was supported by the Russian Science Foundation, Grant No. 23-12-00039-П, https://rscf.ru/project/23-12-00039-П/

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ROOM-TEMPERATURE INVESTIGATION OF THE MAGNETIC PROPERTIES OF FERROFLUIDS BASED ON MFe_2O_4 (M=Fe,Co,Ni) NANOPARTICLES

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In this study, the magnetic properties of ferrofluids synthesized on the basis of 3d transition metals (Fe,Co,Ni) at different concentrations were experimentally investigated at room temperature (T ≈ 300 K). Magnetic MFe_2O_4 (M=Fe,Co,Ni) nanoparticles were synthesized using the chemical condensation method. The internal structure and dimensions of the resulting $FeFe_2O_4$, $CoFe_2O_4$ and $NiFe_2O_4$ magnetic nanoparticles were examined using an Empyrean PANalytical X-ray diffractometer equipped with an X-ACT silicon drift detector and a LEO 912 AB transmission electron microscope. MFe_2O_4 nanoparticles were used as the magnetic core of the ferrofluid, oleic acid as the surfactant, and distilled water as the carrier liquid. Using these three components, ferrofluids with volume concentrations ranging from 0.5% to 5% were prepared, and their magnetic properties were measured using a vibrating sample magnetometer (VSM).

The magnetic properties of the ferrofluids based on the synthesized MFe_2O_4 (M=Fe,Co,Ni) nanoparticles are strongly dependent on particle size and shape, the state of the surfactant layer, and interparticle interactions. As the nanoparticle size in the ferrofluids decreases, the multidomain structure transforms into a single-domain structure, leading to a superparamagnetic state. In the present study, the sizes of the $FeFe_2O_4$, $CoFe_2O_4$ and $NiFe_2O_4$ nanoparticles were in the range of 5.5–8.5 nm, confirming that the ferrofluids exhibit a fully superparamagnetic state. The magnetic properties of the ferrofluids based on MFe_2O_4 nanoparticles were measured using a vibrating sample magnetometer (VSM).

It was established that the values of saturation magnetization (Ms), remanent magnetization (M_r), and coercive field (Hc) depend significantly on the composition and concentration of the ferrite nanoparticles.

Samples	T (K)	C (%)	ρ (g/cm³)	Ms (emu/g)	M_r (emu/g)	Hc (Oe)	χ_0 (1/Oe)
Fe_3O_4	300	0.5	1.085	7.20	-0.02	6.1	0.002607
		5	1.25	71.98	-0.09	3.6	0.025901
$CoFe_2O_4$	300	0.5	1.12	5.81	-0.24	173.7	0.001392
		5	1.28	58.03	-2.49	179.1	0.013868
$NiFe_2O_4$	300	0.5	1.16	5.21	-0.04	26.8	0.001559
		5	1.33	51.93	-0.38	24.5	0.015656

An increase in the concentration of MFe_2O_4 (M=Fe,Co,Ni) ferrite nanoparticles in the ferrofluids was found to result in higher saturation magnetization and magnetic susceptibility. The experimentally obtained M–H curves were in very good agreement with the Langevin model, which is characteristic of superparamagnetic systems.

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DETERMINATION OF ION MOBILITY IN MAGNETIC FLUIDS BASED ON LIQUID DIELECTRICS BY AN ELECTRO-OPTICAL METHOD

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Magnetic fluids based on dielectric liquids are typical examples of weakly conductive liquid dielectrics. In magnetic fluids, electrophysical processes can be significantly influenced by the magnetic field, developing electrohydrodynamic processes, and the formation of various types of aggregate structures from nanoparticles. Electro-optical methods can be effectively used to study the electrophysical processes in such systems. Reliable data on the conductivity mechanisms of magnetic fluids based on dielectric liquids are important for understanding the complex dynamics of the interaction of such systems with an electric field, their stability, and for developing practical applications in microfluidics, electrorheological, and electro-optical devices [1].

We present a new, original method for determining ion mobility in weakly conducting liquid dielectrics based on measuring the dynamics of the electro-optical Kerr effect in a pulsed electric field. The Kerr effect is highly dependent on the field strength and is characterized by a very short relaxation time (several microseconds). This makes it possible to use the electro-optical effect to study the processes by which a steady-state field strength is established through various mechanisms.

After the field pulse is applied, the relaxation of the electric field in such systems is determined by the competition between the migration and Maxwell-Wagner relaxation times. Particularly interesting cases arise when these times are close together and when the migration relaxation time exceeds the Maxwell-Wagner time. In this case, the relaxation curve of the electro-optical signal has a characteristic shape with a pronounced minimum (Fig. 1). Ion mobilities in various magnetic colloid samples based on dielectric liquids were determined by measuring the time to reach a minimum at various electric field amplitudes.

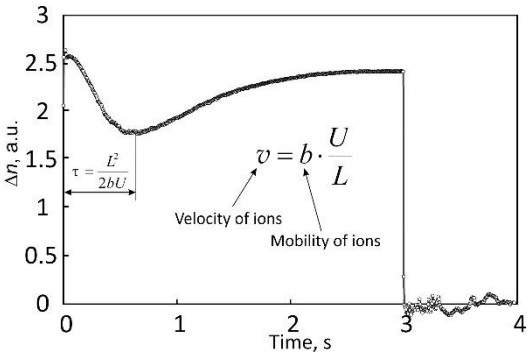

Fig. 1. Electro-optical signal in a kerosene-based magnetic fluid in a pulsed electric field (E=2MV/m, duration 3 sec.).

The validity of the experimental method used was confirmed by a charge transport model for liquid dielectrics based on the numerical solution of the Nernst-Planck-Poisson equations.

Support by Russian Ministry of Science and Higher Education (project FSRN-2026-0006) is acknowledged.

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ORAL SESSION

Low Dimensional Magnetism

Thursday, 20 August, 15:00 - 17:00

MAGNETIC ORDERING AND SPIN DYNAMICS IN NABOKOITE FAMILY COMPOUNDS

Glazkov V.N.[1], *Rebrov Ya.V.*[1,2], *Dubovitskii M.A.*[1,2], *Markina M.M.*[3], *Murtazoev A.F.*[3], *Berdonosov P.S.*[3], *Vasiliev A.N.*[3]

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Nabokoite family compounds $ACu_7(TeO_4)(SO_4)_5X$ (here alkali ion A=K, Na, Rb, Cs and halogen ion X=Cl, Br) are considered as a possible realization of a 2D square kagomé lattice (Fig.1). This lattice is highly frustrated and a gapped spin-liquid state is predicted for the ideal equilateral SKL model [1]. Real nabokoite structure features an additional 'decorating' copper ion in interlayer Cu2 position bridging neighboring SKL layers.

High degree of frustration in nabokoites is highlighted by the difference in Curie-Weiss temperature Θ~150 K and antiferromagnetic ordering temperature T_N=3...5 K [2].

Variation of non-magnetic alkali of halogen ions in nabokoite family magnets opens a route to subtle tuning of material parameters and gives us an instrument to study influence of the subtle modification of the frustrated magnet on the formation of its low-temperature phases.

We report results of the detailed electron spin resonance study of spin dynamics both in the paramagnetic and magnetically ordered phases of nabokoite family compound along with the complimenting study of the high-frequency dielectric properties of nabokoites. Experiments were performed at 1.7-200 K temperature range, 9-140 GHz frequencies and at magnetic field up to 5 T. ESR spectroscopy is a powerful instrument for the study of antiferromagnetically ordered phases being highly sensitive to the type of magnetic ordering, providing access to the spin-waves zero-field gaps and spin-reorientation transitions.

We have found that light (Na, K) and heavy (Rb, Cs) alkali ion compounds follow drastically different scenarios of magnetic ordering.

Heavy-alkali-ions nabokoites demonstrate conventional collinear antiferromagnetic ordering with easy-axis anisotropy. Characteristics of the ordered phase are very close for all heavy-alkali-ions compounds: spin-waves zero field gap around 120 GHz and spin-flop field around 4.0 T.

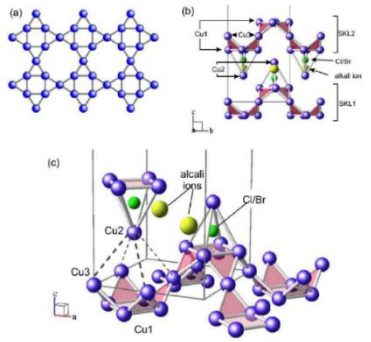

Figure 5 (a) schematic representation of a 2D square kagomé latice (b) and(c) fragments of nabokoite ACu7(TeO4)(SO4)5X structure (only copper, alkali and halogen ion positions are shown).

Light-alkali-ions nabokoites follows much more complicating route with a staircase of structural and magnetic phase transitions and very individual parameters of the low-temperature ordered state. On cooling from room temperature we observe strong anomalies both in real and imaginary parts of high-frequency dielectric parameters at 25-100 K depending on the compound [3]. This dielectric phase transition is accompanied by a minute structural alternation which partially lifts frustration and 'pre-cooks' the ongoing magnetic phase transition. Low-temperature order is formed via the two-step phase transition with T_{N1}=5...6 K and T_{N2}=3...4 K. The formed low-temperature magnetic order is non-collinear, which is evidenced by a characteristic frequency-field dependence of the antiferromagnetic resonance qualitatively different from that of a 'conventional' collinearly ordered antiferromagnet [2]. Spin-waves spectra of a light-alkali-ion nabokoites features three zero-field gaps (approx. 30, 112 and 155 GHz for Na/Cl compound) and two spin-reorientation transitions (0.51 and 2.0 T for Na/Cl compound). Corresponding values for other light-alkali-ion compound differ by up to approx. 50%, highlighting importance of the individual minor structural modifications 'pre-cooking' the low temperature phase.

The work was supported by RSF Grant 22-12-00259-П.

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LiCu3O3 – AN ANTIFERROMAGNET WITH A HIGHLY DILUTED SQUARE LATTICE. AN NMR STUDY

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$LiCu_3O_3$ is a new quasi-two-dimensional magnet (S=1/2) with strong substitution of magnetic ions with non-magnetic ions. The crystal structure of $LiCu_3O_3$ contains "triads" of magnetic planes of Cu^{2+} ions (S=1/2) located at the sites of a square lattice. Li^+ ions occupy the same crystallographic positions as Cu^{2+} ions with different degrees of substitution for the inner and outer planes – 20% and 40% (fig.1). These triads of square planes (B-A-B) are separated by planes of non-magnetic Cu^+ ions, which determines the quasi-two-dimensionality of $LiCu_3O_3$. The degree of substitution in the inner planes (A) is less than the percolation threshold in a square lattice, therefore, the magnetic ions in such planes form an infinite cluster, while in the outer planes (B) the degree of substitution is critically close to the percolation threshold.

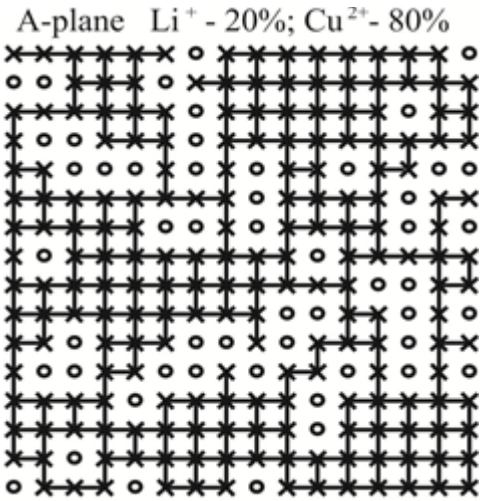

Fig.1 The scheme of Li+-Cu2+ random distribution on A-plane.

These unusual samples are stable under normal conditions and have well reproducible properties.

Studies of the magnetic structure of $LiCu_3O_3$ [1-3] have revealed a number of macroscopic properties of the magnetic structure of $LiCu_3O_3$. Below T_N = ~123 K, a three-dimensional magnetic collinear order is observed, with spins directed along one side of the square lattice. It was found that at T_N = 123 K, only a portion of the magnetic Cu2+ ions are ordered, while a significant portion of the sample remains paramagnetic down to T_1 = ~25 K.

The report reviews the results of magnetometry, neutron and X-ray diffraction studies, ESR and discusses new results of a ^{7}Li NMR study of $LiCu_3O_3$, attempting to reconstruct the local distribution of magnetic moments at square lattices sites and their configuration.

Supported by the Russian Science Foundation Grant No 22-12-00259-П .

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STRUCTURAL DEFECTS AND FERROMAGNETISM IN TX_5 (T=MO,W; X=CL,BR)

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Early heavy 4d/5d transition metal pentahalides, such as $MoCl_5$ and WBr_5 (Fig. 1), are promising high-temperature ferromagnets, exhibiting Curie temperatures of 22 K[1] and 35 K, respectively. Their magnetism arises from a T_2X_{10} dimeric structure, where edge-sharing TX_6 octahedra (T = Mo, W; X = halogen) link into layers via halogen bonds. An important structural feature is the opposing off-center displacement of $T^{5+}(d^1)$ cations within the dimer, resulting in large intradimer distances between the transition metals. It effectively suppresses direct d-d overlap and enhance ligand-mediated ferromagnetic exchange within dimers [2]. This octahedral distortion also lifts the degeneracy of a d^1 center presented in an ideal octahedral environment (which would otherwise lead to zero net magnetic moment from S=1/2 and L=1 cancellation, M=2S-L), thus enabling the manifestation of a magnetic moment. Experimental saturation moments are 0.7 μ_B/f.u. for $MoCl_5$ and 0.15 μ_B/f.u. for WBr_5, with DFT calculations confirming ferromagnetic intra- and inter-dimer exchange and magnetic anisotropy energies of 4.75 meV (Mo-based) and 24.89 meV (W-based).

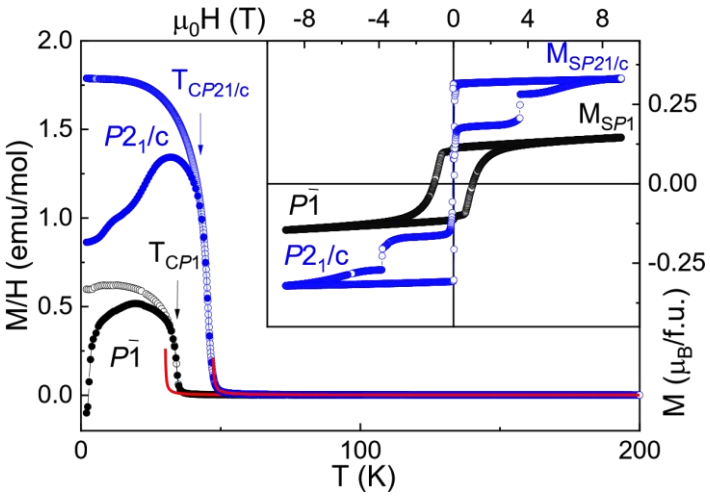

Fig. 1. The temperature dependence of reduced magnetization of $P\bar{1}$ and $P2_1/c$ WBr_5 obtained in a field – cooled (open circles) and zero – field cooled (closed circles) regimes at $\mu_0 H$ = 0.1 T. Solid lines are the fits with Curie – Weiss law. Inset: Magnetization loops of $P\bar{1}$ and $P2_1/c$ WBr_5 taken at 2K.

We have found that structural defects, specifically tungsten (W) disorder manifesting as a b/2 shift between the W(1) and W(1') dimer sublattices, lead to a significant increase in the Curie temperature up to T_C = 45 K in a new polymorphic modification of WBr_5 (Fig. 1), described by the $P2_1/c$ space group. In contrast, chemical substitutions in $MoCl_5$—namely, replacing half of the $Mo^{5+}(4d^1)$ cations with either $Re^{5+}(5d^2)$ or $Nb^{5+}(4d^0)$—result in the formation of a ferrimagnetically ordered state below T_{NRe} = 4.6 K or suppresses the formation of long-range order in $Nb_{0.5}Mo_{0.5}Cl_5$, respectively. For isolated $MoCl_6$ octahedra in the novel compound PCl_4MoCl_6, long-range antiferromagnetic order is observed below T_{NPCl4} = 4.2 K.

Support of RSCF grant No. 25-12-00028 is acknowledged.

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EXPERIMENTAL REALIZATION OF LOW DIMENSIONAL ANTIFERROMAGNETS

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Low-dimensional quantum magnetic materials, including one-dimensional (1D) chains and two-dimensional (2D) spin-frustrated materials, have attracted significant attention in the past decades because of their exotic quantum phenomena such as quantum spin liquid state, fractional excitation, and potential applications in spintronics and quantum computing [1-3]. However, the underlying mechanisms of these exotic quantum phenomena in low-dimensional quantum magnetic materials remain incompletely understood. Meanwhile, in the present, exploration and synthesis of novel low-dimensional quantum magnetic materials is usually random. Therefore, rational design and experimental synthesis of low-dimensional quantum magnetic materials is urgent.

In this presentation, I will introduce how to fully use the diversity of chemical groups to rationally design and directionally synthesize low-dimensional quantum magnetic materials with specific magnetic lattices.

For 1D chains, there are two different strategies. The first strategy is a topochemical dehydration/rehydration route to construct ideal 1D chains. A novel 1D chain antiferromagnet (2,2'-bpy)$FeF_3 \cdot 2H_2O$ (2,2'-bpy = 2,2'-bipyridine) with the best 1D magnetism was rationally prepared by a controlled topochemical de/re-hydration approach from a hydrous precursor (2,2'-bpy)$FeF_3(H_2O) \cdot 2H_2O$ with isolated spins (S = 5/2). In addition, this controlled topochemical de/re-hydration approach can be universally applied for other systems, for example, for successfully obtaining 1D S = 3/2 spin chain antiferromagnet (2,2'-bpy)$CrF_3 \cdot 2H_2O$ from the precursor (2,2'-bpy)$CrF_3(H_2O) \cdot 2H_2O$. The second strategy is utilizing long organic molecules for effectively separating spin chains to directly synthesize a series of ideal antiferromagnetic spin chain materials such as a nearly-ideal 1D spin S = 5/2 chain antiferromagnet $[H_2(4,4'\text{-bpy})](H_3O)_2Fe_2F_{10}$ (4,4′-bpy = 4,4′-bipyridine) with the best 1D magnetism.

For 2D spin-frustrated materials, we have used various triangular units such as BO_3, PO_3, and SeO_3 to directionally coordinate magnetic ions. A series of 2D spin-frustrated materials, including $KMB_4O_6F_3$ (M = Co, Fe), $K_2Co_2(HPO_3)_2(C_2O_4)(H_2O)_2$, and $Cu_3O_2(HSeO_3)(HSO_4)(H_2O)$, have been synthesized.

Support by the National Key Research and Development Program (No. 2023YFA1406500), the National Natural Science Foundation of China (NSFC Nos. 22271107 and 22422111) is acknowledged.

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ORAL SESSION

High Frequency Properties. Nanocomposites

Thursday, 20 August, 15:00 - 17:00

HIGH GYROMAGNETIC RATIO IN THULIUM-GALLIUM IRON GARNETS

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The high gyromagnetic ratio γ is observed in ferrimagnets near the angular momentum compensation point T_A and $\gamma \to \infty$ at $T \to T_A$ [1-3]. This phenomenon attracts a considerable interest because the dynamic properties of magnetic materials are largely determined by the gyromagnetic ratio: the velocity of domain walls and the frequency of magnetization vector oscillations are proportional to γ. The implementation of such phenomenon in actual applications is difficult due to the strong temperature dependence of $\gamma(T)$ and to the requirement for a rigorous thermal stabilization of the ferrimagnetic material.

Thulium iron garnet $Tm_3Fe_5O_{12}$ has a low gyromagnetic ratio, characterized by the Landé factor g~1.7 [4]. It has been shown in this work that the effective gyromagnetic ratio in such materials can be significantly increased (Fig. 1) by a factor of 3–5 by diluting iron with gallium ions [5]. In this case, the gyromagnetic ratio depends on both the content of gallium ions and their distribution between the octahedral and tetrahedral sublattices of the iron garnet.

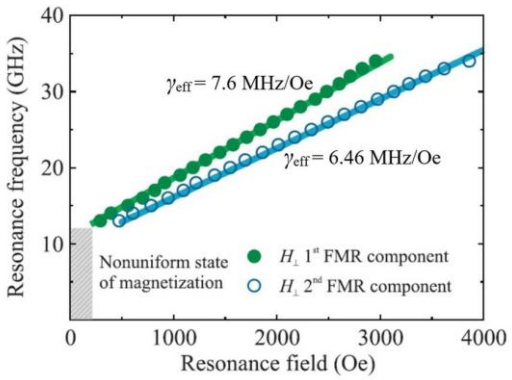

Fig. 1. FMR frequency vs the resonance field perpendicular to the film plane.

The possibility of achieving a high gyromagnetic ratio in ferrimagnets, which have no magnetic and angular momentum compensation points, has been experimentally discovered and theoretically confirmed for the first time. The gyromagnetic ratio is a key parameter determining the speed of processes in a magnetic spin system, and the results obtained in this work are important for a significant increase in the operation speed of spintronic devices based on ferrimagnetic materials.

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ON FERROMAGNETIC RESONANCE IN A FEROMAGNETIC CONDUCTING SPHERE

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When studying ferromagnetic resonance in conducting ferromagnetic particles, there are often used formulas relating the magnetic permeability of a particle μ_p and the permeability of the material μ_i the particle is made from [1]. This approach seems to be approximate for two reasons. First, the permeability of both the material and the particle is a tensor with different diagonal components, as well as non-zero non-diagonal components. Secondly, and more importantly, the alternating magnetic field inside a conducting particle is spatially inhomogeneous, and therefore the particle's magnetization oscillations are also spatially inhomogeneous, which makes the particle's permeability coordinate dependent function.

