The 4th International Baltic Conference on Magnetism

IBCM 2021

Book of Abstracts

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Research and Education Center
"Smart Materials and Biomedical Applications"
Institute of Physics, Mathematics
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1) Nanobiomedicine

- Hyperthermia, drug delivery and theranostics;
- Tweezers and cell manipulation;
- Lab-on-a-chip + microfluidic;
- Biosensors;
- Tissue regeneration;
- Magnetic resonance imaging;
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- Nanoparticles, 2D systems, thin films, and patterned structures;
- Molecular magnets;
- Magnetization dynamics, spin-waves and magnonics.

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IEEE MAGNETICS LETTERS

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Plenary lectures

Molecular spin qudits: a promising ingredient for quantum computers

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The potential to solve problems with large impact on science, society and economy makes the realization of quantum computers one of the hottest topics in current research. The most advanced architectures currently are based on superconducting qubits or ion traps and can already be exploited for interesting proof-of-principle calculations [1,2]. A promising alternative in the race towards quantum devices is represented by molecular nanomagnets (MNMs). These magnetic molecules are characterized by a sizeable number of accessible low-energy states that can be coherently manipulated by microwave and radiofrequency pulses, thus opening the possibility use them as molecular qudits.

In my presentation, I review some recent results on molecular qudits/qubits. In particular, I show that MNMs can be exploited to define qubits with embedded quantum error correction in single molecules [3,4], thus circumventing the large overhead in the number of physical units required by standard quantum error correction codes. Moreover, I show that molecular qudits can improve the potential for quantum simulations. Then, I briefly report the characterization of promising molecular qudits using broadband NMR. At last, I discuss some recent results on the study of the two main sources of decoherence in MNMs, i.e., interactions with nuclear spins and phonons [5].

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Advances in coherent magnonics

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Magnonics addresses dynamic excitations of a magnetically ordered material. These excitations, referred to as spin waves and their quanta, magnons, are a powerful tool for information transport and manipulation on the micro and nanoscale. A flow of magnons — magnon current — represents a form of spin currents, which can propagate in a different kind of magnetically ordered material including insulators. One can distinguish between two principal kinds of magnon currents, coherent (or ballistic) and incoherent (or diffusive) ones. For coherent magnon currents, the wave nature of the magnons is apparent, i.e. the frequency, wavelength, and phase of the spin waves are well defined, and the magnon current flow is determined by the wave's dispersion relation and by interference effects. In contrast, for incoherent diffusive magnon currents, the driving mechanisms are magnon density gradients and temperature, and no well-defined frequency and phase exist. In the field of magnonics, wave-based computing devices are constructed utilizing both coherent and incoherent magnon currents. The field is developing rapidly due to its potential to implement innovative ways of data processing as a CMOS complementary technology.

In this talk, I will give an overview of the fundamentals and the current trends in coherent magnonics. So far, basic building blocks of coherent magnonics have already been realized. Examples are linear and nonlinear spin-wave waveguide structures and magnonic crystals, magnonic logic gates, as well as the magnon transistor. Nevertheless, an important topic is the realization of new functionalities and devices by using novel concepts borrowed from integrated optics and combining them with the specific advantages found in magnetic systems. Examples are directional couplers and quantum-classical analogy devices, such as a magnonic Stimulated Raman Adiabatic Passage (STIRAP) device.

Another important direction in coherent magnonics is the use of macroscopic quantum phenomena, such as magnon Bose-Einstein condensates (BEC) at room temperature, as a novel approach for information processing technologies. The miniaturization of magnon BEC-based magnonic devices constitutes an extraordinary challenge for their future applications. I will present recent progress in this field and discuss the realization of magnonic qubits formed from magnon-BECs, and the calculus using these qubits.

Multifunctional superparamagnetic nanoparticles for biomedical applications

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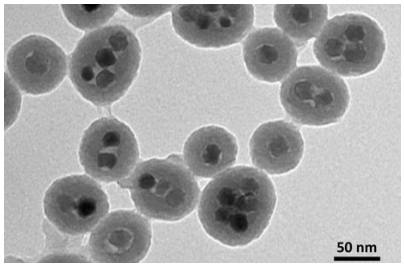
Multifunctional magnetic nanoparticles (MNPs), offer significant potential for biomedical applications, as they make it possible to manipulate, adjust, or study cellular events in diseases or healthy conditions, thus giving insights into fundamental biomechanisms or providing new theragnostic tools [1].

A large plethora of core@shell structures are used to endow MNPs with multifunctional abilities, based on superparamagnetic (SPM)-cores loaded with specific biological/therapeutical agents. From single core to multi-core structures can be used across many application domains, as magnetic heaters for magnetic hyperthermia (MH) applications [2] to kill cancer cells or stimulate controlled drug delivery, as contrast agents with superior performance in magnetic resonance imaging and positron emission tomography (MRI/PET), as transfection agents in cellular therapies, or as nanoprobes for biodetection kits [1].

This lecture will combine insights into multifunctional magnetic nanostructures and their MH/MRI response, along with the most recent research into hybrid nanoplatforms for theragnostics and tissue engineering [1-3].

a) 

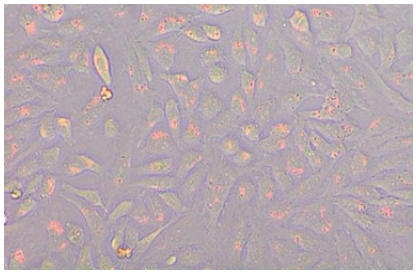
b) 

Figure1. a) TEM image of multi-core Fe_3O_4@SiO_2 NPs, b) Fluorescent confocal micrographs of HeLa cells transfected with rhodamine-loaded MNPs.

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Design advanced magnetic nanocomposites

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Magnetic Nanoparticles (MNPs) are unique complex objects whose physical properties differ greatly from their parent massive materials. In fact, the magnetic properties are particularly sensitive to the particle size, being determined by finite size effects on the core properties, related to the reduced number of spins cooperatively linked within the particle, and by surface effects, becoming more important as the particle size decreases. MNPs have generated much interest because of their possible applications in high density data storage, ferrofluid technology, catalysis, environmental technology, and biomedicine (e.g., drug delivery, contrast enhanced MRI)[1]. To synthetize Magnetic nanocomposites (MN) represent an additional tool to further tuning physical properties of MNPs, obtaining new multifunctional materials. MN consist in a magnetic core embedded in shell/matrix that may be composed of polymers[2], mesoporous structures (e.g., silica[3], zirconia[4], zeolites[5], metalorganic framework[6]) or even molecules[7]. Shell/matrix can have magnetic properties and in this case properties of MN rely even more strong on the interplay between those of the constituent components. When the individual components themselves, are complex systems belonging for examples to the family of correlated electron oxide with exotic physical properties, it becomes non-trivial and extremely fascinating to customize the properties of these bi-magnetic nanocomposites[8–10]. Based on this framework, this communication will focus on the design of MN highlighting that means to control the matter at the nanoscale, correlating magnetic properties, micro- and meso-structure and molecular coating. Some recent results on synthesis of magnetic nanocomposites and their application in energy (e.g., permanent magnets, thermoelectricity), biomedicine, catalysis and other technological field will be discussed.

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Magnetism in the light of x-rays

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The field of spintronics has become a flourishing synonym of dense, ultra-fast, persistent and especially low-power future information technologies with fantastic promises ranging from replacement of CMOS techniques to impacts in quantum computing. But, serious drawbacks are present not only from the technological site but even from fundamental aspects. The key issue for a further development is the visualization of magnetic nano structures with sufficient space and time resolutions on the nanoscale.

X-ray synchrotron methods based on the phenomenon of x-ray magnetic circular dichroism (XMCD), discovered nearly 40 years ago, are available to investigate magnetic characteristics of electronic, crystallographic and geometric structures of solids. Due to the enormous magnetic cross sections which can exceed up to 50 % very small moments and magnetization variation in the order of 10^{-3} Bohr magnetons can be addressed in an element-specific manner.

Time resolved soft scanning transmission x-ray microscopy combines 20 nm special with temporal resolution of 10 ps given by the time structure of the synchrotron light. This opens a new avenue to study magnetization dynamics, switching event and magnon propagation at the fundamental and technological relevant scales as demonstrated for various spintronic and magnonic systems.

Invited talks

Magnetic nanoparticles for cardiovascular diseases

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Venous thromboembolism (VTE) is a condition in which unwanted blood clots formed in leg veins travel through the bloodstream and lodge in the lungs, which may lead to death. Additionally, VTE is related to long-term complications such as post-thrombotic syndrome (PTS), chronic vein insufficiency as well as significant disabilities and life impairments. Current treatment of venous thromboembolism involves the systemic administration of either anticoagulants to prevent further thrombus growth, or thrombolytic enzymes to try to lyse the clot. Yet systemic circulation of both pharmacological agents often leads to major unwanted bleeding in patients.

Magnetic nanoparticles (MNPs) are currently utilised in an extensive range of biomedical applications. Thanks to their ability to generate targeted hyperthermic stimuli in tumours when exposed to alternating magnetic fields, MNPs have shown potential to improve the treatment of some of the most aggressive forms of cancer. However, this significant effort to conceive less invasive therapies to treat cancer contrast with the still scarce utilisation of this nanotechnology in cardiovascular diseases therapeutics. In this talk we will discuss how magnetic nanoparticles can be used to improve current treatments of VTE. By functionalising MNPs with anti-fibrin antibodies and tissue plasminogen activator (tPA), MNPs can target blood clots to deliver tPA locally and potentially reduce secondary effects associated with systemic circulation of the thrombolytic enzyme. Additionally, the MNPs can be magnetically stimulated to deliver a localised heating to the clot to increase tPa activity, as well as breakdown the cellular barriers on the thrombus surface to all fibrinolytic enzymes to permeate deeper into the clot. By combining future in vitro studies in a humanised vein model and in vivo studies to confirm the biocompatibility of MNPs, we aim to demonstrate the feasibility of using MNPs as a more effective and safer treatment for VTE.

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Magnetic colloids: from magnetofluorescent nanofluid to magnetic anisotropies of core/shell nanoparticles

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The purpose of this talk is to shed light on innovation aspects of magnetic colloids research. We focus on two issues, one regarding the production of novel advanced nanomaterials based on ferrofluids and one other that reports on the magnetic anisotropy fields of the dispersed core@shell nanoparticles.

In the specific case of magneto-fluorescent nanofluids, most of the currently available dispersions are achieved via the assembly of magnetic and fluorescent particles/molecules in a single nanostructured object. It usually requires some sort of encapsulating process that restricts several interesting properties that are sensitive to the particle/medium interface, limiting the potential of sensor applications. Our approach is based on the mixture in controlled conditions of aqueous magnetic colloids with aqueous dispersions of nitrogen rich carbon dots, a method which is practical, low-cost and reproducible [1]. The achieved colloidally stable aqueous hybrid nanofluid presents long-term colloidal stability at the macro and microscopic level, with and without the presence of an external magnetic field. It also preserves the magnetic and fluorescent properties of each one of the nanocomponents, unlocking the possibility of use in multiple forms of applications.