In our work we use a different approach based on solving Maxwell's equations in a quasi-static approximation for a given distribution of the time-dependent component of the particle's magnetization and the subsequent solution of the Landau-Lifshitz equation. This method was used for the magnetic film in Ref. [2], and for the magnetic wire in Ref. [3]. In zero alternating field, a ferromagnetic sphere is assumed to be uniformly magnetized in a constant magnetic field $\boldsymbol{H}_0$. The solution of Maxwell's equations in the quasi-static approximation for a magnetic field can be written as $h=h_m[m]+h_h(h_0)$, where m and h_0 are the alternating components of the magnetization and the external magnetic field, respectively. The functional $h_m[m]$ non-locally depends on the magnetization of the particle, and $h(h_0)$ is a function of the external field and coordinates. The resulting solution is substituted then into the linearized Landau-Lifshitz equation. Solving this equation we find the alternating component of the magnetization as a function of the external field, oscillation frequency, and the coordinates. Since the magnetization oscillations are spatially inhomogeneous we take into account the contribution from the energy of the exchange interaction in the Landau-Lifshitz equation. The problem is solved by decomposing the alternating components of the magnetization and the magnetic field into a series of orthogonal functions. This procedure makes it possible to calculate not only the frequency dependence of the particle's susceptibility, but also the spatial distribution of the magnetization oscillations inside the sphere.

This work was supported by the Russian Science Foundation under Grant No. 25-19-00393.

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STATIC AND DYNAMIC MAGNETIC PROPERTIES OF $Co_{67}Fe_7B_{26}$ FILMS OBTAINED BY MAGNETRON SPUTTERING

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Ferromagnetic films show promise for a variety of high-frequency applications, since they can exceed the Snoek limit, allowing microwave devices to operate at higher frequencies [1]. Amorphous CoFeB films exhibit excellent soft magnetic properties and have the ferromagnetic resonance (FMR) frequency above 1 GHz. The dynamic magnetic properties of CoFeB films on rigid and flexible substrates have been investigated over past decades. However, all studies of CoFeB films were restricted to ultra-thin films with a maximum thickness of 500 nm.

In this work, we systematically investigate the thickness effect on the magnetostatic and microwave properties of amorphous $Co_{67}Fe_7B_{26}$ films deposited using DC magnetron sputtering onto a flexible substrate. Films with thicknesses in the range of 0.19 to 1.40 μm are obtained. The in-plane hysteresis loops are measured in the field range of ±1 kOe using a vibrating sample magnetometer. The microwave permeability is studied using coaxial technique in the frequency range of 0.1 to 10 GHz. The measured frequency dependences of the permeability are fitted by the Lorentzian dispersion law. To analyze changes in the microwave permeability depending on the film thickness, the Acher parameter [1,2] is used.

It is observed that the frequency dependence of the imaginary part of the permeability for all films has one peak, which is attributed to the FMR. For films of a thickness of 0.33 μm and higher, both the static permeability and the FMR frequency depend weakly on the film thickness, while the peak in the imaginary part of the microwave permeability decreases with the film thickness increase. The Acher parameter for all studied films is close to unity, which indicates the presence of in-plane magnetic anisotropy in the films.

The influence of the skin effect on the frequency dependence of the microwave permeability of CoFeB films is studied within the framework of an analytical model [3]. The calculated results satisfactorily describe the changes in the microwave permeability with a growth of the film thickness, and it is found that an increase in the damping factor with the film thickness is due to the skin effect.

The impact of the mechanical stresses arising due to bending of the studied samples to the measured permeability is analyzed. It is found that the effective magnetoelastic anisotropy field induced in the studied films is higher than the magnetic anisotropy field, which leads to a change in the easy magnetization axis direction. A model taking into account a contribution from the magnetoelastic effect to the measured microwave permeability of the films is proposed. The results obtained may be useful for microwave applications of soft magnetic CoFeB films.

This work was supported by the Russian Science Foundation under grant No. 25-19-00393.

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RETRIEVING THE INTRINSIC PERMEABILITY OF FERRITES FROM THE EFFECTIVE PERMEABILITY OF COMPOSITE MATERIALS

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Bulk ferrites and composite materials filled with ferrite powders are widely used to develop novel materials for microwave applications. Evaluation of their high-frequency magnetic properties is crucial for assessing their practical potential. A key challenge is to describe the effective properties of a composite as a function of the inclusion and matrix properties. Mixing rules are commonly applied to solve this problem. Unlike bulk ferromagnets, the microwave properties of bulk ferrites can be measured using standard techniques due to low eddy current losses. This allows for a direct comparison of the measured permeability with the values predicted by mixing rules.

In this work, we investigate the dynamic magnetic properties of various ferrite grades and composite materials based on them. The grades of ferrites with static permeability of 30, 1000, and 6000 were studied. Particles with the same shape but different sizes were obtained from the bulk ferrites under study. The dependences of the permeability of the composites on frequency, inclusion size and concentration are studied. Additionally, the dynamic permeability of the ferrites was measured under an external magnetic field.

The applicability of different mixing rules to the measured permeability of composite materials is analyzed. Using the Odelevsky mixing rule, the intrinsic permeability of ferrite inclusions of various sizes and grades was retrieved.

It was found that the intrinsic permeability of inclusions depends on their size and differs from the measured permeability of bulk ferrites, which does not agree with commonly used effective medium theories. However, the application of an external magnetic field eliminates the difference in permeability among particles of various sizes.

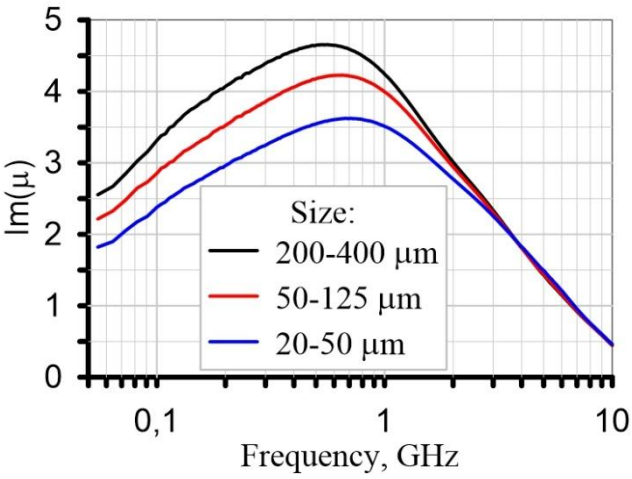

Fig. 1. Imaginary permeability of composites filled with ferrite particles of different sizes

To explain the observed phenomena, the effective medium theory described in [1] is applied, which allows taking into account the difference between the permeability of the inclusion and that of the bulk material. While authors in [1] attributed these variations to the shape of the inclusions, the discrepancy observed in the present work is due to the influence of domain wall resonance, as well as FMR features in the presence of a domain structure.

This work was supported by the Russian Science Foundation under grant No. 25-19-00393.

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MAGNETOTRANSPORT PROPERTIES OF CoFeB/SiO_2 COMPOSITE THIN FILMS DEPOSITED IN Ar AND Ar + N_2 ATMOSPHERES

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Composite metal–dielectric thin films based on ferromagnetic alloys are promising for spintronics, magnetoresistive sensors, and flexible electronics [1]. Their transport properties are strongly affected by microstructure, intergranular barriers, carrier localization, and spin-dependent tunneling [2]. CoFeB–SiO_2 composite films were obtained by ion-beam sputtering from metallic CoFeB and dielectric SiO_2 targets onto flexible lavsan substrates. Two series of films were prepared: S1, obtained in an Ar atmosphere with a pressure of 26.7 mPa, and S2 in an Ar + N_2 mixture, with pressures of 22.6 and 2.7 mPa, respectively. The substrate holder rotated at 5 rpm, creating a uniform composition along the composite film strip with the same width as the ion beam. For S1 deposition time was 100 min, and anode voltage was 2.8 kV. For S2, these parameters were 155 min, and 2.3 kV. The plasma current was 60 mA for both series. The introduction of nitrogen in S2 is assumed to partially encapsulate CoFeB clusters, forming insulating shells that suppress their coalescence and stabilize the granular structure. In contrast, the absence of nitrogen in S1 favors stronger cluster coalescence and the formation of a more inhomogeneous conducting network. Film morphology, thickness, and composition were studied by SEM and EDX using a TESCAN MIRA3 system. Surface morphology and magnetic regions structure were investigated by AFM and MFM using an NTEGRA Prima system. Magnetotransport measurements were performed using a PPMS-9 system in the temperature range of 2–400 K and magnetic fields up to 9 T by the four-probe method. To analyze the conduction mechanism, temperature dependences of resistance at zero magnetic field were considered. The dependence was described in the general form For series S1, no single conduction law describes all samples over the entire temperature range. The dependence of ln$R$ on $T^{-1/4}$, corresponding to three-dimensional Mott variable-range hopping, is closest to linear only in the middle temperature region. Strong deviations at low and high temperatures indicate a mixed conduction mechanism involving hopping through localized states, intergranular tunneling, and percolation-channel contributions. For series S2, the resistance behavior is more consistent with localized intergranular tunneling-hopping transport. The most indicative dependence is lnR on $T^{-1/2}$, especially for sample S2-2. This behavior may correspond to Efros–Shklovskii-type conduction or intergranular tunneling with a Coulomb contribution. Other S2 samples show weaker linearity, indicating that their transport also remains mixed. For S1, the magnetoresistance demonstrates competition between positive and negative contributions. Negative magnetoresistance at low and intermediate temperatures may be related to spin-dependent tunneling or reduced magnetic disorder, whereas the positive contribution at higher temperatures indicates the involvement of more connected metallic or percolation channels. For S2, the magnetoresistance is generally more consistent with granular transport: negative contributions are attributed to spin-dependent intergranular tunneling, while small or positive values reflect the influence of tunneling barriers, localization, and conducting-network inhomogeneity.

This study was supported by grant No. 25-72-20063, from the Russian Science Foundation, https://rscf.ru/project/25-72-20063/

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ANALYSIS OF MICROWAVE PERMEABILITY OF MAGNETIC FILMS USING MAGNETOSTATIC MEASUREMENTS

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The study proposes an approach for extracting the ferromagnetic resonance (FMR) contribution from a frequency dependence of microwave permeability of ferromagnetic films and composites filled with platelet particles. The method obtains the imaginary part of the permeability spectra by employing magnetostatic data and consists of several steps.

The first step is the derivation of the anisotropy field distribution $P(H_k)$ from the magnetic hysteresis loop measured along the hard axis. The second step is the recalculation into the resonance frequency distribution:

$$G(f_{res}) = P(H_k(f_{res}))\frac{dH}{df_{res}} \quad (1)$$

The relation between the anisotropy field H_k and the resonance frequency f_{res} for magnetic films with saturation magnetization M_s and gyromagnetic ratio γ is given by Kittel's equation [1]:

$$f_{res} = \gamma\sqrt{H_k \cdot 4\pi M_s} \quad (2)$$

The frequency dependence of the imaginary permeability $\mu''(f)$ is calculated from $G(f_{res})$ under the assumption that the magnetic loss curve consists of resonances with negligible damping. In other words, contributions from neighboring resonances at a given frequency may be neglected, and the integral Acher law [2] may be rewritten as:

$$\mu''(f_{res})\, f_{res}\, \Delta f = \frac{\pi}{2}(\gamma 4\pi M_s)^2\, G(f_{res})\Delta f \quad (3)$$

where Δf is the discretization range in f. Therefore, the imaginary permeability $\mu''(f_{res})$ at a certain frequency f_{res} is given by:

$$\mu''(f_{res}) = \frac{\pi}{2}(\gamma 4\pi M_s)^2 \frac{G(f_{res})}{f_{res}} \quad (4)$$

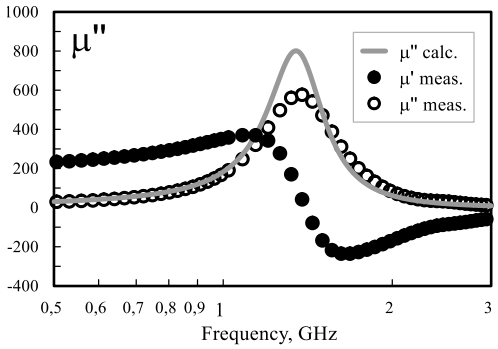

Fig. 1. The frequency dependence of permeability of NiFeMo film with a thickness of 0.2 μm. Circles show the measured data (filled: the real part; empty: the imaginary part). The line shows the magnetic loss calculated from the magnetostatic data

As an example, Fig. 1 shows the measured and calculated frequency dependencies of the permeability of the NiFeMo film with a thickness of 0.2 μm. The circles show the permeability measured with a short-circuited strip. The line is the magnetic loss calculated from the hysteresis loop and fitted with the Lorentzian dispersion law. A good agreement between the measured and the calculated curves is observed. Thus, the magnetic loss caused by natural FMR is obtained using magnetostatic data. This method can be useful for separating the FMR contribution from other sources, such as the skin effect and domain wall resonance.

Support by the Russian Science Foundation under the project No. 25-19-00393.

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MAGNETO-OPTICAL KERR SPECTROSCOPY OF CoFeB-$LiNbO_3$ AND CoFe-$LiNbO_3$ NANOCOMPOSITES

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Magneto-optical (MO) Kerr spectroscopy is an effective non-destructive method for studying fine details of magnetic microstructure, as well as the electronic and crystal structure of a wide class of homogeneous, and especially inhomogeneous magnets [1]. We present last experimental and theoretical results on MO spectra of $(CoFeB)_x(LiNbO_3)_{100-x}$ and $(CoFe)_x(LiNbO_3)_{100-x}$ film nanocomposites with x=8-60 at. % and of memristors [2] based of them. The samples were fabricated by ion beam sputtering of composite targets on silicon and captoon substrates. MO measurements were performed in the transverse Kerr effect (TKE) geometry at room temperature in the spectral range 0.5-4.5 eV and magnetic field up to 3.0 kOe.

It was shown that MO field dependences and MO spectra, both in magnetite and shape, are very sensitive to the presence of boron in ferromagnetic granules. Samples without boron are saturated in stronger magnetic fields and exhibit larger MO signal (Fig.1a). The most pronounced ransformations of MO spectra were observed for compositions close to the percolation threshold. MO response of memristor structures with x=8-12 at. % is linear on applied field up to 3.0 kOe.

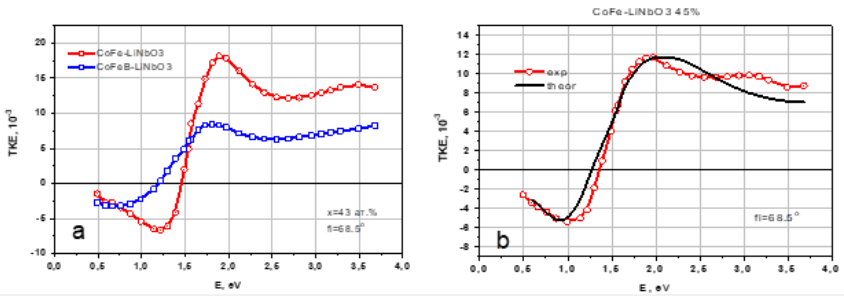

Fig. 1 a) TKE spectra of $(CoFe)_x(LiNbO_3)_{100-x}$ and $(CoFeB)_x(LiNbO_3)_{100-x}$ nanocomposites on a Si substrate at a concentration of x = 43 (at.%). b) Spectral dependences of the TKE of the $(CoFe)_x$ $(LiNbO_3)_{100-x}$ nanocomposite: experiment (circles), theory (solid line). Theoretical parameters: shape factor L = 0.4, grain size ag = 3.5 nm, surface layer thickness: a/ag = 1/10, ratios of the spin–orbit interaction (SOI) parameters in the surface layer and in the bulk $\lambda s/\lambda b = -0.5$, $Rs/Rb = -2.5$.

To interpret the obtained spectra, we used a modified effective medium method [3], which takes into account both the quasi-classical size effect and the difference between the spin-orbit interaction in a thin granular surface layer and the bulk values. Fig. 1b shows the example of such modeling.

The work was supported by the Russian Science Foundation (grant No. 25-22-00554). The measurements were carried out using the equipment of the Kurchatov Institute Resource Center.

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MAGNETIC PROPERTIES OF MULTI-NANOLAYER FILMS $[(COFEB+SIO_2)+SIO_2/SI]_{50}$ WITH DIFFERENT LAYER THICKNESSES

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In recent years, there has been increasing interest in studying multi-nanolayer films, which exhibit a wide range of unique properties, mainly due to the presence of numerous interfaces and nanoscale layer thickness [1]. Of particular practical interest are films with composite layers containing magnetic granules and microregions, which exhibit complex behavior of magnetic properties depending on the external magnetic field and temperature [2]. In this work, the magnetic properties of multi-nanolayer films were experimentally studied: a composite - dielectric/semiconductor with the compositions $[(CoFeB+SiO_2)+SiO_2/Si]_{50}$ in the temperature range of 2 - 400 K and magnetic fields from 0 to 9 T. Sputtering of multi-nanolayer films on sitall substrates was performed at VSTU using the UVN-2M vacuum setup [1]. Composite films of the composition $(Co_{40}Fe_{40}B_{20})_{34}(SiO2)_{66}$ and dielectric films of SiO_2 (or semiconductor films of Si) deposited on sitall substrates were used as targets [1, 2]. The elemental composition and thickness of multi-nanolayer films were determined using a TESCAN MIRA 3 LMN scanning electron microscope with an AZTEC X-ACT X-ray detector (Oxford Instruments). The number of bilayers: composite-dielectric/semiconductor was 50.The film thickness varied from 250 to 500 nm, and the thickness of the dielectric and semiconductor layers varied from 1.5 to 4 nm, and the concentration of CoFe metals varied from 10 to 20 at. %. The magnetic moment of the samples was determined using an MPMS 3 SQUID magnetometer with a magnetic field directed parallel to the film plane [2]. The results showed that the magnetization of all the studied multi-nanolayer films decreases exponentially with increasing temperature from 20 to 400 K in magnetic fields of 0.1-7 T. The temperature dependence of magnetization upon cooling the films in zero magnetic field shows a sharp decrease in magnetization at T = 15 K for films with dielectric layers and at T = 12 K for films with semiconductor layers. The region of sharp decrease in magnetization is associated with a change in the magnetically ordered state in the composite nanolayers of the films. The saturation magnetization of films with dielectric layers increases with increasing layer thickness from 1.5 to 2.5 nm, with the lower the temperature, the greater the increase in magnetization. At the same time, for films with semiconductor layers, magnetization depends weakly on layer thickness, especially at high temperatures T > 20 K. It was shown that the studied multi-nanolayer films are soft magnetic materials in a wide range of studied temperatures, with the exception of low temperatures T <20 K.

This study was supported by grant No. 25-72-20063 from the Russian Science Foundation.
https://rscf.ru/project/25-72-20063/

[1] M.P. Lasek, L.N. Kotov, M.V. Yakimov, A.V. Sitnikov, Yu.E. Kalinin, Journal of Surface Investigation: X-ray, Synchrotron and Neutron Techniques, **20** (2026), 49-57.
Котов Л.Н., Уткин А.А., Семяшкин И.В., Калинин Ю.Е., Ситников А.В., Bulletin of the Russian Academy of Sciences: Physics, **89** (2025) 516-521.

ORAL SESSION

Magnetic Nanostructures

Thursday, 20 August, 15:00 - 17:00

MAGNETIC PARTICLE SENSING BASED ON INDUCTIVE TECHNIQUES

Panina L.V.[1,2], *Acuna A.*[1,2], *Yudanov N.A.*[1], *Pashnina A.*[1], *Ignatov A.A.*[2], *Kolesnikova V.G.*[2], *Rodionova V.V.*[2]

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Detection and classification of magnetic particles is required in many areas of research and technology. Among different sensing technologies, this study specifically focuses on providing a review of inductive sensing-based devices used for magnetic particle detection, especially for iron ore enterprises. We believe that there is a high potential for this sensing method due to the low cost, flexibility in the sensor design, mature fabrication technologies, and high sensitivity. The possibility of inductive devices integration in Si technology by using planar coils includes features related to precision of fabrication and reproducibility. This also opens interesting perspectives for the development of more complex systems such as sensor matrices for the analysis of different components or large samples.

Among the different inductive sensor strategies, the simplest one is based on the changes in the inductance of a coil due to the presence of magnetic particles in the sample under analysis. In this case, the application of permanent magnetic field is not required for sensor operation. The potential of these inductive devices for the development of high-sensitivity sensors is strongly conditioned to the availability of a suitable signal conditioning circuit. One of the most used approaches is based on the measurement of the resonant frequency of an *LC* circuit containing the inductive sensor. However, for very high-sensitivity applications, this approach is compromised by the stability required for the oscillator circuit. The problem can be solved by using a differential type of sensor configuration with a modified Maxwell bridge.

More sophisticated inductive technologies involve non-linear magnetization dynamics ether regarding particle magnetization or magnetic sensing element. Nonlinear dynamics presents distinct advantages especially when employed in conjunction with spectral analysis techniques for signal detection and characterization. This approach enables not only improved performance in terms of sensitivity but also robustness against environmental noise. The other advantage of sensors based on spectral analysis over resonant inductive sensors refers to the output signal which can be made independent on detection distance by using several harmonics amplitudes.

One method involves the frequency mixing which utilizes the simultaneous application of a low-frequency, high-amplitude magnetic field and a high-frequency, lower-amplitude field. This configuration enhances the nearest significant non-linear term in particle magnetization The induced voltage is then measured at combined frequencies. The presence of magnetic particles can also change a non-linear magnetization behavior of the sensing element and influence its output harmonic spectrum. This can be realized using negative magnetostriction amorphous wires with specific circular anisotropy.

Support by Russian Science Foundation under Project no. 25-72-30009, https://rscf.ru/en/project/25-72-30009.

[1] A. Byberi, R.K. Amineh, M. Ravan, *IEEE Access*, **12** (2024), 102566–102578 [2] L.C. Wu, Y. Zhang, et al, *AJNR Am. J. Neuroradiol.*, **40** (2019), 206–212 [3] L.V. Panina, A. Acuna, N.A. Yudanov, et al, *Sensors*, **26** (2026), 428.

MAGNETIC PROPERTIES OF Cu_2MnBO_5 AT HIGH TEMPERATURES

Eremina R.M.[1], *Fazlizhanov I.I.*[1], *Moshkina E.M.*[2], *Batulin R. G.*[3]

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Oxyborates with the formula $MM'BO_5$, where M and M' are di- and trivalent metal ions, respectively, are called ludwigites. These metal ions occupy four non-equivalent crystallographic positions in the unit cell, which leads to a random distribution of magnetic ions, mixed valence of ions, strong electron correlations, and unusual charge ordering. As a result, they exhibit extremely unusual magnetic properties. It has been shown that in the paramagnetic phase of Cu_2MnBO_5:Cr below 300 K, the slope of the inverse magnetic susceptibility depends on the magnitude of the magnetic field [1]. We have measured EPR spectra and magnetization in Cu_2MnBO_5 at temperatures above 295 K. As can be seen from the Figure (left side), in addition to a broad and a narrow line at $g \approx 2$, a line whose resonance magnetic field increases from zero to 3400 Oe is detected in the temperature range from 420 K to 525 K. The origin of this signal is likely related to the formation of magnetic polarons in the compound. Above 525 K, peaks resembling resonances are observed in the temperature dependence of the Seebeck coefficient (see right Figure), and their positions agree with the Einstein temperatures obtained by fitting the temperature dependence of the specific heat capacity.

This work was supported by the Russian Science Foundation, project no. 23-72-00047.

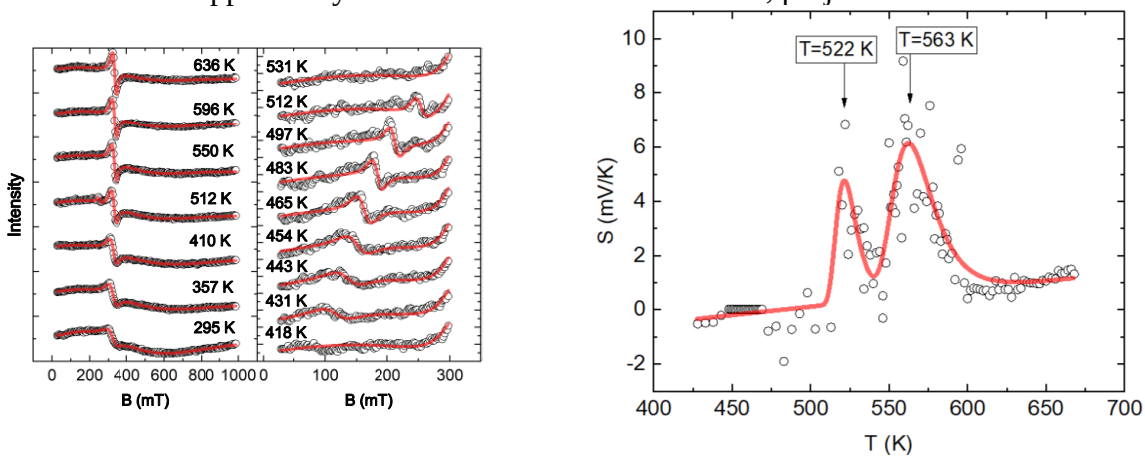

Fig.1. Temperature dependence of the EPR spectral shape and the Seebeck coefficient in Cu_2MnBO_5 at T > 295 K.

[1] D.V. Popov, R.G. Batulin, M.A. Cherosov, et al. *Journal of Alloys and Compounds*. **1040** (2025) 183213

MAGNETIC INHOMOGENEITIES OSCILLATIONS IN MULTILAYER NANOSTRUCTURES AS A BASIS FOR A SPIN WAVE GENERATOR

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Modern experimental capabilities in nanotechnology and magnetic measurements stimulate in-depth studies of the dynamics of magnetic inhomogeneities, especially in multilayer magnetic nanostructures, whose demand in various applications is steadily growing. Theoretical analysis of one-dimensional dynamics of these inhomogeneities in ferromagnetic multilayers, representing a periodic sequence of layers of different thicknesses and with different magnetic properties (in particular, anisotropy), shows a connection with the problem of interaction of sine-Gordon equation solitons with impurities [1]. It has been shown in [2,3] that the dynamics of domain walls in multilayer structures can lead to their pinning at potential wells and to the generation of localized magnetic solitons. These processes are accompanied by the emission of spin waves.

In this work, we investigate the possibility of creating a spin-wave generator based both on pinning and oscillations of a domain wall and on magnetic breathers and solitons excited at potential wells in a three-layer ferromagnetic nanostructure (see, e.g., [4]). It is found that the parameters of the structure layers directly affect the characteristics of the generated spin waves, allowing control of their amplitude and frequency. Special attention is paid to the application of the autoresonance method using a weak alternating magnetic field to achieve controlled generation of spin waves. The frequency of these waves is fixed and is determined both by the parameters of the structure and by the frequency of the applied magnetic field.

The work was carried out within the framework of a state assignment, agreement No. 075-03-2024-123/1 dated February 15, 2024, topic No. 324-21.

[1] J. Cuevas-Maraver, P. Kevrekidis, F. Williams (Eds.), *Springer*, (2014);
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[3] E.G. Ekomasov, V.N. Nazarov, A.M. Gumerov, K.Yu. Samsonov, R.R. Murtazin, *Letters on Materials*, **10** (2020) 141-146;
[4] E.G. Ekomasov, D.K. Kabanov, I.F. Sharafullin, *Phys. Met. Metallogr.*, **127** (2026) 177-184.

LOW DIMENSIONAL STATES IN MAGNETIC SYSTEMS

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Two-dimensional (2D) magnetic materials have attracted considerable attention in the fields of magnetism and spintronics, as well as in the broader 2D materials research community. Particularly intense interest in 2D magnetic materials was sparked by the observation of ferromagnetism at finite temperatures in atomically thin layered van der Waals materials. Such layers allow the construction of heterostructures that exhibit both magnetic properties and hold promising low-dimensional spin-polarized states, either at the surface or at the edges. Magnetism has also been induced in initially nonmagnetic single-element monolayers, such as graphene-like topologically nontrivial systems, through proximity to magnetic substrates or via magnetic adatoms. Furthermore, the combination of broken inversion symmetry in heterostructures, magnetism, and strong spin-orbit interactions gives rise to another fundamental phenomenon, the Dzyaloshinskii-Moriya interaction, i.e., the magnetic texture of engineered systems can be richer than that of the original constituents.

This talk will provide a brief overview of the effective integration of experimental and theoretical methods, with a focus on density functional theory calculations, for studying the electronic structure of low-dimensional states, including semiconductors, topological insulators, and magnetic metallic compounds, taking into account our recent advances in this field.

Acknowledgement: This work was supported by the Saint-Petersburg State University (research project 125022702939-2).

WHEN THE LATTICE LEARNS TO SPIN: NI_3TEO_6

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Pohang University of Science and Technology, Pohang, Korea
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Rutgers University, Piscataway, NJ, USA
[5] Institute of Metal Physics UB RAS, Ekaterinburg, Russia
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It has been recently argued that the nickel oxides containing heavy elements — such as Bi or Sb — are a promising platform for the realization of Kitaev physics [1]. In this sense the lattice dynamics of the Mn-doped nickel oxide Ni_3TeO_6 has been investigated. Using *ab initio* DFT+*U* calculations, we demonstrate the presence of high-frequency chiral phonon modes both in the collinear antiferromagnetic and in the non-collinear phases of the compound. These modes involve collective twisting of $(Mn,Ni)O_6$ octahedra and are intrinsically chiral due to the polar chiral crystal structure. The results confirm the observed giant circular dichroism (CD) for two high-energy modes in RIXS experiments [2].

This work was supported by the Russian Science Foundation (project No. 23-12-00159-P).

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[1] C. Hickey et al., *Phys. Rev. Research*, **2** (2020) 023361.
[2] J. Okamoto et al., arXiv:2512.00388.

FEATURES OF SPIN WAVES AND PHASE TRANSITIONS IN FRUSTRATED HETEROSTRUCTURES

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Thin-film heterostructures are currently being actively studied. Control of spin waves, kinetics of phase transition, and surface effects offer new perspectives for the creation of energy-efficient magnonics and reservoir computing devices [1]. One of the features of such systems is the competing interactions – exchange interactions, the Dzyaloshinskii-Moriya interaction, anisotropy, and interlayer interactions – that shape noncollinear spin configurations, skyrmion phases, and surface modes, which determine the dynamics of phase transitions [2].

We study the spin-wave elementary excitations in magnetic films consisting of magnetic anisotropic layers sandwiched between frustrated magnetic layers with Dzyaloshinskii-Moriya interactions. Skyrmion phases in the ground state can arise at the interface. The Hamiltonian of the model:

$$H = H_{fm1} + H_{fm} + H_{in}$$

For surface magnetic layers:

$$H_{fm1} = -J_1 \sum_{i,j} \vec{S}_i \vec{S}_j - J_2 \sum_{i,k} \vec{S}_i \vec{S}_k - \sum_{i,j} \vec{D}_{i,j} [\vec{S}_i \times \vec{S}_j] - I \sum_{i,j} \vec{S}_i \vec{S}_j - h \sum_i \vec{S}_i$$

where J_1 is the ferromagnetic interaction between the nearest neighboring spins, J_2 is the antiferromagnetic interaction between the next nearest neighboring spins, $\vec{D}_{i,j}$ is the in-plane Dzyaloshinsky-Moriya interaction, I is the easy-axis anisotropy, and h is the external magnetic field directed along the z-axis. For internal anisotropic magnetic layers:

$$H_{fm} = -J_1 \sum_{i,j} \vec{S}_i \vec{S}_j - J_2 \sum_{i,k} \vec{S}_i \vec{S}_k - I \sum_{i,j} \vec{S}_i \vec{S}_j - h \sum_i \vec{S}_i$$

The interlayer interaction between magnetic films will be described by the Hamiltonian:

$$H_{in} = -J^{in} \sum_{i,j} \vec{S}_i \vec{S}_j$$

Using the two-time Green's function method, analytical expressions were derived for the dispersion relations and thermodynamic characteristics of the model, taking into account the interlayer interaction, the Dzyaloshinskii-Moriya interaction, and the external magnetic field. It was shown that, for certain values of the DM interaction parameter, the energy gap in the excitation spectrum changes, forming minima due to the emergence of skyrmion phases. Thermodynamic analysis demonstrates that stabilization of skyrmions lowers the critical phase transition temperature and suppresses long-range ferromagnetic order.

The parameters of the proposed model can be compared with real thin films, in particular, heterostructures $Pt_3/CoFe_{0.6}/MgO$, $W_2/CoFeB_1/MgO$, $Ta_5/CoFeB_{0.8}/MgO$ [3].

The work was carried out within the framework of the state assignment agreement No. 075-03-2024-123/1 dated 02/15/2024.

[1] A. A. Nikitin, A. A. Nikitin, A. B. Ustinov, S. Watt, M. P. Kostylev, *J. Appl. Phys.*, **131** (2022) 113903.
[2] R. Gupta, R. K. Kotnala, *J. Mater. Sci.*, **57** (2022) 12710–12737.
[3] R. A. Gallardo, D. Cortés-Ortuño, R. E. Troncoso, P. Landeros, *arXiv:1903.04288* (2019).

Plenary

Friday, 21 August, 09:00 - 10:30

SIMULATIONS OF MANY-BODY PHYSICS ON DIGITAL QUANTUM PROCESSORS

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Gate-based digital quantum simulation offers an exciting new paradigm for studying the manybody physics of strongly correlated systems. In this talk, after a brief review of currently available digital quantum computing platforms, I will outline how a universal set of one- and two-qubit gates enables the simulation of interacting fermionic models through the so-called Trotterized time evolution encoded in a quantum circuit. I will illustrate this concept using the canonical two-dimensional Fermi–Hubbard model as an example [1]. I will then demonstrate how simulations of generalized Hubbard models with all-to-all two-body interactions may potentially provide a quantum advantage over conventional quantum chemistry methods in determining the ground-state properties of molecular systems [2].

In the second part of the talk, I will turn to the fascinating field of quantum simulation of many-body systems with non-Abelian topological order. Specifically, I will present the results of our recent experiment performed on the IBM Fez quantum processor, aimed at emulating a nonadiabatic braiding protocol for elusive Majorana fermions [3]. In the absence of decoherence and noise, the theoretical fidelity of such a non-adiabatic braiding process is predicted to exceed 99%. In practice, however, this upper bound cannot be reached because the virtually simulated Majorana modes lack genuine topological protection. Nevertheless, the application of advanced error-mitigation techniques allows the experimental fidelity to be restored to values very close to the ideal theoretical limit.

This talk is intended for a broad audience, and no prior knowledge of quantum computing is required. I am indebted to my many collaborators from Forschungszentrum Jülich (FZJ), the German Aerospace Center (DLR), the Fraunhofer Institute for Chemical Technology (ICT), the University of Innsbruck, and HQS Quantum Simulations GmbH, whose contributions to this research will be discussed throughout the presentation.

[1] G. Bishop, D. Bagrets and F. K. Wilhelm, "Quantum algorithm for Green's-function measurements in the Fermi-Hubbard model", *Phys. Rev. A* **111** (2025) 062610

[2] C. Possel, W. Hahn, R. Shirazi, M. Walt, P. Pinski, F. K. Wilhelm and D. Bagrets, "Truncated Variational Hamiltonian Ansatz: efficient quantum circuit design for quantum chemistry and material science", *arXiv:2505.19772*

[3] S. Schmitz, K. Lively, M. Drieb-Schoen, T. Bode, B. Fauseweh, and D. Bagrets, "Nonadiabatic Majorana braiding on a digital quantum processor", *to appear*

XMCD: DISCOVERY, INSIGHTS AND NEW HORIZONS

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Discovery of X-ray magnetic circular dichroism (XMCD) nearly four decades ago [1] marked a major breakthrough in magnetism research enabling investigations previously that were previously unattainable. XMCD is defined as a difference between X-ray absorption spectra of a magnetized sample measured with left and right circularly polarised photons. In this sense, it can be viewed as the high-energy counterpart of the magneto-optical effects in the visible discovered by Faraday and Kerr. Unlike these effects, XMCD offers the unique advantage of being element-specific and orbital-selective, as it arises from transitions of core electrons into unoccupied states governed by dipole selection rules.

Furthermore, the derivation of magneto-optical sum rules [2,3] has greatly strengthened XMCD, providing a unique capability for the quantitative determination of the orbital and spin contributions to the total magnetic moment of the absorbing atom. The availability of high fluxes of circularly polarized X-rays at synchrotron radiation facilities has made this technique widely accessible. In addition, increasingly sophisticated end stations now offer a broad range of sample environments, including high magnetic field, ultralow temperatures, and high pressures.

Two examples are presented to illustrate how XMCD helps to decipher a long-standing quantum conundrum in condensed matter physics: coexistence of magnetism and superconductivity. The first concerns plutonium paramagnetism in the vortex phase of an exotic superconductor $PuCoGa_5$. The second addresses the dual nature of uranium 5f electrons in the heavy fermion ferromagnetic superconductor UGe_2. Beyond solid-state systems, XMCD has also proven to be a powerful probe of local electronic structure in molecular systems, as illustrated by recent studies of 5d paramagnetic complexes, where it provides detailed insight into spin–orbit coupling and orbital magnetism.

More recently, major advances in X-ray optics, coherence, and detection schemes have opened new perspectives for XMCD-based imaging. In particular, dichroic coherent diffraction imaging now enables the visualization of magnetic structures with spatial resolutions approaching 20 nm or better, providing direct access to nanoscale magnetic textures.

Overall, concomitant progress in X-ray instrumentation and theoretical approaches has transformed XMCD from a scientific curiosity into a workhorse technique in modern magnetism research, paving the way for new applications in chemistry, Earth science, biology, and beyond.

[1] G. Schütz et al., *Phys. Rev. Lett.* **58** (1987) 737.
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ORAL SESSION

Soft and Hard Magnetic Materials

Friday, 21 August, 11:00 - 12:45

COMPREHENSIVE APPROACH: FROM GRANT-FUNDED FUNDAMENTALS TO INDUSTRIAL ORDERS

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The translation of fundamental scientific knowledge into industrial solutions is rarely linear – yet the trajectory of ferrite research offers a compelling example of how grant-funded basic science can systematically evolve into commercially relevant technologies. This contribution outlines a comprehensive pathway from foundational studies in ferrite synthesis and characterization, supported by RFBR and RSF grants, to the industrial applications at different technological readiness level.

The foundational work spanned several interconnected research directions, collectively forming a robust scientific base for subsequent applied developments. Thermodynamic modeling of growth conditions for single crystals of hexagonal ferrites was carried out, including a comparative analysis of various flux solvents. This systematic approach enabled identification of optimal temperature and composition ranges and solvent systems, providing reproducible pathways to high-quality single-crystal substituted hexaferrites samples. Building on the modeling results, single crystals of solid solutions based on M-type hexagonal ferrites ($BaFe_{12}O_{19}$, $SrFe_{12}O_{19}$) with various substituents were successfully grown. X-ray absorption spectroscopy and single crystal X-ray diffraction studies revealed the substitution mechanisms.

In parallel, ferrites with both spinel (AB_2O_4) and magnetoplumbite ($AFe_{12}O_{19}$) structures were synthesized by solid-state sintering method. A systematic comparison showed that ceramic synthesis yields crystallite larger sizes depending on composition, while additionally used sol-gel methods provided significantly finer microstructures (e.g. for $NiFe_2O_4$ and $ZnFe_2O_4$) – opening pathways to nanostructured functional materials with enhanced controllability of magnetic properties. Complementing these studies, high-entropy hexaferrite phases with magnetoplumbite structures were synthesized for the first time worldwide, with representative compositions such as $BaFe_{5.83}Al_{1.19}Ti_{1.08}Cr_{1.12}Cu_{0.78}Ga_{1.03}In_{0.97}O_{19}$.

The most mature applied outcome of this research program is a self-calibrating temperature sensor exploiting the physics of magnetic phase transitions in ferrite materials. The scientific groundwork – Curie temperature behavior in substituted ferrites – was directly accumulated over the course of the grant-funded fundamental studies described above.

Another promising area with potential for practical implementation is the development of materials based on the IGZO (indium gallium zinc oxide) system. Within the framework of the ongoing RSF project, our team is actively working on obtaining modified structures of this system, conducting experiments to develop scalable synthesis techniques, and creating targets for magnetron sputtering. These efforts have enabled us to create a working transistor prototype based on the developed IGZO material. Our next step is to investigate how the transistor characteristics of depend on the composition of the target.

Taken together, the described research program demonstrates that a coherent, long-term strategy – anchored in grant-supported fundamental science, catalyzed by university innovation programs, and oriented toward concrete industrial needs – can successfully navigate the full innovation chain from basic materials discovery to market-ready technology.

The reported IGZO material study was supported by the by the Russian Science Foundation (project no. 24-19-00468).

RESEARCH OF MATERIALS IN ULTRAHIGH MAGNETIC FIELDS

Korshunov A.S.[1], *Bykov A.I.*[1], *Egorov N.I.*[1], *Maslov D.A.*[1,2], *Kudasov Yu.B.*[1,2], *Makarov I.V.*[1], *Platonov V.V.*[1,2], *Surdin O.M.*[1,2], *Strelkov I.S.*[1], *Kozabaranov R.V.*[1], *Katenkov P.Yu.*[1]

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Magnetic fields have traditionally been one of the primary tools for measuring the characteristics of substances. To study the properties of materials in ultrahigh magnetic fields, a number of high-energy facilities are used worldwide. At VNIIEF (All-Russian Research Institute of Experimental Physics), a cascade generator of ultrahigh magnetic fields, designated MC-1 [1] (Fig. 1), is employed for this purpose. With this generator, record-high magnetic fields - up to 2800 T - have been achieved in practically significant volumes, and the properties of a number of substances have been investigated, including under isentropic compression by the pressure of an ultrahigh magnetic field.

As a result of many years of work, the idea of magnetic flux compression has been developed at VNIIEF into a laboratory method for generating ultrahigh magnetic fields. Techniques have been established to incorporate this method into scientific practice, enabling systematic research in fundamental areas of physics: solid-state physics (optical, magnetic, transport, and other properties of substances), and the physics of materials under extreme conditions [1].

Unique results from earlier experiments in ultrahigh magnetic fields [1] are discussed, as well as those obtained recently: measurements of the magnetisation of substances in fields above 400 T; investigations of the magnetic phase diagram of hard magnetic materials; the construction of the magnetisation curve of the Haldane low-dimensional magnet Gd_2BaNiO_5 in an ultrahigh magnetic field up to 300 T [3], with determination of its magnetic structure parameters; and the study of phase transitions in $GdMn_2Si_2$ in an ultrahigh magnetic field up to 350 T [3]. The results of recent experiments on the isentropic compression of condensed samples of carbon dioxide [4] are also discussed.

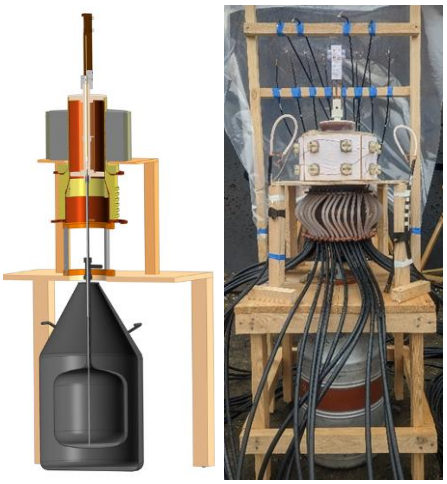

Fig. 1. Schematic representation and external view of the MC-1 generator before an experiment.