The magnetic anisotropy fields of ferrofluid nanoparticles arise from their magnetic core shell structure. Indeed magnetization studies point out a well-ordered ferrimagnetic core surrounded by a layer with spin glass-like arrangement. Quasi-static SQUID magnetization measurements and ferromagnetic resonance experiments allow one to discern three types of magnetic anisotropies affecting the dynamics of the magnetic moment of the well-ordered ferrimagnetic NP's core: the easy-axis (uniaxial) anisotropy, the unidirectional exchange-bias anisotropy and the rotatable anisotropy [2]. We will review some of our recent results on exchange bias properties in ferrite core@shell nanoparticles in order to enlighten the role of interface, anisotropy contrast and interparticle interactions on the magnetic behavior of magnetic colloids [2, 3].

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Aggregates and dipolar interactions in nanoparticle assemblies for magnetic hyperthermia

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Magnetic hyperthermia is one of the most promising biomedical applications of magnetic nanoparticles (NP) and is intended to be alternative to cancer therapies based on drug delivery and radiotherapy. It is based on the fact that magnetic NP dissipate heat when an oscillating magnetic field is applied to them in a quantity (specific absorption rate, SAR) that is closely related to the area of the hysteresis loop. The main problem in the field has become to find the suitable range of parameters that maximize SAR for a given material [1], SAR depends of course on the amplitude of the applied magnetic field and its frequency, but also on intrinsic parameters of the NP such as saturation magnetization, anisotropy, shape and size. Related studies will be put together in the first part of the talk [2,3]. Although the role of external parameters is somehow well contrasted, there is still ongoing controversy on the role that dipolar interactions (DI) and aggregation state of the assemblies play on SAR, which will be the focus of the second part of the talk. Monte Carlo simulations of hysteresis loops of interacting NP assemblies in the macrospin approximation will be presented [3]. First, we will show results of different regular spatial arrangements of NP, showing the influence of interparticle separation and particle size on SAR. Next, we will study the case of randomly placed NP with varying concentrations mimicking experimentally found situations [4] (inside and at the surface of liposomes/cells, clusters). It is found that formation of chain-like arrangements or assemblies with prolate shapes, lead to considerable increases in SAR due to DI.

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Magnetic Nanogels for Transport

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Magnetic nanogels (MNG) - soft colloids made of polymer matrix with embedded in it magnetic nanoparticles (MNPs) - are frequently regarded as promising magneto-controllable drug carriers [1-4]. In order to develop or verify this potential, however, one needs to clearly understand the relationship between nanogel magnetic properties and its behaviour in a hydrodynamic flow. Considering the size of the MNG and typical time and velocity scales involved in their nanofluidics, experimental characterisation of the system is challenging. In this contribution I will discuss the results of molecular dynamics (MD) simulations combined with the Lattice-Boltzmann (LB) scheme with the main aim of describing the impact of the shear rate on the shape, magnetic structure and motion of an MNG.

As the first step, magnetic and structural properties in equilibrium will be discussed shortly and the reasons for particular magnetic response of MNGs will be revealed. Next, the motion of a MNG centre of mass will be followed and its steady position in the shear flow will be explained. We will explain why along with translation the monomers of MNGs are involved in two more types of motion: they rotate around the centre of mass and oscillate with respect to the latter.

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Advanced approaches for the synthesis and characterization of highly ordered $L1_0$ alloys

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Magnetic binary alloys with a CuAu-I type chemically ordered face centered tetragonal (fct) structure, mainly known as $L1_0$ structure, have attracted a special attention in the last decades due to their peculiar physical properties and excellent chemical stability, which arise from the particular arrangement of the atoms that alternate in composition along the c-axis direction of the fct unit cell [1]. Among the $L1_0$ alloys, ferromagnetic (e.g. FePt, FePd, CoPt, CoPd, NiPt, MnAl, FeNi) and antiferromagnetic (e.g. MnPt, MnPd, MnNi, CrPt) nanostructured materials are of particular interest in view of their potential applications in many technological fields.

Many studies have been carried out to find the optimum conditions for the preparation of $L1_0$-ordered alloys that are commonly obtained by post-deposition high-temperature treatments for a few hours in order to favour the conversion from the chemically disordered fcc (A1) phase into the chemically ordered fct ($L1_0$) phase.

However, in the last decade advanced chemical synthesis strategies have been proposed, allowing highly-ordered $L1_0$ magnetic alloys to be synthesized at a much milder conditions than usual; this is the case of the Pre-ordered Precursor Reduction (PPR) method [2] where the desired MePt phase (Me=Fe, Co, Ni) is obtained by a thermal decomposition in a reductive atmosphere of a pre-ordered $Me(H_2O)_6PtCl_6$ crystalline precursor salts consisting of alternating planes of pure Me and Pt atoms, which mimic the atomic structure in the alloy.