This work is carried out within the scientific programme of the National Center for Physics and Mathematics (Direction No. 7 “Research in High and Ultra-High Magnetic Fields”)

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[3] A.I. Bykov et al., *Physical Review B*, **110** (2024) 214439
[4] K.D. Litasov et. al., *Physical Review Materials*, **9** (2025) 123606

PREDICTING THE MAGNETOCALORIC EFFECT IN PEROVSKITE MANGANITES USING MACHINE LEARNING METHODS

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Perovskite manganites of the general formula $R_{1-x}A_xMnO_3$ (where R is a rare-earth element and A is an alkaline earth metal such as Ca, Sr, or Ba) attract considerable attention as promising materials for magnetic cooling due to their high chemical stability, low cost, and tunable Curie temperature and magnetocaloric effect (MCE) [1]. However, direct experimental screening of all possible compositions is time-consuming and expensive. In this work, we develop machine learning (ML) models to predict the maximum isothermal magnetic entropy change ΔS_M from the chemical composition alone, which enables rapid virtual screening of new manganites.

A database of experimental samples was compiled from published literature data. Compositional descriptors (501 in total) were generated using the XenonPy library: 58 atomic properties (electronegativity, atomic radius, valence electron count, melting point, bulk modulus, etc.) aggregated via 7 functions (weighted average, variance, geometric mean, harmonic mean, max pooling, min pooling, weighted sum), plus elemental counting features, with external magnetic field added as a separate descriptor. Feature selection using recursive elimination with cross-validation (RFECV) reduced the set to the 12 most informative descriptors. Six regression models were compared: Ridge, Lasso, ElasticNet, Random Forest, XGBoost, and a Voting regressor. Random Forest achieved the best performance on the test set (R^2= 0.44 in original units, MAE = 0.94 J/(kg·K)), outperforming linear models, which confirms the strongly nonlinear nature of the composition– ΔS_M relationship. SHAP analysis revealed that the most important predictors are the external magnetic field, variance of the Mendeleev number, variance of the valence electron count, maximum covalent radius, harmonic mean of electronegativity, and geometric mean of electron affinity. These features are physically interpretable: they reflect chemical disorder on A/B sites, lattice distortions (Mn–O–Mn angles), and the Mn^{3+}/Mn^{4+} ratio, which governs the double-exchange mechanism responsible for MCE. Importantly, not average values but variances and extremes of atomic properties dominate the MCE magnitude. The developed Random Forest model, despite the limited dataset, provides accuracy comparable to state-of-the-art literature results obtained on much larger databases [2]. It can be used for targeted doping optimization of composite materials such as $La_{0.5}Gd_{0.1}Sr_{0.4}MnO_3/Ti_3C_2T_x$ within the framework of ongoing research. Future work includes expanding the database, incorporating synthesis parameters (grain size, annealing conditions), and integrating the predictor with a generative model for inverse design of novel manganite compositions with record MCE.

This work was supported by the Russian Science Foundation (project no. 25-43-20052, https://rscf.ru/project/25-43-20052/)

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TEMPERATURE RANGE OF THE SPIN-REORIENTATION TRANSITISION IN A MIXED RARE-EARTH ORTHOFERRITE

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Antiferromagnets achieve terahertz processing speeds beyond the fundamental limits of ferromagnets. Among antiferromagnets, particular attention is given to the rare-earth orthoferrites $RFeO_3$, which provide a unique platform for studying ultrafast spin dynamics, terahertz magnonics, and magnetophononic phenomena. An important distinguishing feature of $RFeO_3$ is their propensity for spin-reorientation transitions, in which the orientation of Fe^{3+} spins changes between different magnetic structures due to competing exchange interactions between iron and rare-earth ions. The most common transition occurs between the high-temperature Γ_4 phase and the low-temperature Γ_2 phase via an intermediate Γ_{24} structure, in which the spins of Fe^{3+} ions rotate continuously. Understanding the evolution of magnetic excitations across these transitions is crucial for fully harnessing the unique properties of $RFeO_3$.

In this work, we investigate the equilibrium spin dynamics across the spin-reorientation transition in the single crystal of the mixed orthoferrite $Sm_{0.55}Tb_{0.45}FeO_3$ using polarized Raman spectroscopy. This study allows us to effectively probe the temperature evolution of the quasiferromagnetic (qFM) and quasi-antiferromagnetic (qAFM) magnon modes at the Brillouin zone center with characteristic frequencies of about 7 cm^{-1} and 18 cm^{-1}, respectively. To reveal the evolution of the magnon modes through the spin-reorientation transition, measurements were carried out in the temperature range from 78 to 400 K in two polarization configurations (Fig. 1). A clear change in the polarization selection rules is observed, enabling us to pinpoint the transition temperatures precisely. The spin-reorientation proceeds sequentially as $\Gamma_4 \leftrightarrow \Gamma_{24}$ at $T_1 \approx 220$ K and $\Gamma_{24} \leftrightarrow \Gamma_2$ at $T_2 \approx 130$ K. Notably, the intermediate Γ_{24} phase exists over an exceptionally broad temperature interval of $\Delta T \approx 90$ K, which is significantly wider than in most pure and mixed orthoferrites.

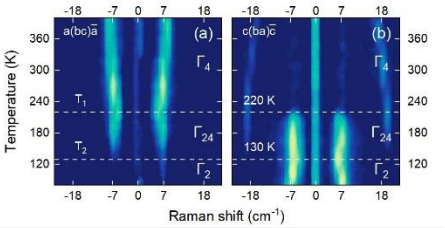

Fig. 2. Temperature maps of the Raman spectra across Γ4 ↔ Γ24 ↔ Γ2 transition for the (a) qFM and (b) qAFM modes.

Analysis of the magnon spectra reveals that the qFM mode behaves as a soft mode, and its frequency exhibits two minima at the spin-reorientation transition temperatures. We attribute this anomalous broadening to the modification of the magnetocrystalline anisotropy, driven by the inhomogeneous magnetic structure resulting from the random distribution of Sm^{3+} and Tb^{3+} ions within the unit cell [1]. Our results not only complement the picture of spin dynamics in this mixed orthoferrite but also demonstrate how compositional tuning can be used to control the properties of spin-reorientation transitions, opening new avenues for the development of temperature-controllable antiferromagnetic devices.

This work was supported by the Ministry of Science and Higher Education (FSWR-2024-0003).

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MAGNETIC PROPERTIES OF THE HEXAFERRITE STRONTIUM CERAMICS EXPOSED TO GAMMA-IRRADIATION

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M-type hexaferrites $SrFe_{12}O_{19}$ belong to ferrites with high magnetocrystalline anisotropy and are related to the rare iron oxide modification ε-Fe_2O_3. These materials are widely used as permanent magnets, magnetic information storage, and high-frequency electromagnetic radiation filters. However, the ε-Fe_2O_3 phase demonstrates significantly higher coercive field values (20–30 kOe) and natural ferromagnetic resonance frequencies (100–220 GHz).

The hard magnetic M-type hexaferrite material ($SrFe_{12}O_{19}$) was synthesized by the sonochemical treatment method followed by calcination process. The surface morphology, structure, and Curie temperature were investigated using powder X-ray diffraction, high-resolution transmission and scanning electron microscopy, and thermogravimetric analysis. The formation of single-phase $SrFe_{12}O_{19}$ with space group P63/mmc (194) and hexagonal structure with an average primary crystallite size of ~44 nm and spherical morphology were confirmed. The Curie temperature (T_C) of the nanopowder was ≈462°C. The magnetic properties were measured using SQUID magnetometer in the temperature range from 4 to 300 K. The saturation magnetization (M_s) at 300 K was 33 emu/g, which is significantly lower than that of bulk $SrFe_{12}O_{19}$, probably due to the nanoscale effect.

The aim of this work was to investigate the influence of ^{60}Co gamma-rays on the electronic structure and magnetic properties of strontium hexaferrite $SrFe_{12}O_{19}$, as well as to compare the experimental results with theoretical calculations.

The crystal structure of $SrFe_{12}O_{19}$ was simulated using the DFT+U calculation method before and after gamma irradiation. The generation of oxygen vacancies induced by gamma quanta with energies of 1.17 and 1.33 MeV and the vacancies effect on the magnetic properties were analyzed. The initial, i.e., non-irradiated, structure exhibited ferrimagnetically ordered state, and the value of the total magnetization was 40.00 (μ_B/cell). At the same time, the absolute magnetization was 105.57 (μ_B/cell). This result indicates the presence of strong superexchange interactions between Fe ions already in the initial structure. In the structures exposed to gamma irradiation, the formation of oxygen vacancies was experimentally observed. In the second model, three oxygen vacancies were introduced; in this case, the total magnetization decreased to 35.98 (μ_B/cell). The absolute magnetization also decreased to 101.09 (μ_B/cell). As the result of vacancy-induced breaking of Fe–O–Fe bonds, local changes in the ferrimagnetic spin ordering occur. Consequently, the exchange integral of some Fe ions decreases, and the compensation of magnetic moments increases. In the third model, where four oxygen vacancies were introduced, the change in magnetic properties became even more pronounced. The total magnetization decreased to 34.70 (μ_B/cell), while the absolute magnetization decreased to 99.43 (μ_B/cell). This indicates a partial ferrimagnetic disordering with increasing concentration of oxygen vacancies. The vacancies cause local distortions of chemical Fe-O bonds in the crystal lattice, leading to redistribution of electronic states. Oxygen vacancies reduce the oxidation state of iron — that is, the valence state changes according to $Fe^{3+} \rightarrow Fe^{2+} \rightarrow Fe^{1+} \rightarrow Fe^{0}$ until complete reduction occurs. The obtained results confirm that gamma irradiation has significant effect on the electronic and magnetic properties of the $SrFe_{12}O_{19}$ ferrite. In particular, the formation of oxygen vacancies weakens the magnetic exchange mechanisms and leads to decrease in the overall magnetization.

OPTIMIZATION OF THE MAGNETOTHERMAL PROPERTIES OF LGSMO–MXENE-BASED NANOCOMPOSITE FOR MAGNETIC REFRIGERATION APPLICATIONS

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This work investigates the influence of magnetocaloric (MC) inclusion geometry on the overall performance of magnetic refrigeration systems. Utilizing numerical methods, we demonstrate how changes in the shape of the active material, while maintaining its volume, can significantly improve key heat transfer characteristics. For this, we adopted known material data for LGSMO and MXene and physical principles about the magnetocaloric effect from established literature and constructed a 3D model in Comsol using the Finite Element Method (FEM) [1, 2, 3]. As a result of the conducted research, incorporating data processing with Gaussian processes and the construction of thermal maps in Python, it was established that specific geometric parameters, including considerations for grain orientation, significantly contribute to more efficient heat removal and, consequently, an increase in the specific cooling power of the system. The obtained results confirm the importance of geometric optimization as a primary parameter for enhancing the efficiency of magnetic refrigerators and suggest further directions for their technological development.

This work was supported by the Russian Science Foundation (project no. 25-43-20052, https://rscf.ru/project/25-43-20052/).

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ORAL SESSION

THEORY

Friday, 21 August, 11:00 - 12:45

THEORETICAL ASPECTS OF MAGNETIC AND MAGNETOCALORIC PROPERTIES OF $Ni_{36.5}Co_{13.5}Mn_{35}Ti_{15}$ HEUSLER ALLOY

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The all-*d*-metal Ni-Co-Mn-Ti Heusler alloys exhibit a giant inverse magnetocaloric effect (MCE) near a first-order magnetostructural transition (MST) from a weakly magnetic martensite to a ferromagnetic austenite [1]. A key experimental finding is the nearly linear shift of the martensitic transition temperature T_m with magnetic field ($dT_m/dH \approx -1$ K/T) up to 7 T, in contrast to strongly nonlinear behavior in Ni-Co-Mn-(In,Sn,Ga) Heusler alloys. Understanding this difference is crucial for designing stable magnetocaloric materials for magnetic refrigeration Using density functional theory (DFT) and Monte Carlo (MC) simulations within the Heisenberg-Blume-Emery-Griffiths (HBEG) Hamiltonian [2], we reveal the microscopic origin of this linearity and successfully reproduce the experimental MCE. The HBEG Hamiltonian explicitly includes three coupled terms: a Heisenberg term for magnetic interactions with ab initio exchange parameters J_{ij} up to the 8th coordination shell, a BEG term for the structural subsystem (austenite vs. martensite), and a magnetoelastic coupling term containing both linear ($\propto H$) and quadratic ($\propto H^2$) contributions.

The key result is that the simulated $T_m(\mu_0 H)$ remains almost perfectly linear up to 7 T when magnetoelastic parameter U_1 dominates over U_2, as it follows from thermomagnetization curves (Fig. 1). Increasing U_2 while keeping U_1 fixed progressively introduces nonlinearity at high fields, mimicking the behavior of Ni-Co-Mn-In [4]. The MC simulations successfully reproduce the experimental $M(T, H)$, the sharp first-order transition, the inverse MCE ($\Delta T_{ad} \approx -6.7$ K at 7 T).

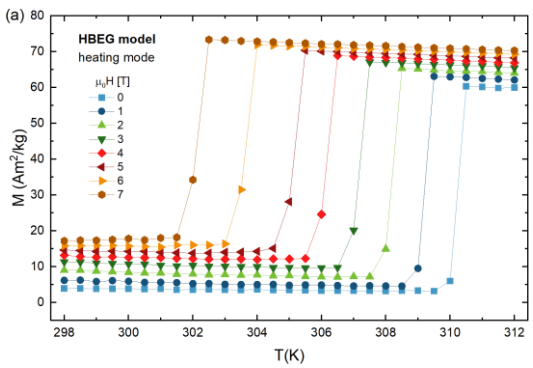

Fig. 1. $M(T)$ for magnetic fields 0-7 T from MC simulations of the HBEG model with $U_1 = -0.85$ and $U_2 = -0.025$ meV^{-1}.

The DFT reveals that the near-flat density of states at the Fermi level in Ni-Co-Mn-Ti ($\rho'/\rho \approx -1.25$ eV^{-1}) leads to a small dimensionless magnetoelastic constant X_3 according to the Ray-Jardin model [3], which directly translates into the dominance of the linear over the quadratic coupling in the HBEG model. In contrast, the steeper DOS slope in Ni-Co-Mn-In ($\rho'/\rho \approx -1.97$ eV^{-1}) gives $X_3^{In}/X_3^{Ti} \approx 2.5$, explaining their strong nonlinear response.

These results validate the HBEG Hamiltonian as a predictive tool for all-*d*-metal Heusler alloys and provide a clear electronic-structure criterion for designing materials with stable, reversible, and linear field-induced magnetocaloric response.

This work was supported by the Russian Science Foundation (project No 25-12-20024, https://rscf.ru/en/project/25-12-20024/).

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ELECTRONIC STRUCTURE AND QUANTUM PROPERTIES OF LOW-DIMENSIONAL MATERIALS: ADVANCES FROM FIRST-PRINCIPLES SIMULATIONS

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The quick rise of low-dimensional materials has changed condensed matter physics and materials science forever. They give scientists the chance to control quantum phenomena at the atomic level like never before. This full review looks at the most recent progress in first principles simulations of the electronic structure and quantum properties of two-dimensional (2D) materials, quantum dots, and other low-dimensional systems. We look at the theoretical underpinnings of density functional theory (DFT) and beyond-DFT methods, such as GW approximation and hybrid functionals, in a systematic way to see how they can be used to predict electronic band structures, topological invariants, and quantum transport phenomena. A lot of attention is paid to the computational problems that only come up in reduced-dimensional systems, like van der Waals interactions, quantum confinement effects, and many-body correlations. We focus on new uses for topological quantum materials, 2D quantum dots in optoelectronics, and pressure-engineered phase transitions. Combining deep learning methods with first-principles calculations is a big change that makes it possible to screen a lot of materials quickly and design materials with specific quantum properties. This work gives researchers who use computational methods to study quantum phenomena in low dimensional materials a state-of-the-art overview and useful advice.

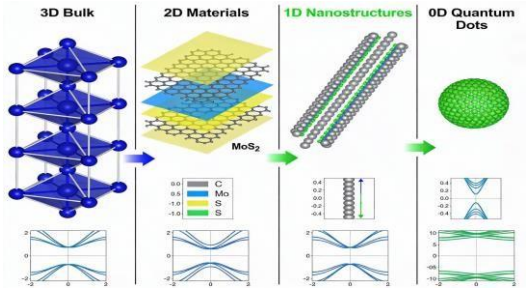

Fig. 1. Hierarchy of low-dimensional materials, showing how (a) three dimensional bulk crystals change into (b) two-dimensional materials with layered atomic structures (graphene, transition metal dichalcogenides), (c) one-dimensional nanoribbon and nanotube structures, and (d) zero dimensional quantum dots with strong quantum confinement.

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EFFECT OF HYDROSTATIC PRESSURE ON THE BAND STRUCTURE AND DENSITY OF STATES OF YBCO: A DFT INVESTIGATION USING THE SCAN FUNCTIONAL

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The development of magnetic levitation-based transport is currently focused on improving magnetic levitation suspension systems through the development of new materials, in particular, the optimization of existing and the discovery of new high-temperature superconducting (HTSC) materials. The key tasks in this area are to increase the superconducting transition temperature (T_C) and the critical current density. The study of the physicochemical foundations of superconductivity in lanthanum hydrides [1-3] showed that these HTSC materials exhibit T_C = 260 K under an applied pressure of 200 GPa and a temperature of 250 K [2]. In this work, the effect of hydrostatic pressure on the structural and electronic properties of the $YBa_2Cu_3O_7$ alloy is investigated within the framework of the density functional theory implemented in the VASP software package [4], taking into account the exchange-correlation interaction in the SCAN approximation.

Calculations of the electron density of states and band structure were performed for the 13-atom orthorhombic (*Pmmm*) cell of the $YBa_2Cu_3O_7$ alloy. Fig. 1 shows the contributions of electrons from the *d*-orbitals of various copper atom configurations located in the CuO (Cu_1) and CuO_2 (Cu_2) layers. The metallic behavior of the electron density of states profiles is retained in the pressure range from 0 to 20 GPa due to the d_{x2-y2} and d_{z2} contributions of the Cu_2 and Cu_1 copper atoms, respectively. It can be noted that at pressures above 4 GPa, the behavior of the $N(E_e)$ dependence changes. This behavior may be due to changes in the distance between the copper atoms and the surrounding oxygen, which is an important criterion for maintaining the superconducting properties of $YBa_2Cu_3O_7$ alloys.

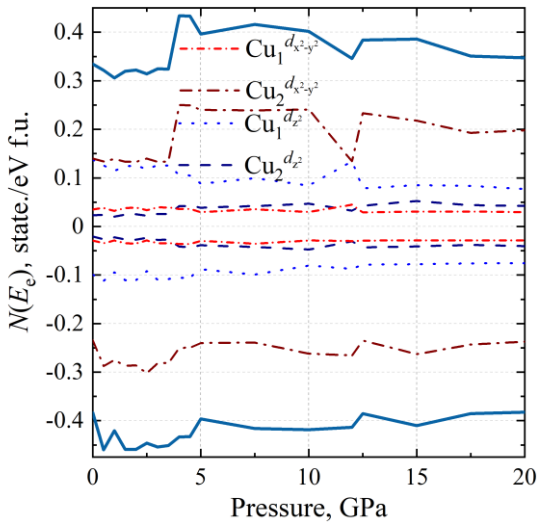

Fig. 1. The contribution of d-electrons of Cu atoms at the Fermi level $N(E_e)$ depending on the applied hydrostatic pressure. The Cu_1 and Cu_2 atoms are located in the CuO and CuO_2 planes, respectively.

This work was supported by the Russian Science Foundation Project No. 25-19-20141 (https://rscf.ru/en/project/25-19-20141/).

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THE PROBLEMS OF MODERN PHYSICS OF PHASE TRANSITIONS

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In recent years, significant progress has been made in understanding the problem of phase transitions (PTs) and critical phenomena (CPs). Nevertheless, the quantitative description of PTs and CPs in various lattice spin systems remains one of the central problems of modern condensed matter theory. Modern PT and CP theory is primarily based on ideas embedded in the scaling hypothesis, universality, the ε-expansion, and renormalization group theory. These ideas have provided the basis for most of the most important results in modern PT and CP theory. The ideas underlying all of these assumptions have significantly enriched our understanding of the nature of critical phenomena. Nevertheless, a rigorous and consistent microscopic theory of second-order phase transitions and critical phenomena currently lacks. Despite significant successes, the creation of the theory of second-order phase transitions and the study of various aspects of critical phenomena in complex thermodynamic systems still remains one of the pressing problems of condensed matter physics [1, 2].

The focus of theoretical research has shifted to the study of more realistic models that take into account numerous factors inherent in real crystals and not accounted for in first-approximation models. These factors include anisotropy, impurities, dipole-dipole interactions, lattice vibrations, and frustrations. Of particular interest are studies of frustrated spin systems and systems with nonmagnetic impurities on lattices of various types and spatial dimensions. When describing critical phenomena in such systems, first-approximation models are most often used: the classical Ising model, the Heisenberg model, the XY model, the Potts model, etc. [1].

Studies performed using computational physics methods have shown that spin systems with frustrations and frozen-in disorder possess unusual magnetic properties and exhibit a rich variety of phase diagrams, phase transitions, and critical behavior features. To date, a number of fundamental questions remain unanswered for such systems. These include issues related to the nature of phase transitions and the characteristics and factors influencing the formation of universality classes for the magnetic and chiral critical behavior of spin systems. Resolving these issues requires a thorough study of the phase transitions and critical properties of such systems, with high-precision calculations of their critical parameters [3, 4].

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ORAL SESSION

Multiferroics

Friday, 21 August, 11:00 - 12:45

MULTIFERROICITY AND MULTICALORICITY: INTERRELATION MECHANISMS AND WAYS TO CONTROL

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Multiferroics are materials in which two or more types of ferroic ordering (ferromagnetic, ferroelectric and ferroelastic) coexist simultaneously.

The multicaloric effect refers to the phenomenon of reversible changes in the temperature (or entropy) of a material under the stimuli of two or more changed external fields (magnetic, electric, or mechanical stress) under adiabatic (or isothermal) conditions. Materials exhibiting multicaloric effects are termed multicalorics.

The nature of the effects and phenomena observed in multicaloric materials is conceptually close to that of multiferroics; thus, the classification approaches applied to multiferroics can also be extended to multicalorics. Accordingly, multicaloric materials can be classified into two types: «natural» and composite. «Natural» multicaloric materials include single-phase compounds in which the origin of the observed multicaloric effects is inherently linked to their crystal structure and its coupling with magnetic and electric subsystems. Composite multicalorics are «artificial» multiphase materials composed of constituents with distinct types of ferroic ordering (ferromagnetic, ferroelectric, or ferroelastic) interconnected via various connectivity types (particulate 0-3, layered 2-2, or cylindrical 1-3). The multicaloric effect is not a simple superposition of individual caloric effects; rather, it is mediated by the coupling between each subsystem (e.g., the magnetoelectric effect in magnetoelectric multiferroics).

In report is considered the relationship between multicaloric effects and multiferroic phenomena (magnetoelectric, magnetoelastic, and ferroelastic effects) depending on the material type and the methods of their control via various external stimuli. FeRh-based alloys ordered to the *CsCl*-type structure (*B2*) and their composites are considered as model multicaloric materials, which represent the most promising candidates for biomedical applications due to their record values of the magnetocaloric effect in the range of physiological temperatures, and good biocompatibility.

This work was supported by the Russian Science Foundation (project no. 24-19-00782, https://rscf.ru/en/project/24-19-00782/).

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NONLINEAR MAGNETOELECTRIC EFFECTS IN A COMPOSITE STRUCTURE WITH TWO TYPES OF NONLINEARITIES

Savelev D.V., Burdin D.A., Bolotina E.V., Chashin D.V., Pereverzeva A.P., Fetisov Y.K.

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Magnetoelectric (ME) effect in composite structures manifests itself as a change of polarization in PE layer under the action of a magnetic field (direct effect) or a change of magnetization under the action of an electric field (converse effect). Study of nonlinear ME effects is of particular interest. Direct nonlinear effects have been investigated in detail, while for converse effects, only the mechanisms of their occurrence are proposed [1]. This work is devoted to investigation of the characteristics of nonlinear converse ME effects of second harmonic generation in a composite structure exhibiting electrostrictive and magnetoelastic types of nonlinearities simultaneously.

The measurements were performed on a composite structure with in-plane dimensions of 10×6 mm containing mechanically coupled plate of electrostrictive piezoelectric ceramics PMN-PT (NKTB Piezopribor, Russia) with a thickness of 0.5 mm and a layer of amorphous magnetic alloy Metglas 2605SA1 (Metglas Inc, US) with a thickness of 25 μm. The structure was placed in Helmholtz coils that created a DC magnetic field H up to 100 Oe and was excited by an AC electric field $e\cos(2\pi ft)$ with an amplitude e up to 175 V/cm in the frequency range f = 30-300 kHz. The change in the magnetization of the FM layer was detected by a measuring coil.

Resonance enhancement of the second voltage harmonics under different excitation frequencies was experimentally observed. Let us denote the amplitude of second harmonic generated when electric field frequency $f = f_r/2$ as v_1 and v_2 when $f = f_r$. Remarkably, v_1 and v_2 had significantly different magnetic field dependences (Fig.1). The observed differences can be explained taking into account different mechanisms of nonlinear conversion. Amplitude of the second harmonic increased quadratically with increasing amplitude of the excitation electric field, which confirms the nonlinear nature of the effects [1]. A theory of nonlinear converse ME effects in a composite structure describing the measurement results well has been developed.

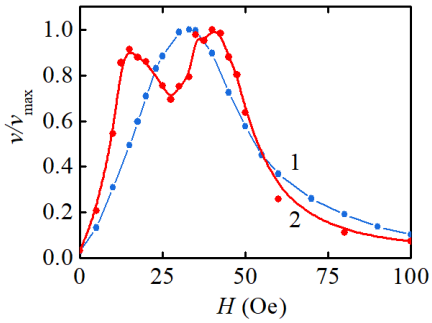

Fig. 1. Field dependences of the normalized amplitudes of the second harmonics caused by electrostrictive (curve 1) and magnetoelastic (curve 2) nonlinearity.

The work is supported by Russian Science Foundation (grant № 25-22-00233, https://rscf.ru/project/25-22-00233/).

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STRAIN-INDUCED LOCAL NUCLEATION OF MAGNETIC DOMAINS IN IRON GARNET FILM

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A new type of flexoelectric effect has been discovered, manifesting itself as the nucleation of cylindrical magnetic domains under localized pressure on the surface of a ferrite garnet film. A comparison with a similar electrically induced effect [1] demonstrates an analogy between the physical consequences of applying an electric field and a mechanical stress gradient to a magnetic sample.

As shown in [2], the magnitude of the Dzyaloshinskii-Moriya interaction, arising from distortion of the crystal structure due to the gradient of epitaxial stresses in the film, is sufficient to explain the charge asymmetry observed in experiments on garnet ferrite films: the identical electric polarity of magnetic domain boundaries in the spontaneous state. However, direct experimental evidence that non-uniform deformation has an effect on the micromagnetic structure of garnet ferrite films similar to the effect of an electric field has not yet been available.

In this study, a series of experiments were conducted demonstrating the equivalence of the electrical and mechanical effects of the probe, as well as the ability of these two effects to enhance or cancel each other out depending on the polarity of the electrical voltage.

A ferrite garnet film sample was placed in a system of two pairs of inductors, generating a magnetic field parallel and perpendicular to the plane of the sample. Local pressure on the film surface was applied using a tungsten probe, to which an electrical voltage could be applied. The sample's domain structure was observed using the magneto-optical effect in Faraday geometry.

Support by Russian Science Foundation (Grant No. 25-79-30019) is acknowledged.

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INFLUENCE OF THE PARAMETERS OF (210)-ORIENTED FERRITE-GARNET FILMS AND AN EXTERNAL ELECTRIC FIELD ON THE MANIFESTATION OF THE FLEXOMAGNETOELECTRIC EFFECT

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The ability to control spin waves with an external electric field represents both a long-standing engineering challenge in magnetic devices and significant fundamental interest. One way to achieve this control is through the use of multiferroics [1], particularly ferrite garnet films. Ferrite garnet films (particularly YIG) occupy a central place in spintronics due to their ultra-low spin wave attenuation and high coherence of spin dynamics, which directly impacts response speed: minimizing dissipative losses allows for the transmission of spin signals with minimal time delay and operation at terahertz frequencies [2]. A non-uniform magnetoelectric effect, later termed the flexomagnetoelectric (FME) effect [3], was also discovered in these same materials. This effect consists of the displacement of a domain wall (DW) in ferrite garnet films under the action of a non-uniform electric field. In this case, the generation, movement, and transformation of magnetic inhomogeneities can be controlled by the action of an electric field. Further study of the observed phenomenon revealed a number of peculiarities, among which one can highlight its significant dependence on the orientation of the developed film surface relative to the crystallographic axes. One of the peculiarities of the observed effect is the dependence of its degree of manifestation on the orientation of the developed film surface: in the (210)-oriented film, the effect is most pronounced, in the (011)-film it is weaker, and in the (111)-film it was not observed at all [4]. In the (210)-films of ferrite garnets, a complex magnetic anisotropy is observed, caused by the superposition of several types of anisotropy. A key role is played by the orthorhombic crystallographic anisotropy, caused by the low symmetry of the substrate, which, in combination with uniaxial and cubic anisotropy, leads to the formation of an inclined easy axis. In particular, a similar analysis of the domain structure carried out for a (210) type plate showed [5] that, regardless of the values of the magnetic anisotropy constants and other parameters of a given sample, 180^0-DWs with a non-circular trajectory of the magnetization vector M are always realized in them, which leads to an increase in the FME effect.

A numerical solution of the Euler-Lagrange equations for the studied film showed that 180° DWs with a non-circular magnetization vector trajectory cannot exist for all material parameters and external electric field values, but only for certain values. Calculations indicate that cubic anisotropy, with its easy axes positioned relative to the easy axes of uniaxial anisotropy, significantly reduces the magnitude of the integral polarization, thereby weakening the FME effect.

Support by State assignment of Russian Federation for the implementation of scientific research by laboratories (no.075-03-2024-123/1 dated 15.02.2024).

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[3] A.P. Pyatakov, A.K. Zvezdin. *Physics-Uspekhi*, **58**, (2015) 981–992
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THE STRUCTURE OF THE TWISTED DOMAIN WALL IN A (210) IRON GARNET FILM AND THE MECHANISM OF ITS INTERACTION WITH AN EXTERNAL ELECTRIC FIELD

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Spintronics is a rapidly evolving new branch of electronics [1] that utilizes various approaches to control the state of magnetic moments. The concept of controlling magnetization includes different stimuli: spin-polarized currents, light beam, external electric fields. A group of materials known as multiferroics allows for adjusting the properties of magnetic moments through the use of external electric fields. Magnetoelectric phenomena were observed in (210) iron garnet films where electric field of external electrode can induce motion of the domain walls (DWs) and nucleation of bubble domains. DWs can be applied in the field of neuromorphic computing [2]. Their twisted structure also can be used from dynamical point of view [3].

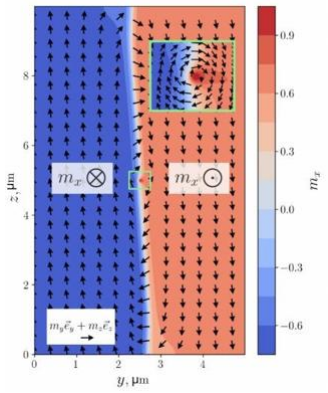

Fig. 1. The structure of the twisted domain wall

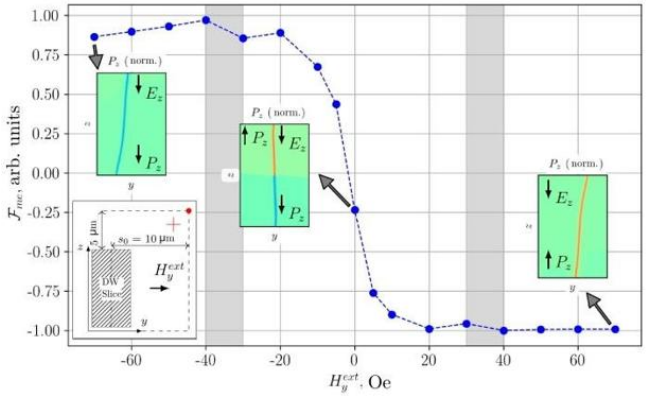

Fig. 2. The dependence of force acting on a DW from a poin charge on an external magnetic field

In this study we investigate the structure of the DW in a (210) iron garnet film with complex magnetic anisotropy. Based on micromagnetic simulations (MuMax3 package) it is shown that the DW in its energetically favorable state has twisted structure and contains horizontal Bloch line (DW cross section is shown in Fig. 1). Since the fragments of DW above and below the Bloch line have different chirality, they possess electric polarization of opposite directions. Another result is that an external magnetic field applied perpendicular to DW direction causes vertical shift of the horizontal Bloch line and changes the way the DW interacts with an external electric field. Fig. 2 shows the force acting on the DW from a point electric charge located 10 μm away from the DW. It can be seen from Fig. 2 that the attraction of the DW to the point electric charge (positive values of the force) is replaced by repulsion (negative values) when external magnetic field changes the DW structure.

The study was supported by the Russian Science Foundation (grant No. 25-79-30019).

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[3] Seong Tae Kim et al., *Journal of Applied Physics*, **135** (2024) 103902

GIANT MAGNETOELECTRIC EFFECT INDUCED BY A PHASE TRANSITION IN FERH-BASED CORE-SHELL NANOPARTICLES

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Magnetoelectric (ME) nanoparticles are promising materials for wireless neurostimulation, targeted drug delivery, and other biomedical applications. However, the efficiency of conventional ME nanoparticles is strongly limited by the small magnetostrictive strain of biocompatible magnetic materials, resulting in output voltages typically below several millivolts [1]. Such values are often insufficient for effective excitation of biological cells.

Here we propose a concept of a giant thermally induced magnetoelectric effect based on the firstorder antiferromagnetic-ferromagnetic phase transition in FeRh alloy. Near the physiological temperatures, FeRh exhibits a reversible magnetoelastic phase transition, accompanied by a lattice volume change of approximately 1% [2]. This deformation is about two orders of magnitude larger than conventional magnetostriction. Thus, the use of this effect to deform the piezoelectric shell can be expected to significantly enhance the resulting ME effect in core-shell nanoparticles (Fig 1).

Finite-element simulations were performed in COMSOL Multiphysics for spherical core-shell nanoparticles consisting of an FeRh core and piezoelectric shells based on $BaTiO_3$ or PVDF. The simulations demonstrate that the phase-transitioninduced expansion of the FeRh core can generate electric potentials up to 89 mV for FeRh@$BaTiO_3$ nanoparticles and 32 mV for FeRh@PVDF nanoparticles. These values exceed the response of conventional Fe_3O_4-based ME nanoparticles by more than two orders of magnitude.

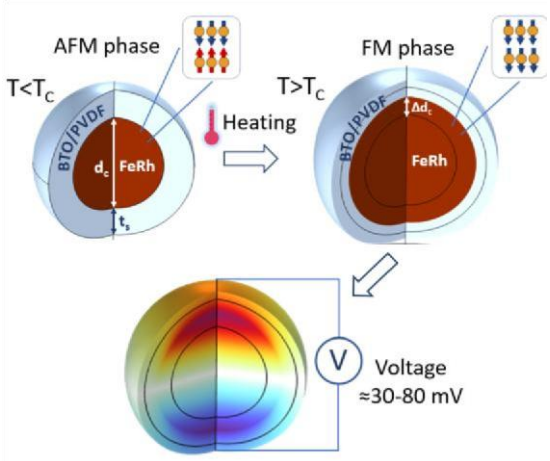

Fig. 1. Schematic illustration of the operating principle of the thermally induced ME effect in FeRh composite nanoparticles.

Thermal modeling of such nanoparticles in an aqueous environment showed characteristic cooling times of approximately 20-40 ns, indicating the possibility of repeated high-frequency operation. The obtained voltages are comparable to characteristic cellular excitation thresholds, demonstrating the strong potential of FeRh-based ME nanoparticles for biomedical and nanoscale actuator applications. The proposed approach opens a route toward highly efficient remotely controlled magnetoelectric nanostructures.

This work was supported by the Russian Science Foundation (project no. 24-19-00782, https://rscf.ru/project/24-19-00782/).

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ORAL SESSION

Miscellaneous

Friday, 21 August, 15:00 - 16:30

ATOMIC SPIN EFFECTS IN RESONANCE PHOTOEMISSION SPECTROSCOPY

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Atomic spin effects in resonance photoemission spectroscopy (RPES) provide deep, element-specific insights into the electronic and magnetic states of rare-earth (RE) and 3dtransition metal (TM) compounds. They reveal how local Coulomb interactions, spin-orbit coupling, and inter-atomic hybridization drive strongly correlated phenomena in these materials. RPES utilizes the photoelectric effect by tuning incident photon energy to match core-level absorption thresholds (4d-4f, 3d-4f in rare-earths, 2p-3d in 3d-transition metals). This creates a core-excited state that decays via an autoionization/Auger process, interfering with direct valence band photoemission. The process relies on quantum interference between direct photoemission from the valence band and the autoionization decay of a core-excited state (4d-4f, 3d-4f in rareearths, 2p-3d in 3d-transition metals). This selectively enhances the photoemission cross-section of localized (d) and (f) electrons. Because the core-hole and the valence electrons interact via intra-atomic exchange, the resonant decay channels are highly spin-dependent. In Rare-Earth Compounds, it is possible to investigate the localization of 4f-states, for example, like Ce, Sm, and Yb are characterized by partially filled, highly localized 4f-shells. RPES using 4d-4f or 3d-4f thresholds drastically enhances these 4f-states, allowing researchers to track intermediate valence fluctuations and Kondo behaviors. The spin state of the 4f-electrons strongly couples to the 5d and 6s valence states. RPES helps map out this intratomic exchange, providing insight into the 4f-5d3d exchange pathways in complex RE-TM intermetallics. This is critical for evaluating halfmetallicity in spintronic applications and altermagnetism in non-relativistic spin-split bands. Understanding these atomic spin effects is foundational for optimizing functional magnetic and quantum materials. It possible to rely on these techniques to investigate tuning 3d and 4f interactions for magnetic materials and observing localized-to-itinerant electron transitions.

This work was supported by the Russian Science Foundation, project № 23-72-00067.

DIFFERENTIAL RESONANCE INDUCTIVE SENSOR FOR MAGNETIC AND CONDUCTING PARTICLE DETECTION

Acuna A.[1,2], *Sobko A*[1], *Yudanov N.A.*[1,2], *Balashko I.A.* [1], *Kolesnikova V.G.*[2], *Panina L.V.*[1,2], *Rodionova V.V.*[2]

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The differentiation between magnetic and conducting particles is important in disciplines including materials science, biomedicine, engineering, and related fields. Consequently, this study proposes a highly sensitive sensor for detecting magnetic and conducting particles. The sensing element comprises a planar spiral coil (PSC), within a circuit formed by two resonant differential filters [1].

For experimental validation, cylinders containing magnetic particles with varying magnetite (Fe_3O_4) content were utilized. The material employed for the conducting component was aluminum cylinders. Furthermore, the study incorporated cylinders of varying dimensions and volumes composed of magnetic or conducting particles. In addition, three planar spiral coils (PSCs) with distinct characteristics and inductances were utilized as the sensing element (L_{PSC-1} = 120µH, L_{PSC-2} = 470µH y L_{PSC-3} = 44µH).

The change in inductance in the planar coils, in the presence of magnetic or conducting particles, was initially determined by simulating the energy variations, using Python. The magnetic field was calculated analytically [2]. These alterations in inductance were obtained by positioning cylindrical materials at varying distances from the center of the coils. The electronic circuit for particle detection consists of an LC resonant differential filter, an amplification stage, and a rectifier.

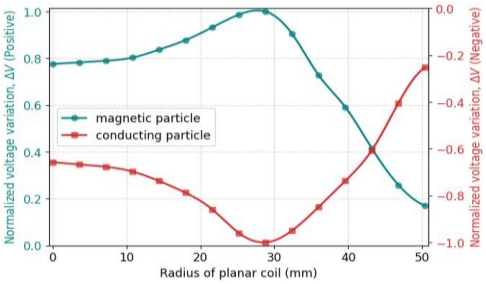

Fig. 1. Normalized voltage variation of the sensor caused by magnetic and conducting particles, using coil PSC_1.

Figure 1 presents the normalized voltage variation of the sensor, induced by magnetic as well as conducting particles. These particles are positioned at varying distances from the coil's center, utilizing cylinders with a diameter of 1 cm and a height of 4 cm. Voltage variations with opposite signs have been observed for magnetic and conducting particles. This phenomenon is attributed to the interaction of magnetic and conducting particles with the magnetic field created by the coil current, which results in the inductance increase and decrease, respectively. The highest sensitivity is achieved near the first spiral of the coil, where the maximum magnetic field density is concentrated. The distance from the center to the first spiral is 29 cm, in the case of PCS_1.

Additionally, the sensor demonstrates an almost linear dependence of the output voltage on the concentration of the magnetic phase, exhibiting a sensitivity of 30 mV/wt%, 44 mV/wt%, and 20 mV/wt% for the PSC_1, PSC_2, and PSC_3 coils, respectively. The sensor also responds with high sensitivity to conducting particles of different sizes.

Support by the Russian Science Foundation under project no. 25-72-30009.

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MANGANESE-DOPED SILICON AS A MAGNETIC FIELD SENSOR

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The magnetoresistance of *p*-type silicon *p*-Si<B,Mn> containing magnetic nanoclusters was investigated at room temperature. A giant negative magnetoresistance (NMR) of Δρ/ρ∼300% was observed. It is shown that with increasing concentration of nanoclusters, the value of negative magnetoresistance significantly increases. The samples have become more sensitive to magnetic field [1], [2].

Keywords: silicon, magnetic field sensor, manganese nanoclusters, negative magnetoresistance.

As can be seen from the figure 1, the magnitude of negative magnetoresistance increases significantly with increasing nanocluster concentration. In samples with a nanocluster concentration of $N_{[Mn]4}=10^{15}$ cm^{-3} at room temperature and under an electric field of E=100 V/cm, a giant negative magnetoresistance of Δρ/ρ∼300 % is achieved, while the magnetic field sensitivity reaches with the slope -147.

These results can be understood with the presence of manganese nanoclusters in the silicon lattice. Moreover, the magnitude of NMR can be controlled over a wide range by varying the nanocluster concentration.

It has been established that with increasing nanocluster concentration in the range 2×10^{13} to 10^{15} cm^{-3}, under identical experimental conditions, the NMR value increases by a factor of 8–10, while the magnetic field sensitivity rises from 33 to 147.

MR have measured at $T = 300$ K and $E = 100$ V/cm, the concentrations of Mn nanoclusters was accordingly in Figure 1: $1 - N(Mn)_4 = 2 \times 10^{13}$ cm^{-3}, $2 - N(Mn)_4 = 2 \times 10^{14}$ cm^{-3}, $3 - N(Mn)_4 = 5 \times 10^{14}$ cm^{-3}, $4 - N(Mn)_4 = 10^{15}$ cm^{-3}.

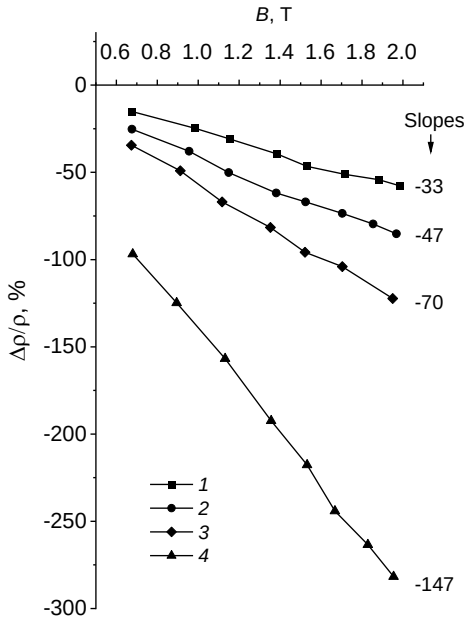

Fig. 1. MR as a function of the magnetic field in samples with various concentrations of magnetic nanoclusters

A correlation was established between the GMR value and the nanocluster concentration, alongside the electrophysical parameters of the nanoclustered samples. It was demonstrated that the GMR value increases significantly with rising nanocluster concentration. Furthermore, it was determined that to achieve maximum GMR, p-type silicon with a resistivity of $\rho = (3 \div 10) \times 10^3\ \Omega \cdot$ cm at room temperature should be utilized.