Among the characterization techniques applied to investigate the structural properties at the local-scale, XAS is an effective tool to probe the chemical environment around an absorber element, and to get information on the average structural features of the materials, thus being complementary to conventional X-ray diffraction techniques. Due to its peculiar characteristics, i.e. selectivity and high sensitivity, Extended X-ray Absorption Fine Structure (EXAFS) analysis represents the main technique to investigate the local properties in many systems whose behaviour is strongly affected by the atomic arrangement, as in the case of the L10 chemically ordered alloys, where the degree of chemical order influences significantly the final magnetic properties.

In this paper, recent studies based on a combination of ex-situ and in-situ X-ray Absorption Spectroscopy (XAS) experiments suitably set-up to describe the local environment around the metals during the synthesis processes of different $L1_0$ alloys are presented. In particular, by comparing PPR-synthetized $L1_0$ alloys by means of EXAFS, X-ray diffraction results, TGA-DTA analysis and magnetic measurements, we could firstly formulate a general and comprehensive explanation of the process at the basis of the thermal treatment that brings to the reduced alloys with such a high ordering degree ($S>0.9$). This allows a greater control on the synthesis method, which can be exploited, by properly choosing the starting salt, to synthesize other binary alloys, such as $L1_0$-FeNi, $L1_0$-MnAl and $L1_0$-MnPt that are of great interest for many technological applications but extremely challenging to be obtained.

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Plasmon induced magneto-optical enhancement in hybrid nanostructures: bright and dark plasmons

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The combination of magnetic and plasmonic materials and their nanostructurization have revealed a prominent pathway to develop novel photonic materials for the active control of the light polarization using a magnetic field. [1,2] Here is shown two relevant advances in the field of magnetoplasmonics.

Until now, physical growth methods have been the only exploitable approach to prepare magneto-optically active magnetoplasmonic nanostructures. We have demonstrated the possibility to use chemical synthesis to prepare hybrid magneto-plasmonic core/shell nanocrystals with optical properties comparable to the best results reported for nanostructure growth by physical methods (Fig 1a). [3]

Secondly, we disclose a currently unexplored approach that exploits hybridization with multipolar dark modes in specially designed 2D magnetoplasmonic nanocavities to achieve a large enhancement of the magneto-optically induced modulation of light polarization (Fig 1b). A critical limitation of the magnetoplasmonic designs explored thus far and that is overcome by the approach proposed here. [4]

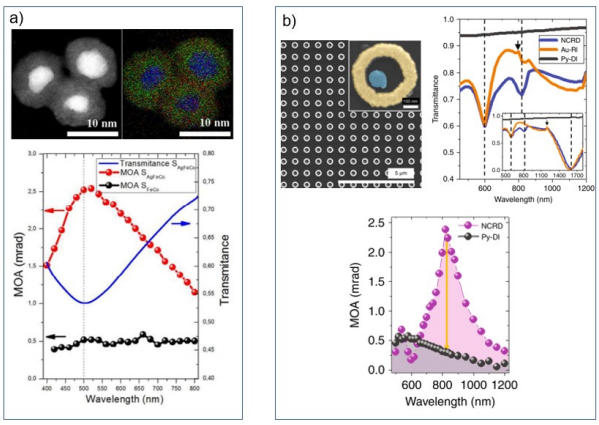

Figure 1. (a) High resolution electron microscopy image of core-Ag/shell-FeCo nanoparticles and the respectively overlay energy dispersive x-ray spectroscopy image for the Fe (red), Co (green) and Ag (blue) elements. Magneto-optical activity (MOA) spectra for core-Ag/shell-FeCo (red) and pure FeCo (black) nanoparticles. Blue curve shows the transmission spectra core/shell nanoparticles. (b) Electron microscopy image of 2D hybrid structure composed by gold plasmonic rings (yellow) and magnetic Py disks (blue). Transmission spectra of the hybrid structure (blue) and single gold rings (orange) and Py disks (black). MOA of the hybrid structure (pink) and pure magnetic Py disks (black).

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"Smart" layered composites based on magnetoactive elastomers and piezopolymer with multiferroic properties

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"Smart" devices and systems have attracted huge interest and became one of the topics on the cutting-edge of contemporary science. For the detection and transformation of electromagnetic and mechanical oscillations, devices based on multiferroic materials, which provide the device autonomy, are widely used. Multiferroics – the class of materials which possesses two of more "ferroic" properties simultaneously. Application of multiferroics covers different areas, but there are still investigations of new types of multiferroic for applications in high-end equipment. Transformation of magnetic excitation into electric signal is possible in such materials due to magnetoelectric effect (MEE). The largest value of the MEE effect was observed in multiferroic composites based on low-dimensional magnetostrictive and piezoelectric materials.

Layered structure with magnetic elastomer and piezopolymer film was investigated in the work. The magnetic elastomers, or magnetoactive elastomers (MAE) could be the alternative of thin magnetostrictive layer. Magnetoactive elastomers is represented as polymeric matrix filled with ferro- (ferri-) magnetic micro- (nano-) particles. Bending deformations in MAE can be observed with the thickness range from several tenths of millimeters to several millimeters. Layered samples based on PVDF thin film with conductive plates and MAE layer with iron microparticles with thicknesses 0.3 mm and 3 mm were treated by gradient DC, pulse and AC magnetic field. Switching DC magnetic field (up to 500 Oe) causes the bending process of the structure with the damped oscillations [1]. Maximum signal is reached at the first peak of the oscillation and depend on the MAE thickness and concentration of iron particles. The value of induced voltage also depends on the duration of pulse magnetic field and was up to 650 mV. AC magnetic field applied to the sample at the frequency range from 10 Hz to 200 Hz and at the amplitude range up to 140 Oe.