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THEORY OF INTERACTION BETWEEN INDUCED ELECTROMAGNETIC RADIATION AND MATTER

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A theory has been developed for the generation of the third harmonic of femtosecond laser radiation in plasma produced by the ablation of various solids. Analytical expressions for the third-harmonic intensity were derived using the slowly varying amplitude approximation, accounting for the phase mismatch between the fundamental wave and third-harmonic pulses. The dependence of the third-harmonic intensity on the energy of the exciting Gaussian laser radiation was obtained through numerical methods. Based on these results, the energy ranges satisfying the phase-matching conditions were determined.

Keywords: femtosecond pulse, third harmonic, plasma, ablation, phase mismatch.

Frequency conversion processes, particularly high-order harmonic generation (HHG) in various media, are utilized to create coherent light sources ranging from the ultraviolet to the ultrashort X-ray spectral regions [1]. It is well known that to enhance HHG efficiency, it is necessary to satisfy the quasi-phase-matching condition (QPM) for the interacting pulses, which is inherently linked to the dispersion of the medium. However, phase-matching cannot be achieved in all media, which limits the efficiency of nonlinear frequency conversion of laser radiation. This condition is realized, for example, in anisotropic crystals by utilizing the phenomenon of birefringence [2], and in nonlinear photonic crystals through the use of QPM conditions [3]. Nevertheless, in such crystals, only relatively low-order harmonics can be generated. High-order harmonic generation (involving several dozen harmonics) is achieved in gases, particularly in plasma, due to the low dispersion of light in these media, which allows the phase-matching condition to be met for specific intensities of the exciting laser radiation [4].

Within the framework of the theory developed in this work, an expression for the intensity of the third harmonic as a function of the distance z and other parameters was obtained using the fixed-field approximation, taking the following form

$$I_3(z) = \frac{576\pi^6}{n_3 n_1^3 c^4 \lambda^2} \left|\chi^{(3)}\right|^2 I_1^3 z^2 \mathrm{sinc}^2\left(\frac{\Delta k z}{2}\right) \quad (1)$$

where: I_1 and I_3 are the intensities of the fundamental radiation and the third harmonic, respectively; n_1 and n_3 are the refractive indices at the fundamental and third-harmonic frequencies; $\chi^{(3)}$ is the third-order nonlinear susceptibility; and $\Delta k = k_3 - 3k_1$ represents the phase mismatch. $\mathrm{sinc}^2(\Delta k z/2)$ – the phase-matching factor. It determines how efficiently the waves stay in phase over the interaction length z.

During the ablation of a substance, the concentration of neutral atoms increases. Under the influence of electromagnetic radiation, these atoms undergo ionization, leading to an increase in electron density-effectively transforming one medium into another. The wave vector $\boldsymbol{k}$ is dependent on these changes, which enables the fulfillment of the phase-matching condition, thereby ensuring an increase in the efficiency of third-harmonic generation.

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OPTICAL VORTICES IN MAGNETIC FILMS

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We experimentally demonstrate the topological Faraday effect (Fig. 1) - the polarization rotation caused by the orbital angular momentum of light. It is found that the Faraday effect of the optical vortex beam [1] passing through a transparent magnetic dielectric film differs from the Faraday effect for a plane wave. The additional contribution to the Faraday rotation depends linearly on the topological charge and radial number of the beam. The effect is explained in terms of the optical spin-orbit interaction.

Additionally, we theoretically and experimentally demonstrate a way to control the intensity of optical vortices by a magnetic field directed along the beam axis. We describe the principle of an optical vortex modulator (Fig. 2) and switch based on the Faraday effect in an iron garnet film. Importantly, the magnetic field influences only the polarization plane of the vortex and keeps its topological charge. These results open a way for extension of the abilities of magneto-optics for the class of beams with an additional orbital degree of freedom of light, which could contribute to more miniature energy efficient tools for controlling OAMcarrying beams for the needs of information technologies, micromanipulation, sensors, etc.

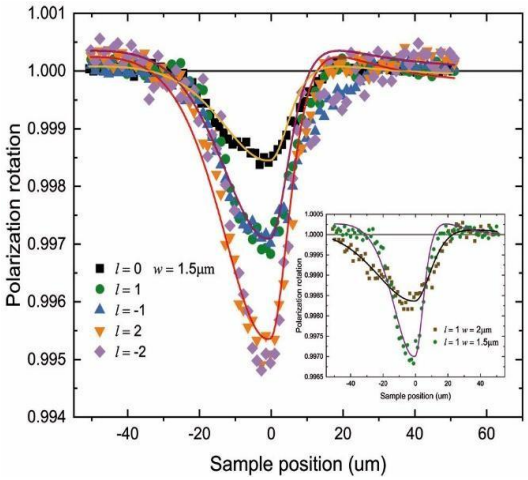

Fig. 1. The normalized Faraday angle for different topological charges as a function of the position of the sample z relative to the beam waist (z=0).

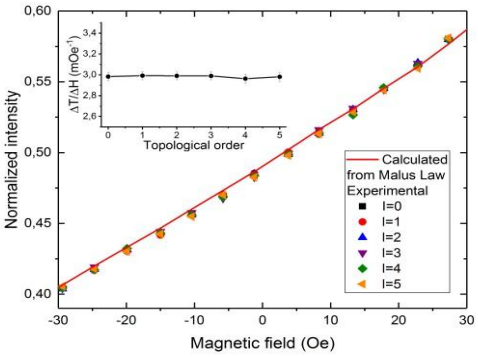

Fig. 2. Experimentally measured MO modulation of transmittance of optical beams passing through a magnetic film.

Support by the Ministry of Science and Higher Education of the Russian Federation, projects (№ FZEG-2026-0011, №075-022026-1313).

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[4] Belotelov, Phys. Rev. App. 18, 054008 (2022).

X-RAY MODELLING OF BENDING MAGNET BEAMLINE FOR MAGNETIC CASES

Burdilov A.A.[1,2], *Dovzhenko G.D.*[1,2], *Platunov M.S.*[1]

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The foundation of research on magnetic materials using modern synchrotron radiation (SR) sources is the X-Ray magnetic circular dichroism (XMCD) method, which enables the study of magnetic materials with element-specific and orbital-selectivity properties. Modern facilities offer beamlines which use an undulator as the radiation source, providing users with control over the polarization vector (linear, circular, or elliptical). However, beamlines based on bending magnets, due to their lower complexity and continuous radiation spectrum, have an advantage in combining methods such as XMCD and X-ray absorption fine structure spectroscopies (XANES/EXAFS), where additional scanning of the sample over a wavelength range near the absorption edge of material is required. At the same time, bending magnets are limited in the generation of polarized radiation and can only produce linear polarization within the plane of the electron orbit. The use of specialized adjustable slits makes it possible to truncate the beam, retaining the central cross-section of the beam with linear (horizontal) polarization, with a corresponding loss of radiation intensity. Obtaining elliptical polarization depends on the deviation from the orbital plane [1], and the balance between small and large deviation allows for different degrees of elliptical polarization.

Here we discuss the concept of the beamline with a bending magnet as a radiation source, based on a "mirror – monochromator – mirror" optical layout, for the 4+ generation SR source at the SRF «SKIF» [2]. The beamline is designed for the comprehensive analysis of synthetic and natural materials using structural and spectroscopic SR-based research methods. The key experimental techniques at the beamline will be X-ray diffraction, X-ray absorption spectroscopy, and XMCD. X-ray optical modeling of the beamline was carried out using the XRT software package [3]. The energy range of beamline is 5–30 keV. The optimal optical scheme allows for obtaining both focused and unfocused beams at the sample, ranging from 30 × 30 μm² to 20 × 200 mm² (vert. × horiz.), controlling the degree of linear polarization, and generating circular polarization using a diamond quarter-wave plate. Various optical configurations and operating modes of the beamline are analyzed, enabling the combination of different research methods for the analysis of complex magnetic materials, including XMCD.

This work was performed within the framework of a budget project of the Ministry of Science and Higher Education of the Russian Federation for Synchrotron Radiation Facility SKIF, Boreskov Institute of Catalysis, Siberian Branch, Russian Academy of Sciences (FWUR-2024-0040).

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ORAL SESSION

Neutrons and synchrotron X-rays for magnetism

Friday, 21 August, 15:00 - 16:30

SYNCHROTRON X-RAYS FOR ADVANCED STUDIES ON COMPOSITIONALLY COMPLEX SYSTEMS

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Synchrotron X-rays have started to be extensively involved in scientific research since their discovery in 1947, and enable many fascinating phenomena in physics, chemistry, materials science, medicine, and other scientific disciplines to be explored. Nowadays, a plethora of unique characterization tools can be found worldwide for advanced element-specific studies at the atomic scale due to energy tunability, variable polarization, high flux and time structure of synchrotron X-ray photons.

Meanwhile, there is a continuous progress in designing multifunctional materials through accurate mixing of different elements in a broad range of desired proportions. Compositionally complex systems, represented by a broad class of materials including multi-principal-element alloys and ceramics, are already recognized as being promising for practical applications in renewable energy technologies, catalysis, battery research, or as coatings under extreme conditions like temperature, mechanical stress and radiation. These systems traditionally refer to high-entropy alloys (HEAs), high-entropy oxides (HEOs), high-entropy carbides (HECs), *etc*, and exhibit many extraordinary properties due to their extremely high chemical complexity achievable through a number of different components. Unveiling the roles of individual constituents in the structural, electronic, and magnetic properties of compositionally complex systems is currently of key importance for further developments in materials science, and makes e.g. X-ray absorption and X-ray photoemission spectroscopies available at different synchrotron radiation facilities even more demanding.

In this talk, some distinct benefits of multi-edge extended X-ray absorption fine structure (EXAFS) spectroscopy along with reverse Monte-Carlo (RMC) simulations, X-ray magnetic circular dichroism (XMCD) spectroscopy performed in pulsed magnetic fields and X-ray photoemission electron microscopy (X-PEEM) in application to studies of d-elements based HEAs [1-7] will be highlighted.

Parts of this research were supported by HORIZON 2020 (CALIPSOplus, #730872, and H2020WIDESPREAD-01-2016-2017-TeamingPhase2), the Latvian Council of Science (project no. lzp-2023/1-0476), BMBF (#05K10PC2, #05K10WR1, #05K10KE1, #05K19KEA, and #05K19W06), and DFG (DI 1419/24-1, DI 24-1, IK125/1-1, DE 796/11-1, LU1175/22-1), DFG via SPP2006 (WI 1899/32-2, FR 1714/7-2, LA 3607/3-2) and DFG via Heisenberg Programme (#541649719). The Helmholtz-Zentrum Berlin (HZB) and Deutsches Elektronen-Synchrotron (DESY) are acknowledged for the provision of access to synchrotron radiation facilities and allocation of measurement time.

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INVESTIGATIONS OF MAGNETIC NEUTRON WAVEGUIDES

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Tri-layer waveguides (Fig. 1) transform a collimated neutron beam of the width 0.1-1 mm into a divergent microbeam of the width 0.1-10 μm [1]. The neutron waveguides produce "clean" microbeam of record narrow width. Disadvantages of this microbeam are low intensity and the angular divergence due to Fraunhofer diffraction on a narrow slit. The non-magnetic waveguide was used for spatial scan of the magnetic wire using polarized neutron microbeam [2]. Waveguides with enveloping magnetic layers were proposed for the resonant enhancement of neutron density for controlled nuclear chain reaction in U [3]. The magnetic waveguides Fe/Cu/Fe and Py/Cu/Py were investigated experimentally in [4]. Py (permalloy) is the soft magnetic alloy Fe(20.6% at.)Ni(79.4% at.).

In this work, we investigated the magnetic waveguides Fe(10 nm)/Al(140)/Fe(50)//glass and Py(10 nm)/Al(140)/Py(50)//glass. The neutron microbeam intensity was registered as a function of neutron scattering length density (SLD) depth $\Delta\rho = \rho_1 - \rho_2$. Here ρ_1 and ρ_2 are SLD of the upper magnetic layer (index 1 in Fig. 1) and the middle non-magnetic layer (index 2 in Fig. 1). The SLD ρ_1 depends on the value of magnetization M and the sign the incident beam polarization (+) or (-).

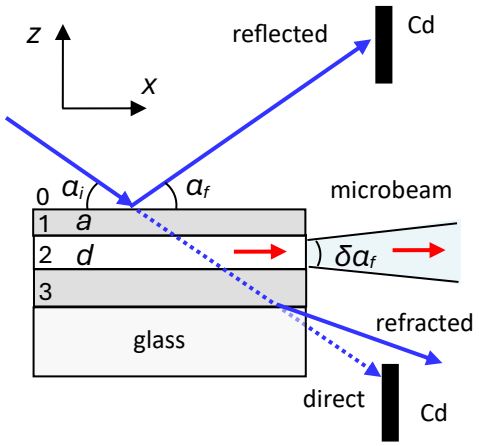

Fig. 1. Geometry of experiment. The collimated neutron beam tunnels through the surface into the middle layer. The neutron microbeam goes out from the end face of the middle (or waveguiding) layer.

Experiment was done on the time-of-flight reflectometer REMUR at the pulsed reactor IBR-2 in Dubna, Russia. Polarized neutron beam was used. The size of the sample substrate was 30 × 30 × 5 mm^3. The grazing angle of the incident beam α_i was equal to 0.236° for Py/Al/Py and 0.228° for Fe/Al/Fe. The angular divergence $\delta\alpha_i$ of the incident beam was 0.009°. Two-dimensional ^{3}He position-sensitive detector (PSD) with spatial resolution 2.5 mm was used. The distance from the sample to PSD was equal to 5030 mm, the time-of-flight distance from the moderator to the detector was equal to 34030 mm. The width of the time-of-flight channels was equal to 256 μs, the cold moderator was used and the wavelength resolution was equal to 0.02 Å.

The integrated microbeam intensity of the resonance of the order n = 0 is not changed within the statistical error ± 15 %. The theory of the neutron resonances in layered waveguides predicts the small changes of the integrated neutron wavefunction density enhancement about 30 %. It is close to the experimental errors of the neutron microbeam intensity. Obtained experimental data may be useful for optimization of neutron planar waveguides in the future.

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POLARIZATION-DEPENDENT X-RAY ABSORPTION SPECTROSCOPY FOR FUNDAMENTAL STUDIES OF MODERN MAGNETIC MATERIALS

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The advent of modern synchrotron radiation sources has provided a significant impetus for the advancement of X-ray spectroscopy, as evidenced by the emergence of numerous experimental techniques that exploit the polarization properties of X-rays. In particular, X-ray magnetic circular dichroism (XMCD) has become a key tool in contemporary magnetism, enabling deeper insights into the microscopic nature of magnetic states with element-specific and orbital sensitivity [1].

A compelling illustration of the potential of the XMCD technique is the study of the ferrimagnet $Co_2FeO_2BO_3$, where element-specific analysis using XMCD in both the soft and hard X-ray regimes enabled the determination of the spin and orbital magnetic moment contributions of Co^{2+} and Fe^{3+} ions. It was found that the material's high coercivity (exceeding 7 T at low temperatures) arises from both strong antiferromagnetic coupling between Co and Fe ions and pronounced anisotropy of Co^{2+}. These results demonstrated that, through controlled charge ordering and the deliberate distribution of cations over crystallographic sites, it is possible to design rare-earth-free magnetic materials with robust magnetic properties, making them promising for practical applications [2,3].

In addition to XMCD, the related magneto-optical effect of X-ray natural circular dichroism (XNCD) and resonant inelastic X-ray scattering natural circular dichroism (RIXS-NCD) are rapidly advancing. While XNCD provides direct visualization of chiral domain distributions in multiferroics, RIXS-NCD can offer complementary element-specific information about electronic excitations. Notably, structural twin domain mapping was successfully demonstrated on a $SmFe_3(BO_3)_4$ single crystal [4]. These findings underscore the potential of XNCD as a sensitive tool for probing domain structures and investigating magnetoelectric coupling mechanisms in rare-earth ferroborates.

The presentation will include additional examples of the application of the methods [5]. Furthermore, it will address the effect of X-ray magnetochiral dichroism (XMχD) [6], which manifests in magnetoelectric systems and chiral molecular magnets. The proposed concept of a universal diagnostic beamline for magnetic materials employing polarized X-rays within the SKIF-synchrotron framework will be offered for discussion.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation within the governmental assignment for Synchrotron radiation facility "SKIF", Boreskov Institute of Catalysis (project FWUR-2024-0040).

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MAGNETISM AND SUPERCONDUCTIVITY IN FIBONACCI LAYERED QUASICRYSTALS: A NEUTRON REFLECTOMETRY AND MULTISCALE STUDY

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Quasicrystals exhibit long-range order without translational invariance, enabling exotic phenomena such as fractal superconductivity [1] and the coexistence of superconducting and ferromagnetic order parameters [2–4]. We propose artificial layered Fibonacci heterostructures (alternating superconducting and ferromagnetic films, orders F_6–F_{12}) as ideal platforms for investigation by polarized neutron reflectometry [5,6], a technique sensitive to both nuclear and magnetic scattering-length densities [7]. Neutron-optical simulations show that from F_{10} the reflectivity stabilizes, with clear "quasi-Bragg" peaks indicating hidden long-range order; notably, the quasiperiodic arrangement can absorb more neutrons than its periodic analogue, and the peaks are robust against thickness errors, which is crucial for experimental feasibility. In Co/Pt Fibonacci stacks at 5 K and 1 T, the first quasi-Bragg peak splits into two components due to competition between strong perpendicular anisotropy and interlayer exchange ("magnetic spring" effect) [5]. In Co/Pb quasicrystals below the Pb critical temperature (7.2 K), Meissner screening currents shift the quasi-Bragg peaks and reduce the reflected intensity by 20 % [6]. In Dy/Nb and Ho/Nb superlattices, superconductivity expands the magnetic helix period by 8–12 %, directly demonstrating the influence of superconductivity on the magnetic structure [3]. A new setup for oscillating magnetic fields (10–30 MHz, up to 10 Oe) installed at the REMUR spectrometer (IBR-2, Dubna) has produced first modulated neutron reflection data, opening the way to time-resolved studies of domain-wall motion and vortex dynamics [7]. The combination of synchrotron GISAXS and PNR makes it possible to separate cluster- and domain-related contributions to the magnetization [5–7]. These results provide a solid basis for experimental searches of fractal superconductivity [1] and long-range magnetic order in quasiperiodic systems [2–4], as well as for the study of quantum critical phenomena in strongly correlated layered heterostructures.

The work was supported by the Russian Science Foundation, grant 24-72-00124.

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STYDY OF RARE-EARTH MULTILAYERS WITH POLARIZED NEUTRON REFLECTOMETRY

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Polarized neutron reflectometry is a powerful experimental technique to probe nuclear and magnetic profiles in multilayered nanostructures. By measuring polarized neutron scattered intensity it is possible to determine depth dependence of magnetic moments (two components) throughout the multilayered nanostructure. In my report I present results of our study of magnetic rare-earth multilayers.

Superlattices Fe/Gd are popular model system displaying a rich magnetic phase diagram depending on temperature and magnetic field. The important feature of this artificial system is strong antiferromagnetic coupling at interface Fe-Gd, in order to initiate spin-flop transition one needs to apply magnet field ca 100 T. By measuring neutron spin-flip scattering we found that it is possible to suppress the field of spin-flop transition by 2-3 orders of magnitude by introducing Pd spacer layer between Fe and Gd. It was shown that spin-flop transition appears in this system without any magnetic anisotropy inside magnetic layers.

Heavy rare-earth metals (Dy, Ho, Tb) are magnetic materials where exist complex magnetic states like helicoidal magnetic ordering. When present in nanostructures (thin films and multilayers), parameters of magnetic helices are highly dependent on proximity effects from neighboring layers, dimentional effects, order-disorder effects at interfaces, epitaxial strains, temperature, magnetic field, etc. The helicoidal magnetic order may be detected with neutron diffraction by measuring magnetic satellites arising near fundamental Bragg peaks like (0002), (0004), etc. The position of these satellites provides information on helix period, intensity – information on magnetic moment. Currently there is no way to determine helix parameters in rare-earth multilayers except neutron scattering. However, wide angle neutron diffraction cannot be applied to rare-earth nanostructures because of lack of scattering material. We have shown that magnetic satellites due to helicoidal ordering should appear also around (000) reflection, i.e. near direct neutron beam. These means that magnetic satellite (000)+ can be detected in neutron reflectometry where due to small angle of incidence neutrons pass through significant amount of scattering material. These techniques has been successfully applied to determine magnetic helices in thin Dy & Ho films, Dy/Ho superlattices, and just very recently in ultrathin Tb films.

Support by RSF (Project No. 24-12-20024) is acknowledged.

ORAL SESSION

SPINTRONICS

Friday, 21 August, 15:00 - 16:30

EMULATING HODGKIN-HUXLEY NEURON-LIKE SPIKING BEHAVIOR VIA NONLINEAR GMI EFFECT IN INSULATOR-SEPARATED MAGNETIC MULTILAYERS

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Due to the rich nonlinear magnetic dynamics driven by magnetic field or electrical current, spintronic devices (spin-torque (ST) diodes and nanooscillators, magnetic-tunnel-junction (MTJ)-based stochastic p-bits, domain-wall (DW) memristors, etc.) are capable of simulating a wide range of functional behaviors of biological neurons and synapses in response to external stimuli. This opens the way to the development of a new generation of bio-plausible neuromorphic spintronic computing systems, enabling high-speed information processing and the execution of complex cognitive tasks. Recently, various types of MTJ-based spiking neuron models with different degrees of bio-fidelity have been proposed: non-step ST neuron with simple (ReLU-like and sigmoid-like) activation functions [1], leaky integrate-and-fire (LIF) [2] and FitzHugh-Nagumo (FHN) [3] DW-MTJ neurons, Hodgkin-Huxley (HH) MTJ neuron [4].

A notable limitation of such neurons is that their spiking functionality typically relies on thermal-activation-driven stochastic switching of MTJ to reset the device to its initial state, which inevitably introduces random errors. To address this issue, the giant magnetoimpedance (GMI) effect can be utilized to mimic the neuron features in a deterministic way without requiring the thermal assistance. The GMI method provides pronounced impedance modulation in insulator (I)-separated multilayered structures with an amorphous ferromagnetic (FM) shell, excited by an AC current passing through a nonmagnetic metal (NM) conductor in a DC magnetic field. The GMI ratio exceeds 700%, surpassing the record 631 % magnetoresistance recently reported for CoFe/MgO/CoFe MTJs [5]. Compared to MTJs, it avoids the stochastic switching, offers a simpler fabrication layout and a lower operating frequency (around tens of MHz).

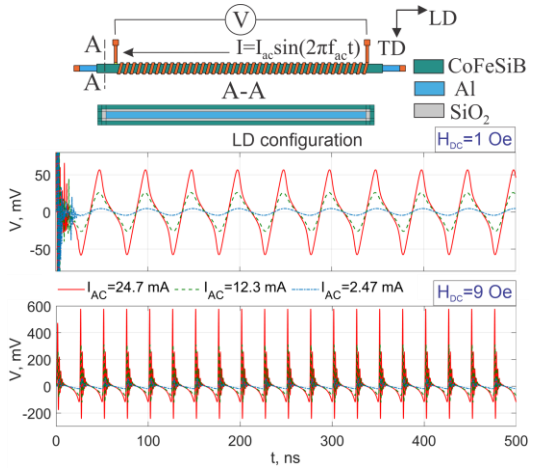

Fig. 1. Different spike shapes of the proposed GMI-based HH neuron.

A novel Hodgkin-Huxley (HH) neuron model was proposed, operating via GMI effect in a FM-I-NM-I-FM structure in a weak magnetic field oriented in longitudinal/transverse direction (LD/TD) relative to the anisotropy axis. Utilizing micromagnetic simulation, we shown that tailoring the frequency (f_{AC}) and amplitude (I_{AC}) of the AC current and DC magnetic field (H_{DC}) enables output signal waveforms that closely approach emulating spiking behavior with a high level of bio-plausibility (Fig. 1). These results facilitate designing a new type of GMI-based neuron. The work was supported by State Assignment No FSMR-2024-0004.

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SPIN-HALL TEMPERATURE DEPENDENCE IN NiFe/$MnBi_2Te_4$ HETEROSTRUCTURE

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This work investigates temperature-dependent spin-charge conversion in NiFe/$MnBi_2Te_4$ heterostructures using broadband ferromagnetic resonance and inverse spin Hall effect measurements from 20 K to 290 K. The effective Gilbert damping and ISHE voltage are extracted simultaneously and modeled via the Landau-Lifshitz-Gilbert equation. Below approximately 120–130 K, the damping and voltage show strong correlation, indicating that spin pumping dominates the measured signal. In this low-temperature regime, the extracted spin Hall angle θ_{ISHE} remains nearly constant, ranging between 0.12 and 0.3. Above 130 K, however, the voltage decreases while the damping increases, signaling a decoupling of the two quantities. This decoupling is attributed to parasitic spin rectification effects and a temperature drift in the intrinsic damping of the NiFe layer, as previously discussed in similar FM/TI heterostructures [1]. Consequently, reliable extraction of the intrinsic spin Hall angle is not feasible above this thermal boundary. These results establish $MnBi_2Te_4$ as an efficient spin-to-charge converter for cryogenic spintronic applications. The findings also define a practical temperature limit beyond which additional voltage contributions must be explicitly considered in such heterostructures.

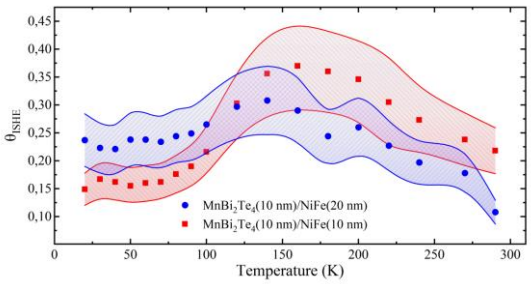

Fig. 1. Temperature dependence of the inverse spin Hall angle θ_{ISHE} for $MnBi_2Te_4$(10 nm)/NiFe(d) heterostructures with d = 20 nm (blue circles) and 10 nm (red squares).

The authors acknowledge financial support from the Russian Science Foundation grant № 22-12-00367-P.

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ENHANCEMENT OF SPIN CURRENT IN EXCHANGE-BIASED CO/FEMN/PT STRUCTURES

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In this work, we propose methods for estimating the inverse spin Hall effect induced by microwave spin pumping (SP) as a spin current generator. We investigated the spin pumping in Co/FeMn heterostructures. The spin pumping was studied for Pt(4)/Co(10)/FeMn(x)/Pt(1.5) samples, where x is 0, 3, 5, 10, 15, and 30 nm. We investigated spin pumping in Co/FeMn/Pt heterostructures with different antiferromagnetic layer thicknesses by measuring the electric current generated in the Pt layer due to the inverse spin Hall effect (ISHE) measurements. To separate this effect from other physical processes that generate the electrical voltage, we analyzed the angular dependence of the total electrical signal.

Figure 1 shows the dependence of the maximum electric current due to ISHE on the antiferromagnetic spacer thickness in the range from 0 to 30 nm. It can be seen that with increasing spacer thickness, the electric current reaches a maximum at a thickness of 5 nm and then tends to zero.

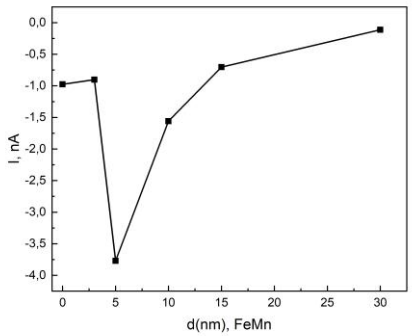

Fig. 1Dependence of the I_{SP} on the thickness of the antiferromag netic layer Co(10)/FeMn(y), where y is 0, 3, 5, 10, 15 nm 30 nm.

Support by Russian Science Foundation (Project No. 23–79-00016) (mathematical model was built as part of this project) and Russian Science Foundation (Project No. 25–79-00052) (spin current measurements were carried out as part of the project) is acknowledged.

MAGNETIC AFTEREFFECTS IN EXCHANGE-BIASED MAGNETORESISTIVE SENSORS

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Stability of signal with time is important characteristic of a measuring device. Anisotropic magnetoresistance (AMR) and planar Hall effect (PHE) sensors are not exclusion from this rule, and a lot of engineering efforts were spent in the last few decades to optimize layer stacks, geometry, layout in an integrated circuit and electronics to reduce signal drifts [1]. Thermal drift is considered to be a major source of undesired variations of signal and its instability [2]. Fluctuations of ambient temperature as well as electrical resistive heating of the device when electric current passes through it, are considered as the dominant sources of signal drift. However, there could be additional drift associated to magnetic aftereffects in the active ferromagnetic layers of the sensors. While the aftereffect magnetization dynamics is relatively well studied for parallel or antiparallel alignment of magnetic field with respect to the exchange bias field [3,4], the contributions of magnetization dynamics when the applied field is perpendicular to the exchange bias are usually considered to be negligible as magnetization rotates coherently.

In this work, we will show that in the AMR sensors based on exchange-biased films, this is not the case and the magnetic aftereffect is the main source of signal drifts. For the NiFe/Cu/IrMn system, the magnetic aftereffect drift exceeds the thermal drifts associated to +-50 °C temperature variations by three orders of magnitude. In addition, a connection of the sensors in a Wheatstone bridge, compensating the thermal drift, does not compensate the drifts associated to the magnetic aftereffects. Magnetization dynamics of the NiFe/Ru/IrMn weakly pinned layers is characterized by electrical resistance measurements in magnetic field at RT and by magnetic measurements within 2 K – 300 K temperature range. In all the experiments, the sample was exposed in magnetic field, applied in-plane, perpendicularly to the exchange bias direction in the sample. Then magnetic field was switched off and recording of the time dependence of resistance or magnetization was performed in zero field. The amplitude of magnetic relaxation ΔM depends on both the magnetic field applied prior to recording the aftereffect and the duration of this exposure. It saturates with the increase of exposure field to the values, higher than the saturation field. A peculiarity of the aftereffect in the in-plane “perpendicular” geometry ($H \perp H_{EX}$) is the growth of ΔM with an increase of the exposure time t_{EXP}. This ´accumulative´ behaviour of the aftereffect, in which the ΔM vs t_{EXP} straightens in M vs ln (t / t_0) coordinates, indicating the magnetization stabilization behaviour in accordance with Neel-Brown model.

Work was supported by the Ministry of Science and Higher Education of the Russian Federation (Government Assignment No. 124013100858-3).

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FORMATION OF THE SKYRMION PHASE IN A MAGNETIC FILM IN THE PRESENCE OF POINT NONMAGNETIC DEFECTS

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Skyrmions are topologically nontrivial stable magnetic structures. Owing to their small dimensions and stability at finite temperatures, skyrmions are considered promising memory elements [1]. One of the challenges for practical implementation is the controlled localization of skyrmions at predetermined positions [2]. Crystal lattice defects, which create local potential wells, can serve as pinning centers for the skyrmion phase [3].

In our studies, we considered bilayer ferromagnetic and magnetoelectric systems with a single hole-type defect created on the surface ferromagnetic or ferroelectric layer, respectively [4, 5]. In certain ranges of interactions, these systems demonstrate the effect of localization of the skyrmion phase in the region directly beneath the defect, which is one of the ways of nucleation of skyrmions in strictly determined locations of the material. The interest of the current study is reduced to determining the influence of non-magnetic point defects randomly introduced into the sites of the triangular lattice, as well as their concentration, on the formation and stability of the skyrmion phase. The concentration of non-magnetic impurities was defined as the percentage ratio of non-magnetic sites to magnetic ones. The studied system is a magnetic film described by the Heisenberg model, which includes ferromagnetic exchange interaction, the Dzyaloshinskii-Moriya interfacial interaction (DMI) and an external magnetic field:

$$H = -\frac{1}{2}\sum_{i,j} J_{i,j}^{m} \cdot \vec{S}_i \cdot \vec{S}_j \; - \frac{1}{2}\sum_{i,j} \vec{D}_{i,j}[\vec{S}_i \times \vec{S}_j] - \vec{h}\sum_i \vec{S}_i \qquad (1)$$

The ground state of the system was determined using the simulated annealing method. The primary parameter under study was the topological charge of the configuration Q_t, which was calculated using the Berg–Lüscher method [6] according to the following formula:

$$Q_t = \frac{1}{2\pi}\sum_{\langle ijk \rangle} arctan\left(\frac{\vec{S}_i \cdot (\vec{S}_j \times \vec{S}_k)}{1 + \vec{S}_i\vec{S}_j + \vec{S}_i\vec{S}_k + \vec{S}_j\vec{S}_k}\right) \qquad (2)$$

To study temperature stability and to estimate the average value Q_t of the configurations, the Metropolis algorithm was employed.

This work was carried out within the framework of the state assignment, agreement No. 075-03-2024-123/1 dated 02/15/2024.

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INVESTIGATION OF DZYALOSHINSKII–MORIYA INTERACTION DMI IN THIN FILMS WITH PERPENDICULAR MAGNETIC ANISOTROPY WITH DIFFERENT APPROACHES

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Dzyaloshinskii–Moriya interaction (DMI) is an important effect in thin magnetic film that stabilizes chirality of domain walls and facilitates creation of chiral spin textures.

There are different approaches that are used to estimate DMI strength [1]. But there is still a problem of different approaches yielding different results, although great work on the subject was already done.

In the current work, DMI strength in thin film magnetron sputtered sample with a composition Si/SiO2/Pt(8 nm)/Co(0.6 nm)/CoO_x/Gd(0.5 nm)/Pt(3 nm) is investigated using three following methods: current driven domain wall motion, field driven domain wall motion, loop shift method.

Current driven domain wall motion. Domain wall inverses the direction of propagation induced by spin-orbit torque (SOT) effect when the in-plane magnetic field along the applied current is larger than 400 Oe. That field is an assessed value of H_{DMI}.

Loop shift method. Field shift of out-of-plane hysteresis loops is measured in respect to the current applied through the Hall-structure and in-plane magnetic field. Resulting dependence of SOT efficiency on H_x is nonlinear. Using correction, described in [2] we acquire H_{DMI} of 1850 Oe.

Field driven domain wall motion in creep regime does not provide information for determination of H_{DMI}. Velocity curves are asymmetrical and do not show characteristic minima in the available field range of H_x.

The findings indicate that discrepancy between considered methods exist. We speculate that values of H_{DMI}, obtained by methods involving application of current, diverge due to different current induced heating of the system. Measurements of field driven domain wall dynamics are thought to be limited due to a chiral damping effect and multiple nucleation of domains in the investigated specific system [3].

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AUTHOR INDEX

A

Abakumov M.A. 301
Abdrakhmanov D.I. 381
Abdulkadirova N.Z. 170
Abramovsky I.E. 82, 251
Acuna A. 335, 365
Afanasyev D.S. 216
Agafonov S.S. 115
Agapov A.A. 114
Akhmedzhanov F.R. 267
Akhtamov J.Sh. 88, 107, 143, 349
Aksenov S.V. 161
Alaei M. 132, 133, 198
Alekseeva O.A. 94
Alex S.G. 168
Alexandrov I.S. 379
Ali H. 150
Aliev A.M. 93, 170
Alisultanov Z.Z. 170
Almeida Alves C.F. 378
Amirov A.A. 207, 211, 217, 237, 347, 357, 362
Amirov R.Z. 238, 240
Amonov B.U. 83
Andreev A.V. 206
Andreev S.V. 103, 169, 221
Andryushchenko T.A. 134, 219
Andryushkov S.A. 301
Anikin A.A. 302, 303
Anisimov V.I. 186
Antonov V.A. 65
Aplesnin S.S. 73, 98, 197
Arbuzov D.A. 374
Arkhipova E.A. 289
Arnalds U.B. 119
Artamonov I.V. 130
Artemov E.A. 228
Artemov V.V. 229
Arzikulov E.U. 266
Astaf'eva S.A. 316
Ataeva G.Ya. 131
Avdeenko D.V. 91, 249
Avdeev P.Yu. 274, 276, 278, 279
Averin N.V. 71
Averkiev N.S. 53, 54

B

Babaev A.B. 129, 131
Babaev. M.A. 129
Badelin A.G. 202, 222
Bagrets D. 342
Bakanov K.K. 41
Bakhmetiev M.V. 293, 378, 380
Bakurskiy S.V. 185
Balaev D.A. 234
Balaeva V.V. 70
Balashko I.A. 365
Balasoiu M.A. 316
Baranov N.V. 80
Bartashevich A.M. 63
Baryshev A.V. 33
Batulin R.G. 115, 336
Bazrov M.A. 275, 311, 379
Belotelov V.I. 178, 278, 368
Belozerov A.S. 186
BelyaevaA.O. 104
Berdiyev R.D. 77, 89, 318
Berdonosov P.S. 321
Bessas D. 174
Bezvikonnyi N.V. 137
Bibikov A.V. 57
Birch M.T. 61
Blanco J.M. 84
Blinov Z.N. 248
Bogach A. 307
Bogdanova T.V. 379
Bolotina E.V. 259, 358
Borodatskii I.S. 111, 112
Bossis G. 43
Botin D.G. 114
Bozhko A.D. 228
Brulev A.I. 348
Buchelnikov V.D. 47, 49, 106, 141, 142, 352, 354
Buldakova A.V. 180
Burdilov A.A. 369
Burdin D.A. 358
Burmistrov I.S. 161
Buryakov A.M. 137, 152, 172, 261, 274, 276, 278, 279
Buznikov N.A. 328, 329
Bychkov I.V. 164, 176, 190

Bychkova E.A. 114, 138, 204
Bykov A.I. 114, 138, 346

C

Cai Y. 60
Campo J. 60
Channagowdra G. 339
Chashin D.V. 358
Chen C.T. 339
Cheong S.W. 339
Cheremnykh N.A. 98, 197
Chernousov N.N. 121, 123
Chernov A.I. 293, 378
Chernov N.O. 299
Chernyshev V.E. 210
Chirikov D.N. 45
Cholopov S.A. 244
Chumakov A.I. 174
Chumakov A.P. 113
Chumakov R.G. 79, 194, 364
Comini D. 297
Corte-Leon P. 84, 167

D

Dasgupta I. 19
Davydenko A.V. 121, 123, 382
Davydov A.B. 223
Davydov V.Yu. 289
Demidov I.A. 265
Demidov V.V. 326, 379
Demidova V.A. 360
Demin G.D. 377
Demishev S.V. 309
Devyaterikov D.I. 233, 280, 375
Dianov M.Yu. 208
Dianov M.Yu. 260
Diep The Hung 203
Diviš M. 168
Dobroserdova A.B. 42, 110
Dolgova T.V. 31, 264, 265
Dovzhenko G.D. 369
Draganyuk O.N. 95
Drozdov A.S. 299
Du K. 339
Dubovitskii M.A. 321
Dubrovin R.M. 257, 289, 348
Dubrovskiy A.A. 234
Dudarev A.V. 140
Dunin-Borkowski R. 150
Durnev M.V. 154
Dvortsova P.A. 290
Dzhamaludinov M.R. 136
Dzuraev D.R. 92, 263

E

Edelman I.S. 125
Egorov N.I. 346
Ekomasov E.G. 176, 337
Elfimova E.A. 42, 304, 317
Eliseev A.A. 113
Eliseyev I.A. 289, 348
Elmekawy A.H.A. 63, 316
Emel'yanova S.M. 105
Erager K.R. 106
Eremeev S.V. 338
Eremin E.V. 86, 87, 96, 97, 102, 104
Eremina R.M 115
Eremina R.M. 202, 222, 309, 336
Es'kova I.V. 319
Esanov Z.U. 101
Eshbekov A. 101
Eshmamatov S.K. 266

F

Fang X. 339
Faraxutdinov A. 266
Farle M. 15, 150
Fazlizhanov I.I. 309, 336
Fazlizhanova D.I. 115
Fedianin A.E. 289
Fedorov A.S. 326, 379
Fedorova A.A. 379
Fedorova N.A. 134, 219
Fedulov F.A. 39
Fedyanin A.A. 31, 156, 180, 264, 265
Feng Y. 311
Fetisov L.Y. 38, 39
Fetisov Y.K. 38, 39, 358
Filatov Ia.A. 290
Filippenko L.V. 163
Filippov A.V. 138, 204
Filippov M.A. 235
Filippova V.V. 236
Finko A.V. 212
Fominskii M.Y. 163
Fominykh B.M. 56, 144
Fradkin B.V. 185
Frolov A.Yu. 180, 264
Frolov N.Yu. 280
Fujimori A. 339

G

Gabrielyan D.A. 66, 67, 68, 69, 81
Gaivoronsky E.I. 308
Galanova S.V. 138
Gamzatov A.G. 195, 352
Gan'shina E.A. 158, 332
Gapochka A.M. 224
Gareev K.G. 201
Gareev T.T. 36
Gareeva Z.V. 37, 236
Garipov R.R. 190
Gauquelin N. 119
Gaviko V.S. 78, 207
Gavrichkov V.A. 189
Gavrilkin S.Yu. 25
Gavriluk S.I. 244, 246
Gazizulina A.S. 277
Gerasimov E.G. 23, 63, 79, 204, 217
Gerevenkov P.I. 290
Ghezlyaev G.E. 233
Ghojavand A. 132
Gimaev R.R. 280
Glazkov V.N. 321
Glushkov V.V. 228
Gokhfeld Yu.S. 25, 102, 104
Golov A.V. 227
Golovchanskiy I.A. 185
Golovnia O.A. 103, 169
Golubiatnikova A.A. 103, 169, 226
Golubov A.A. 185, 282
Gómez-Polo C. 295
Gonchar L.E. 26
Gonzalez A. 167
Gorbatova A.V. 172, 276, 278, 279
Gorbunov D.I. 206
Gorodov V.V. 41
Goto T. 20
Gotovko S.K. 322
Gouder T. 168
Govorina V.V. 206, 207
Grabar V.A. 53
Gracheva M.A. 174
Granovsky A.B. .90, 100, 158, 224, 250, 332
Grasselli Y. 43
Gridin D.M. 90
Grigoriev S.V. 63, 113
Grigoryeva N.A. 63, 113
Grokhotova E.V. 42
Gudim I.A. 86, 87, 97
Gudkova S.A. 194
Gunyaga A.A. 154
Gusev N.A. 279
Gusev N.S. 32, 274, 276, 278
Gusev S.A. 32, 71
Gushchina N.V. 229

H

Hafizov A.A. 68
Hai N.T. 378
Hamrayev N.S. 72, 77, 89
Hamrayeva N. 89
Han G. 175
Harin E.V. 100
Havela L. 168
Hayitov D.E. 92
Hedayat H. 297
Hegedűs G. 174
Hirschberger M. 61
Hoang T.T. 272
Hong J.I. 272
Horák L. 168
Horváth Z.E. 174
Hosokoshi Y. 60
Huang D.J. 339
Huang H.Y. 339
Huang J.C.A. 378
Huber F. 168