Coefficient of MEE was calculated as induced electric field divided by amplitude of applied magnetic field. Coefficient of MEE is in three times larger for the sample with thick MAE layer (93 mV/cm*Oe) then for the sample with thin MAE layer (31 mV/cm*Oe). Bias magnetic field 80 mT, which was applied perpendicular to the sample plane, lead to increase of MEE in the sample with thin MAE layer up to 220 mV/cm*Oe.

The model based on dipole-dipole interactions between magnetic particles, their interaction with gradient external magnetic field and their interaction with elastic matrix was developed. Numerical simulation was carried out in the frame of the molecular dynamic method. To simulate the dynamic oscillations of the layered structure the viscoelastic couple between particles was used. The results of numerical simulation are in accordance with experimental data.

Tunable energy utilization by novel composites allows to develop the different types of sensors and energy harvesting devices.

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Engineering iron oxide nanocatalysts for water remediation

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The need to eliminate organic pollutants from water that can be degraded into carcinogenic and toxic compounds affecting human health, is a great concern nowadays. Magnetic nanoparticles have been proposed as good candidates to be used as catalyst or adsorbents in these water remediation processes. These nanoparticles offer the advantages of high surface area, easy separation by means of a magnet and high heating capabilities to assist the degradation processes under alternating magnetic fields [1].

Here we present the design of superparamagnetic iron oxide nanocatalysts to be used in water remediation. We have evaluated these nanoparticles as heterogeneous Fenton catalysts for the degradation of Azo dye methyl orange used as model and then, in the treatment of real and highly contaminated industrial wastewaters [2]. In this study we have designed a self-heating catalyst with a finely tuned structure of small cores aggregates to develop multicore particles with high magnetic moment and high colloidal stability. This nanocatalyst, that can be separated by magnetic harvesting, is able to increase reaction temperatures (up to 90 °C at 1 mg/mL suspension in 5 min) under the action of alternating magnetic fields. These high removal and degradation ability of the magnetic nanocatalyst was sustained with the formation of strong reactive oxygen species by a Fenton-like mechanism. These findings represent an important advance for the industrial implementation of a scalable, non-toxic, self-heating catalysts that can certainly enhance advanced oxidation processes for wastewater treatment in a more sustainable and efficient way.

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Magnetooptics of Opal-Cobalt based photonic heterostructure

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Photonic and plasmonic crystals of various types are perspective for a plethora of applications as active elements of optoelectronic devices. The most pronounced features of such structures are the formation of the so called photonic band gaps (PBG) for the case of photonic crystals (PhC), or plasmonic resonances and plasmonic band gaps for plasmonic ones. These features lead to resonant localization of the electromagnetic field and bright peculiarities in optical spectra of such structures. Moreover, combination with ferromagnetic materials leads to the possibility of the magnetic field control over the spectral properties of such structures, so that they are recalled, correspondingly, magnetophotonic or magnetoplasmonic crystals (MPC). Here we investigate a poorly explored kind of magnetophotonic structure made of thin colloid (opal) films covered by a ferromagnetic cobalt nanolayer [1].

Opals are 3D PhC formed by closely packed SiO_2 sub-microspheres forming a hexagonal lattice; they exhibit PBG with the spectral position determined by the colloidal crystal's periodheter. Moreover, periodic surface structure of opal films can be exploited to produce the surface plasmonic lattice and form plasmonic crystals if the opal is covered by an appropriate metal layer [2]. Thus by changing the spheres' size, one can reveal the interrelation between the plasmonic and photonic properties of the opal-cobalt composite, as well as their role in the formation of resonant magnetooptical effects.

Here we study optical and magnetooptical spectral properties of cobalt-opal films, with the diameter of silicon oxide spheres varied in the interval 270-680 nm, the effective thickness of Co layer being about 10% of the silicon oxide spheres' diameter. We show that periodic arrays of nanoholes in coverage Co film can provide anomalous transmission, while magnetooptical effect is strongly enhanced in the spectral vicinity of surface plasmon-polariton (SPP) modes. Analogously to previously studied flat magnetoplasmonic structures, the mechanism underlying this effect is the magnetic field induced shift of SPP resonances, which is confirmed by numerical calculations. At the same time, we show experimentally that the PBG of opal films nearly does not influence the magnetooptical response of the composite. Importantly, the observed effects clearly demonstrate the ability to construct the resonant optical and magnetooptical response of opal-cobalt composites.

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Nanostructured amorphous and hybrid magnetic composites

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In the quest to develop novel materials, combining two or more phases in a composite structure allows engineering emergent properties. Furthermore, nanostructuring the constituents of magnetic composite materials allows taking advantage of the unique magnetic phenomena that occur at the nanoscale. The main challenge in this approach is to maximize the integration among components, hence, controlling and improving the quality of the interfaces.

In crystalline heterostructures, structural transitions, and/or defects always reduce the coupling at the interfaces. On the other hand, amorphous composites provide smooth interfaces without structural discontinuity and conventional defects. Besides, the epitaxial growth is restricted to phases with matching lattice constants, hence limiting the magnetic properties. On the contrary, the magnetic properties of amorphous materials can be tuned almost continuously through their composition. Moreover, amorphous materials perfectly fit with processes like sputtering and additive manufacturing, allowing easy industrial-scale production.ö

This contribution will present examples of nanostructured amorphous composites. First, we will investigate the interphase exchange coupling of hard $Sm_{15}Co_{85}$ and magnetically soft $Co_{85}(Al_{70}Zr_{30})_{15}$ multilayers, prepared by magnetron sputtering [1]. Then, we will present the combination of ion implantation with pre-sputtered $Fe_{89}Zr_{11}$ samples using lithographic techniques. The process produces amorphous 3D micro and nano-magnets embedded in the original amorphous matrix with extreme long-range coupling [2]. Finally, we will show how to combine crystalline and amorphous phases creating hybrid nano-architectures using crystalline cobalt ferrite and the amorphous parent material [3]. This novel hybrid design exploits the properties of each component and maximizes their integration resulting in unique magnetic properties.

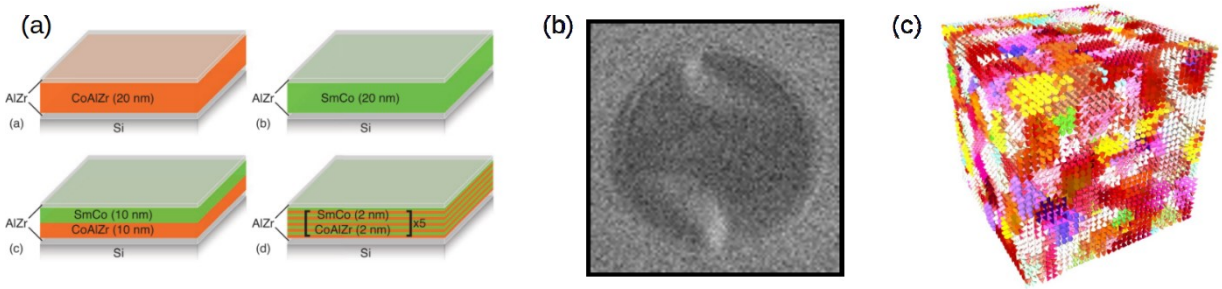

Figure 1. (a) Schematic representation of the multilayered samples [1]. (b) Example of the magnetic domain structure of an implanted 3D micromagnet [2]. (c) Micromagnetic structure of the hybrid nanocomposite [3].

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Smart biomedical nanoagents and enhancement of their in vivo performance with the "MPS-cytoblockade" technology

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Smart materials (SM) that can switch between different states under the influence of chemical triggers are highly demanded in biomedicine, where specific responsiveness to biomarkers is imperative for precise drug delivery and diagnostics[1].

We have developed several designs of smart nanomaterials that feature advanced properties for drug delivery and biosensing. As the first example, we demonstrated, that nanoparticles, virtually regardless of their nature, can be transformed to autonomous biocomputing structures capable of implementing a functionally complete set of Boolean logic gates (YES, NOT, AND and OR) and of binding with a target as a result of the computation[2]. Next, we showed a novel approach to the construction of ultra-sensitive smart nanoagents with ON/OFF switchable affinity to a biomedical target by combination of low energy polymer structures with gold nanoparticles[3]. In the proposed method, a nanoparticle-based agent is surface coated with a custom designed flexible polymer chain, which has a switchable input-dependent structure that regulates accessibility of the terminal receptor for target binging. Implementation of the concept with a DNA-model of such polymer has yielded nanoagents that have regulating input-dependent cell-targeting capabilities and a responsiveness to as little as 30 fM of DNA input in lateral flow assays. As the base for implementation of the abovementioned smart agents, we have developed a range of nanoparticle-based and solid-phase materials that can carry various payloads (e.g., genetic constructs), implement advanced biosensing, etc.

While nanoagents hold great potential for biomedicine as they outperform molecular agents in vitro, most of the promising nanoagents become theranostically inefficient in vivo because of rapid elimination from the bloodstream by the mononuclear phagocyte system (MPS). We have developed a universal method for increasing the circulation half-life of nanoagents by preceding stimulation of the MPS clearance of the organism's own intact blood cells[4]. We show that administration of a minute dose (1.25 mg/kg) of allogeneic anti-red blood cell antibody that induces Fc-receptor mediated erythrophagocytosis causes a temporary "MPS-cytoblockade," which provides up to 32-fold increase in nanoagent circulation half-life. The proposed method of gentle blocking of the MPS is a powerful tool that enables in vivo use of a wide variety of novel nano-sized probes and agents in life science, and significantly improves the efficiency of various nanotherapeutics.

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Plasmons interacting with magnetic fields: an application-oriented perspective in magnetoplasmonics

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Magnetoplasmonics studies the interaction between plasmon resonances and magnetic field. [1] From plasmon-enhanced magneto-optical spectroscopy to active modulation of resonances through magnetic fields, several exciting applications of magnetoplasmonics have been proposed. In this talk, I will introduce the basic concepts of the discipline, review the current progress toward viable applications and highlight some novel concepts involving magnetic fields interacting with plasmon resonances.

I will focus especially on the potential of magnetoplasmonics for sensing three different entities:

-high-performance plasmonic refractometric sensing of (bio)molecules through magnetic modulation of the plasmon resonance; [2-4]

-field-enhanced magneto-optical spectroscopy of ultrathin films of magnetic molecules on surfaces; [5]

-quantitative sensing of magnetic fields at the nanoscale with magnetoplasmonic nanostructures.