I

Ibragimov G.B. 238
Ibragimova E.M. 107, 224, 349
Ignatov A.A. 213, 214, 335
Ignatova K. 119
Iliev Kh.M. 366
Imamnazarov D. 88, 143
Inishev A.A. 79
Inou M. 31
Irkhin V.Yu. 48, 56, 144, 194
Isaev D.A. 111
Isaev I.M. 308
Isamov S.B. 366, 367
Isayeva A.A. 72
Islamov A.H. 63
Ivankov O. 316
Ivanov A.O. 315
Ivanov A.S. 117
Ivanov I.A. 169, 226
Ivanov P.A. 328, 331
Ivanov V.Yu. 144, 194
Ivanova E.V. 316
Ivanova O.S. 125
Izvekov G.P. 322

J

Jabbarov I. 269
Jangra Shivani 296

K

Kabanov D.K. 337
Kachurin K.I. 67, 68, 69, 81
Kadyrbardeev A.T. 195, 352
Kagramanian A.I. 350
Kalandiia M.R. 300
Kalashnikov D.S. 185
Kalashnikova A.M. 179, 280, 289, 290
Kalinin Yu.E.242, 243, 244, 245, 246, 247, 248, 253, 330, 333
Kalyabin D.V. 379
Kamantsev A.P. 47, 187, 190
Kamashev A.A. 374
Kaminskaya T.P. 223
Kamiya Y. 60
Kanareykin E.A. 350
Kantorovich S.S. 110
Kanurin D.A. 211, 237, 347
Karashtin E.A. 276, 279
Karpacheva A.A. 35, 359
Karpasyuk V.K. 202, 222
Karpenkov A.Yu. 231
Karpenkov D.Yu. 205, 231
Karpukhin D.A. 190
Kartashev A.V. 86
Kartsev A.I. 135, 137
Kashnikova M.E. 220
Katanin A.A. 186
Katenkov P.Yu. 114, 138, 204, 346
Kaul A.R. 68
Kazak N.G. 85
Kazak N.V. 25, 102, 104
Kazin P.E. 113
Khakimullina A.A. 235
Khamraeva Z. 75
Kharin A.S. 199
Kharitonskii P.V. 201
Kharkov A.M. 98, 197
Kharlamova A.M. 111, 215, 223
Khasanov Kh. 88, 143
Khizriev K.Sh. 65
Khokhlov N.E. 36
Kholopov S.A. 242, 246, 330
Khomitov Sh.A. 72
Khoroshiy I.N. 218
Khovaylo V. 75
Khovaylo V. 47
Khovaylo V. 307
Khrenov M.M. 163
Kichanov S.E. 316
Kichin G. 18
Kim C.G. 272
Kim Dong-Hyun 287
Kim K. 287
Kim S.K. 61
Kimel A.V. 16, 36
Kimura A. 51
Kinoshita Y. 24
Kirgizov S.E. 116
Kirillov D.E. 190
Kirillov V.L. 234
Kirilyuk A. 29
Kiryanov M.A. 31, 264, 265
Kiseleva T.Y. 192, 212
Kislyuk A.M. 259
Kitsay A.A. 201
Kizirgulov I.R. 124
Klenov N.V. 163, 185
Klimin S.A. 310
Klimov A.A. 261
Klokov A.Yu. 280
Knyazev Yu.V. 25, 234
Kojima K. 60
Koledov V.V. 47, 164, 187, 190
Kolesnikova V.G 255
Kolesnikova V.G. 213, 214, 309, 335, 365
Kolesov K.A. 164, 187, 190
Koliushenkov M.A. 362
Kolmychek I.A. 32
Kolodkin D.A. 78
Koloskova O. 168
Kolupaev E.D. 372, 374
Komarov I.V. 328
Komarova V.A. 80
Komlev A.S. 192, 205, 210, 212
Komleva D.I 205
Komleva E.V. 339
Kondratev O.A. 104
Korkh Yu.V. 194
Korshunov A.S. 114, 138, 204, 346
Koshelets V.P. 163
Kostishin V.G. 308
Kostrov S.A. 41
Kostylev S.I. 192, 212
Kotov L.N.82, 208, 227, 242, 243, 244, 245, 246, 247, 248, 251, 253, 260, 330, 333
Kotov O.L. 208, 260
Kovacs A. 150
Kovalev P.D. 248, 253

Kozabaranov R.V. 114, 138, 204, 346
Kozhevnikov S.V. 372
Kozhevnikova P.Y. 215, 223
Kozlov A.G. 121, 123, 275, 311
Kramarenko E.Yu. 41, 111
Kravtsov E.A. 233, 375
Krivulin D.O. 172
Krug von Nidda H.A. 202
Krutyansky L.M. 261
Krylasova O.S. 117
Krylov A.S. 86
Kubasov I.V. 259
Kudasov Yu.B. 114, 138, 204, 346
Kudinov D.A. 319
Kudryvtsev A.V. 135
Kuklin A.I. 63
Kulikova D.P. 33
Kupriyanov M.Yu. 185
Kurbaniyazov S.Kh. 269
Kurbanov J.O. 267
Kurbanova D.R. 136
Kurlyandskaya G.V. 215, 223
Kuvandikov O.K. 72, 88, 89, 107, 116, 143, 349
Kuvondikov Sh.J. 83
Kuzmin D.A. 164, 176, 190, 225
Kuzmin N.N. 310
Kuzmin V.I. 160
Kuznetcova M.A. 123
Kuznetsov K.G. 278
Kuznetsova M.A. 275, 311
Kuznetsova T.V. 79, 194, 364

L

Lagarkov A.N. 328, 329, 331
Lapteva M.S. 261, 278
Lasek M.P. 243, 245, 247
Lasukov A.I. 234
Lebedeva E.A. 316
Lebedeva E.D. 274, 276
Lengyel A. 174
Leonov I.V. 184
Levada E.V. 303
Levada K. 302
Li R.W. 166, 271
Likholetova M.V. 144
Lis.O.N. 316
Liu E. 291
Liu Y. 21
Lobanov A.D. 194
Logunov M.V. 326
Lonchakov A.T. 105
Lu H.C. 324
Lukoyanov A.V. 48
Lupitskaya Yu.A. 209
Lyapilin I.I. 55
Lyaschenko S.A. 134, 219
Lyashko S.D. 91
Lyubutin I.S. 94

M

Madjitov M.Kh. 366
Magomedov K. 255
Magomedov M.A. 136
Maiburov M.V. 82
Makarin R.A. 205, 224, 231
Makarov I.V. 114, 138, 204, 346
Makarova L.A. 111, 112, 300
Makarova M.V. 120, 233, 375
Maklakov S.A. 328
Maklakov S.S. 328, 329, 331
Maksimov N.S. 139
Maksimova E.M. 94
Maksimova I.K. 120
Malinkovich M.D. 259
Maltoni P. 173
Maltsev I.V. 190
Maltseva V.E. 169
Mantsevich V.N. 54
Mantuzov A.V. 228
Marchenkov V.V. 48, 56, 105, 144
Marchenkova E.B. 78, 105
Markelova M.N. 68
Markina M.M. 321
Martyanov O.N. 234
Mashirov A.V. 47, 187, 190
Mashkovich E.A. 155
Maslov D.A. 114, 138, 204, 346
Maslova S.A. 79, 194
Matasov A.V. 67, 68, 69, 81
Matveev A.A. 74
Matveev O.V. 70, 71
Matyukhov V.V. 233, 375
Matyunina M.V. 164, 187, 190, 354
Mavlonazarov I.O. 82
Mavlonov G.Kh. 366
Meng F. 311
Merkel D.G. 174
Mikhailov I.E. 133, 198
Mikhashenok N.V. 96
Mikhaylovskiy R.V. 30
Milenin S.A. 41
Milošević M.V. 132
Milyaev M.A. 120

Minchukova O.F. 73, 98, 197
Mironovich A.Yu. 308
Mirzoeva E.T. 135
Mishina E.D. 152, 276, 279
Mitina M.N. 245
Miyakawa M. 306
Mogilenec Yu.A. 94, 193
Mogilnikov P.S. 215
Mogunov Ia.A. 280
Molchanova A.D. 310
Monakhov M.P. 138
Morgunov R.B. 293, 378, 380
Morozov S.D. 308
Morozova M.A. 70, 71
Moshkina E.M. 86, 96, 115, 220, 336
Moskal I.E. 68
Motorzhina A.V. 303
Mou C.Y. 339
Murtazaev A.K. 129, 131, 136, 355
Murtazoev A.F. 321
Murzina T.V. 32
Musaev M.T. 111
Musatov V.I. 39
Mushnikov N.V. 23, 63, 79, 204, 217
Musikhin A.Y. 44
Mussaeva M.A. 101
Mustaghfiroh Q. 287
Myasnikov N.V. 35, 361

N

Nagy D.L. 174
Namsaraev Zh.Zh. 275, 311, 379
Nasarov V.N. 337
Nasirov A.A. 277
Naumkin P.I. 58
Naumov S.V. 144
Naumova L.I. 120
Nayak Ch. 244, 251
Nayak H.B. 272
Nazhestkin I.A. 163
Neilo A.A. 185
Ne'matov O.S. 268
Németh A. 174
Nerovnaya A.A. 180
Neznakhin D.S. 169, 206, 207
Niaz S. 353
Nikitin A.A. 301
Nikitin S.E. 218
Nikitinsky O.V. 98, 197
Nikitov S.A. .66, 67, 68, 69, 74, 81, 261, 379
Nikolaev A.V. 57, 58
Nikolaev E.G. 322
Nikolaev G.S. 250
Nikolaev S.N. 224, 250, 332
Nikolaev S.V. 140, 160
Nikolaev V.I. 201
Nizamov T.R. 217
Nizomova Sh.K. 263
Norov D.A. 372, 374
Nosov Yu.G. 201
Novikov I.A. 264
Novikov V.B. 32
Novokreshchenov D.V. 312
Novokshonov S.G. 55
Nugumanov A.G. 124
Nugumanov R.R. 239
Nurimov U.E. 318
Nuritdinov I. 101
Nurmatov K.J. 381

O

Ochilov U. 266
Oganov A.R. 132, 198
Ohishi K. 60
Okamoto J. 339
Olenich E. A. 41
Ono T. 60
Ordoqui-Huesa E. 295
Orshulevich M.A. 190, 225
Osipov A.V. 328
Ostanin G.S. 31
Ovchinnikov A.S. 202
Ovchinnikov S.G. 104, 134, 160, 219
Oveshnikov L.N. 223
Ovsyannikov G.A. 68

P

Pakhomov A.S. 128, 378
Panina L.V. 213, 214, 303, 335, 365
Papoyan E.S. 273
Parchinskiy P.B. 277
Pardo-Sainz M. 60
Park M. 175
Parkhomenko Y.N. 259
Pashenkin I.Yu. 172
Pashenko A.S. 121, 123, 382
Pashnina A. 335
Pastuhov V.I. 103
Patrakov E.I. 194
Pavlovskii M.S. 102
Pavlukhina O.O. 141, 190, 354
Paz E. 378
Peddis D. 147

Peng Li.....277
Perevalova A.N.....144
Pereverzeva A.P. 358
Perevozchikova Yu.A. 105
Perov N.S.99, 111, 158, 192, 205, 212, 224, 229, 230, 254, 300
Perova N.N. 158, 192, 212, 259
Petrov D.A.....331
Petrov Yu.V. 172
Philippov A.V.....114
Piao Hong-Guan 287
Pisarev R.V. 348
Platonov V.V. 114, 138, 204, 346
Platunov M.S. 369, 373
Pohle R. 61
Polismakova M.N. 199
Polulyakh S.N.....91, 249
Polushkin N.I. 172
Ponomareva E.A. 79, 364
Popov A.I. 37
Popov D.V.....115
Popov V.V. 91, 180, 249
Popova A.M. 125
Popova M.N.....310
Preobrazhensky V.L. 152, 261
Prikhodchenko A.V. 275, 311
Prilepsky D.Yu.....193
Prishchepa A.V.....301
Prisyazhnyuk A.V. 91
Proglyado V.V. 120
Protasov A.V. 169, 207, 226, 280
Prusakov A.D.....308
Pshenichnikov S.E. 302, 303
Pugach N.G.....188
Punda A.Yu. 224
Pyatakov A.P.....35, 217, 361

Q

Qaiumzadeh A. 151, 198
Qiao K. 195

R

Radnóczi Gy.Z. 174
Radushnov D.I. 304
Rahmani F. 287
Raiker Yu.L. 314
Rajabov R.M.....89
Rakhmatullaev T.R. 122
Ramachandran R.....162
Razhabov R.M. 72, 75
Rebrov Ya.V. 321
Repin P.B. 114, 138, 204
Rezaei N. 132, 198
Rhim S.H. 175
Rimsky G.S.....197
Rodionova V.V. 213, 214, 255, 309, 335, 365
Rodríguez J.P. 167
Rodríguez-Velamazán J.A. 60
Rogachev K.A. 122
Rogalev A. 150, 343
Rogovoy A.A. 50
Romanenko D.V.....71
Romanova O.B. 73, 98, 197
Romanyuk O.....168
Romashov D.V. 227
Rozanov K.N. 328, 329, 331
Rusakov V.S.....224
Rusanov. M.S.....317
Rutkauskas A.V. 316
Ruzmetov K.N.U. 272
Rylkov V.V. 250, 332
Rymski G.S.....73

S

Sadradze R.N. 374
Sadykov A.F.....220
Safin A.R.66, 67, 68, 69, 74, 81, 139, 261, 273
Safiullin D.A.....31
Safonov S.S. 379
Sajti Sz.....174
Salakhitdinov F.A. 266
Salakhitdinova M.K.....107, 224, 349
Salamatov Yu.A. 233, 375
Salnikova V.D. 214
Samardak A.S. 122, 149
Samardak A.Yu. 122
Samarin A.N. 228
Samigullina A.I. 340
Samoilenko K.D. 66, 67
Samsonov D.O.....211
Sandulyak A.A.....199
Sandulyak A.V. 199
Sandulyak D.A.....199
Sapovskii I.M.....122
Sapozhnikov M.V. ...152, 172, 274, 276, 279
Sarychev M.N.....144, 194
Savelev D.V. 39, 111, 358
Savin V.V. 213
Saydullaeva I. 126
Sboychakov A.O. 327
Schäfer R. 182
Seidov Z.Y. 202, 222

Seleznev K.A. 193
Selezneva N.V. 169
Seleznyova K.A. 94, 193
Semeno A.V. 228
Semenov S.V. 234
Semiannikova A.A. 105
Semisalova A. 150
Semuck E.Yu. 91
Seredina M. 307
Sergienko E.S. 201
Shaikhulov T.A. 379
Shalaginov A.N. 103, 169, 221, 226
Shalimova A.V. 254
Shalomov K.V. 229
Sharafullin I.F. 124, 176, 203, 239, 337, 340, 381
Sharipov M.Z. 92, 263
Sharkov A.I. 280
Shaykhutdinov K.A. 218
Sheftel E.N. 100
Sheglov V.I. 208, 260
Shelukhin L.A. 290
Shendrikova L.A. 99
Sherstyuk D.P. 230
Shestakov A.V. 202, 309
Shestopalov R.A. 275, 311
Shevchenko E.V. 144
Shevchenko V.A. 218
Shilov N. 255, 302
Shim Je-Ho 287
Shin H.J. 287
Shipkova E.D. 224, 230
Shiryaev A.O. 328, 329, 331
Shishkin A.G. 185
Shishkin D.A. 80, 194
Shneyder E.I. 140
Shodiyev Z.M. 77, 88, 143
Shubin A.A. 134
Shustin M.S. 161
Shustov V.A. 202, 222
Sidorenko A.S. 185
Silina S.K. 275, 311
Simdyanova M.A. 250, 332
Sitnikov A.V. 100, 242, 243, 244, 245, 246, 247, 248, 250, 253, 330, 332, 333
Sitnikov K.A. 87, 97
Sitnikov M.N. 73, 98, 197
Skibinsky K.M. 193
Skidanov V.A. 157
Skirdkov P.N. 18, 128, 378
Skorlupin G.A. 308
Skornyakov S.L. 186
Skorobogatov S.A. 218
Skorokhodov E.V. 172
Smekhova A. 371
Smirnov A.A. 308
Smirnov D.S. 54
Smirnova E.S. 94
Smolnikov A.G. 220
Smolyakov D.A. 86
Snegirev N.I. 94
Sobirov M.I. 122
Sobko A. 365
Sobolev K. 255
Sofronova S.N. 220
Sokolov A.E. 125
Sokolovskaia I.A. 142
Sokolovskiy V.V. 49, 106, 141, 142, 195, 312, 352, 354
Solonetskiy R.V. 258
Soloviev I.I. 185
Somov S.A. 117
Sopetik A.V. 229
Spichkin Y.I. 350
Spitz L. 61
Srajev S.N. 268
Stashkova L.A. 78
Stepanov G.V. 45
Stepanova E.A. 169
Stolbov O.V. 314
Stolbova O.S. 50
Stolyarov V.S. 185
Strelkov I.S. 114, 138, 204, 346
Streltsov S.V. 339
Strugatsky M.B. 94, 193
Su S.H. 378
Subbotin I.M. 315
Subkhankulov I. 72
Sukhachev A.L. 104, 125
Sulaymanov O.A. 318
Sundeev R.V. 254
Surdin O.M. 114, 138, 204, 346
Suslov D.A. 190
Svistov L.E. 322
Syrnikov P.P. 289
Sysoev M.A. 308
Szilágyi E. 174

T

Taaev T.A. 65
Tagiyev V.S. 240
Talantsev A.D. 380
Tanrıverdili K.V. 238
Tanriverdiyev V.A. 240

Tao L.L. 57, 58, 285
Taran L.S. 196
Tarasenko S.A. 154
Tarasov A.S. 134, 219
Tarasov I. 150
Tarasova A.S. 102, 104
Taskaev S.V. 49, 225
Tatarsky D.A. 374
Tedzhetov V.A. 100
Temirov A.A. 259
Terentev P.B. 204, 217
Tereshina I.S. 27
Tereshina-Chitrova E.A. 168
Thakur Atul 296
Thakur Preeti 296
Thomas K.J. 162
Tian H. 288
Timushev A.V. 247
Tishin A.M. 108, 237, 347
Titova V.R. 97
Tokura Y. 61
Tomilin F.N. 134, 219
Toshboyev T.U. 268
Tripathi V. 162
Trochina A.M. 239
Trofimchuk N. 126
Trukhinov D.K. 316
Tselebrovskiy A.N. 215
Tsyrulnikova L.A. 273
Turchenko V.A. 308
Turkin Y.V. 188
Turniyazov R.K. 269
Turpak A.A. 123, 382
Turutin A.V. 259
Tuymanov B. 101
Tyumenev R. 185

U

Udod L.V. 73, 98, 197
Ulyanov M.N. 209
Umetsu R.Y. 306, 307
Umrzakov F. 75
Umrzokov F.B. 83
Urzhumtsev O.I. 347
Usachev P.A. 181
Usov N.A. 90
Ustinov V.V. 120
Utarbekova M.V. 225
Utesov O.I. 61
Utkin A.A. 242, 330, 333

V

Vagizov F.G. 202
Vakhitov R.M. 235, 258, 360
Valkov A.V. 74
van Loosdrecht Paul H.M. 297
Varava T.V. 120
Varnakov S.N. 134, 219
Vashchenkova A.R. 192, 205
Vasiliev A.D. 25, 102, 104
Vasiliev A.N. 47, 114, 138, 321
Vedeneev A.S. 250
Veligzhanin A.A. 254
Velikanov D.A. 25
Versteeg R. 297
Vetoshko P.M. 91
Vinnik D.A. 194, 216, 224, 230, 345
Vlasov E. 119
Volegov A.S. 103, 169, 221, 226
Volkov D.A. 67, 68, 69, 81
Volkova O. 43
Volkova O.S. 323
Volochaev M.N. 125
von Gratovski S.V. 190

W

Wagner J. 297
Wang S. 288
Wang Y. 286, 311
Wiemeler J. 150
Wilhelm F. 150
Wintz S. 62
Won C. 339
Wu Anhua 348
Wu J.C. 378

X

Xiao J. 21
Xie Y. 166, 252, 271

Y

Yagupov S.V. 94, 193
Yakimov M.V. 247
Yang H. 271
Yang Hua Li 166
Yang S. 272
Yanson S.Yu. 201
Yaroshenko F.A. 209
Yatsyk I.V. 202, 222
Yavorsky M.A. 368
Yerin C.V. 319

Yin L. 310
Yin W. 306
Yoshino T. 306
You J.Q. 283
Yudanov N.A. 335, 365
Yuldasheva A.R. 203
Yumaguzin A.R. 360
Yurlov V.V. 18, 128, 378
Yusupov D.B. 367
Yusupov D.M. 93, 217

Z

Zagorskiy D.L. 229
Zagovorich A.D. 242, 333
Zagrebin M.A. 130, 141
Zakhidov U. 269
Zaky A. Zaky 374
Zamkova N.G. 95
Zavarin D.V. 248, 253
Zavertkin K.A. 300
Zavornitsyn R.S. 120
Zezyulina P.A. 100, 328, 331
Zhaboev E.I. 32
Zhaketov V.D. 372, 374
Zhaludkevich A.L. 73
Zhandun V.S. 25, 85, 95
Zhang H. 195
Zhao Y. 287
Zheleznyi M.V. 231
Zhezlyaev G. 375
Zhezlyaev G.E. 280
Zhilyaev P.A. 137
Zhivulin D.E. 230
Zhivulin V.E. 194, 230
Zhivulina N.A. 194
Zhou S. 294
Zhukov A. 84, 167
Zhukov D.A. 122
Zhukova V. 84, 167
Zhuravlev M.Ye. 57, 58
Zhurkin V.S. 228
Zikrillaev N.F. 366
Zou R. 271
Zubarev A.Yu. 44, 45
Zverev V.I. 280
Zverev V.S. 304, 317
Zvezdin A.K. 37, 128, 257
Zvezdin K.A. 18, 37, 128, 378