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Magnetoactive elastomers with high-coercive filler: ferromagnetic particles under non-saturated magnetization and restricted mechanical freedom

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Magnetoactive elastomers (MAE) filled with a mixture of low and highly coercive (LC and HC) particles are more versatile with respect to controlling their functionality (e.g. shape changes) in comparison with conventional MAEs, i.e., those with only an LC filler. This advantage is due to the HC fraction that, after subjecting a freshly prepared sample to a strong field, makes such a MAE permanently magnetized. As the magnetic field applied to an MAE acts directly only on the embedded particles, the magnetic control over the sample as a whole, i.e., its magnetomechanics, is entirely defined by the character of the particle/matrix coupling that converts the field action into internal mechanical stresses and, finally, deformations. Unlike LC particles, the embedded HC ones respond to an applied field not only by translational but also by rotational displacements inducing mesoscopic forces and torques. To study this specific set of effects, in our work we consider exclusively HC-MAEs, i.e., those filled with only magnetically hard particles, taking NdFeB micropowders as a generic example.

In these systems, all the field-induced particle rotations could be traced by magnetization measurements, and one may use such observations in a multi-purpose way. For example, to probe the rheology of the matrix with given particles, or, going the opposite way, to characterize the particles if the matrix parameters are well known. Whatever the purpose, the investigation of: (*i*) formation of magnetic moment of a particle and (*ii*) the extent of particle/matrix adhesion – are crucial points for the correct interpretation of any experimental data.

Point (*i*) is nontrivial because a single micron particle has a complicated structure of a `raisin-cake', i.e., is a clot of single-domain $Nd_2Fe_{14}B$ nanograins with randomly oriented easy axes interlaid with a paramagnetic alloy. After initial magnetization, such a particle acquires an overall magnetic moment, approximately half of the saturation one. Under a field change, the net magnetic moment of the particle behaves in a complicated way since the individual switching fields of the grains depend on the angular displacements of the particle as a whole. This situation and its reflection in the magnetization curves of HC-MAEs are analyzed following Refs. [1,2].

Point (*ii*) – the case of finite adhesion – has never been discussed before; until now in the MAE science a perfect unbreakable particle/matrix adhesion was considered as an incontestable postulate. In other words, the particle is believed to be in point-to-point with the matrix and always entrains it when moving. Meanwhile, when compared against the real parameter estimates, that assumption turns out to be rather questionable. By discarding it, one arrives at some important new predictions explaining the origin of the magnetization curves of HC-MAEs [3,4].

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Intensity-based wide-field magneto-optical microscopy

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In conventional Kerr- and Faraday microscopy the sample is illuminated with plane-polarised light and a magnetic domain contrast is generated by an analyser making use of the Kerr- or Faraday rotation. In this presentation we review possibilities of analyser-free magneto-optical microscopy based on magnetisation-dependent intensity modulations of the light: (i) The transverse Kerr effect can be applied for in-plane magnetised material, demonstrated for an FeSi sheet. (ii) Illuminating the same sample with circularly polarised light leads to a domain contrast with a different symmetry as the conventional Kerr contrast. (iii) Circular polarisation can also be used for perpendicularly magnetised material, demonstrated for a garnet film and an ultrathin CoFeB film. (iv) Plane-polarised light at a specific angle can be employed for both, in-plane and perpendicular media. (v) Perpendicular light incidence leads to a domain contrast on in-plane materials that is quadratic in the magnetisation and to a domain boundary contrast. (vi) Domain contrast can even be obtained without polariser. In cases (ii) and (iii), the contrast is generated by MCD (Magnetic Circular Dichroism, i.e. by the differential absorption of left and right circularly polarised light, induced by magnetization components along the direction of light propagation) while MLD (Magnetic Linear Dichroism, i.e. by the differential absorption of linearly polarised light, induced by magnetisation components transverse to the propagation direction) is responsible for the contrast in case (v). The domain boundary contrast is due to the magneto-optical gradient effect in metallic samples. A domain boundary contrast can also arise due to interference of phase-shifted magneto-optical amplitudes.

All reported contrasts can be applied directly for domain imaging. In any case they need to be considered also in conventional magneto-optical Kerr microscopy and MOKE magnetometry as they can be superimposed on any regular Kerr signal.

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On-surface control of magnetic and quantum functionalities of single molecule magnets: from metal substrates to superconductors

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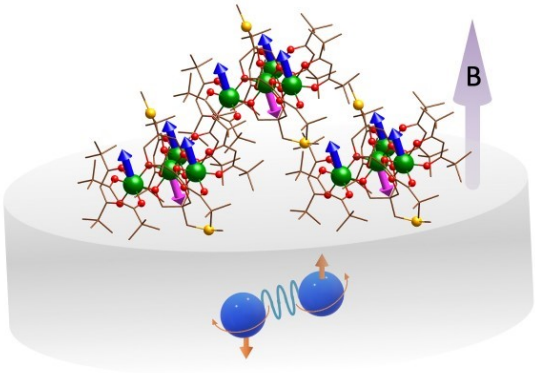
Single Molecule Magnets (SMMs) are molecules with remarkable magnetic properties as extremely long magnetization relaxation time and magnetic hysteresis at the single molecule level at low temperatures.[1] Being able to join magnetic memory and quantum features, they represent suitable building blocks for novel technologies at the nanoscale, such as spintronic applications. Both the electronic and magnetic properties of SMMs are particularly sensitive to the interaction with substrates, and the signature of this interaction has been observed on a wide range of metallic and non-metallic substrates either at the single molecule level or at the larger scale of molecular films.[2–4] The evidence of the strong interactions occurring at the surfacemolecule interface are found in the magnetic hysteresis loop of SMMs films, which is quenched when molecules interact directly with conducting substrates but preserved - or even boosted - by the use of decoupling layers. Here I will present a route for controlling the magnetism and quantum features of diverse SMM systems by engineering the substrate with decoupling layers or superconducting materials. The investigation of magnetic molecules on substrates here presented will be discussed based on a multitechniques approach involving scanning tunnelling microscopy, photoemissions techniques and synchrotron experiments. In particular, I will focus on the role of the superconductors in influencing magnetic molecules and how these hybrid systems hold potentials for spintronics and quantum technologies.[5,6] Indeed the transition of the substrate to the superconducting state affects the magnetization of the SMMs that locally switch from a blocked magnetization state to a resonant quantum tunneling regime. Exploiting the different nature of SMM systems interaction with the substrate, the sensitivity to the spatial magnetic field variation on the superconductor is resolved. This innovative approach opens interesting perspectives for controlling single molecule magnets in spintronic devices as well as for their use as local probes for superconducting materials.



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Organic coating effects on the magnetic behavior of nanoparticle systems

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Recent studies have demonstrated that organic coatings modify the magnetic properties of nanoparticles. Their effect on the magnetic behaviour depends on the type of the magnetic nanoparticle, of the type of coating and the amount of coverage. [1-3]

Here we present our results on the magnetic behavior of (a) Mn ferrite nanoparticles covered with albumin and (b) Co ferrite nanoparticles covered with oleic acid (OA). In the latter case we have also studied numerically how the OA percentage of coverage affects the magnetic behavior of the Co ferrite nanoparticles.

In our study we use multiscale simulations approach. First, using Density Functional Theory (DFT) approach, we have calculated the magnetic moments, magnetocrystalline anisotropy energies (MAE) and Heisenberg type exchange coupling constants for the $MnFe_2O_4$ and $CoFe_2O_4$ nanoparticle of inverse spinel structure in the presence of the coating. Then, we have compared our results with the corresponding ones for uncoated particles. Our findings demonstrate that the organic coatings produce the decrease of the mean magnetocrystalline anisotropy energy, reduction of the magnetic moments and variation of the exchange coupling constants. This is attributed to the partial recovery of the bulk spinel structure at the coated surface. The DFT results have been used as input in the Monte Carlo simulations of the assemblies of the nanoparticles and they have shown that:

(a) The coated Mn ferrite nanoparticle assembly has lower coercive field and higher saturation magnetization than the uncoated nanoparticles assembly, which are attributed to clustering effects in the assembly.

(b) The presence of the coating layer increases the coercive field in the OA coated Co ferrite nanoparticles. The increase is bigger as the surface coverage increases and is attributed to the gradual reduction of the interparticle exchange coupling.

The behavior of these systems is in agreement with recent experimental findings. [1-3] Importantly, the results suggest the possibility of tailoring the magnetic properties of Mn and Co ferrite nanoparticles for high performance biomedical and magneto/thermoelectric applications by varying the type of coating or/and the surface coverage.

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Heusler-based microwires and nanowires for SMART shape memory and magnetocaloric applications

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Heusler alloys represent wide group of materials with wide range of functional properties starting from thermoelectric, shape memory, magnetocaloric, spin polarization, etc. Replacement of single atom in the stoichiometric composition changes completely their functional properties [1]. This allows one to combine different, sometimes complementary, properties into the single material.

Within the contribution, we will mainly focus on shape memory and magnetocaloric effect of Heusler alloys in the shape of glass-coated microwires as well as electrodeposited nanowires.

The advantages and disadvantages of wire shape material for shape memory and magnetocaloric applications will be shown [2]. Considering the shape anisotropy of wires together with preferred orientation of crystalline structure, it is possible to use such material like actuator and sensor together [3].

Starting from different compositions of Heusler wires, we will shift to NiFeGa composition that offers multicaloric functionality. From practical point of view, NiFeGa is characterized by excellent reproducibility of production. Even though, the magnetocaloric effect is smaller comparing to NiMnGa alloy, it is possible to simply tune the martensitic transformation and Curie temperature. We will show, how properly selected composition together with alloying leads to proper set up of structural transformation and Curie temperature and to enhancement of magnetocaloric effect [4].

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Controlling the dominant magnetic relaxation mechanisms in magnetic fluid hyperthermia through the shell composition of $Fe_3O_4/(Zn/Co)Fe_2O_4$ nanoparticles

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The magnetic losses in magnetic fluid hyperthermia (MFH) is originated from the phase shift between the nanoparticle's magnetic moment and the magnetic vector H of the applied alternating magnetic field, where the magnetic relaxation dynamic depends on the relaxation time of two different concurrent mechanisms. One mechanism consists in the mechanical or Brownian relaxation, where the particles physically rotate with a characteristic time τ_B, in presence of the alternating magnetic field. The second mechanism is the Néel relaxation, with a characteristic time τ_N, which involves the inversion of the magnetic moment within the crystal lattice through its anisotropy energy barrier $K_{eff}V$, where K_{eff} is the effective anisotropy constant and V is the volume of the particle. Depending on the different parameters of the system, one of the mechanisms is dominant, i.e., Néel relaxation dominates systems with small magnetic anisotropy energy and/or high viscosity, whereas Brown mechanism governs in the opposite situation. To improve the heating power, it is necessary to optimize the nanoparticles characteristics as the size, morphology, magnetic anisotropy, saturation magnetization and surface functionalization. Usually, the improvement of one parameter leads to the change in another (not always in a positive sense). Then, it is crucial to be able to perform a selective optimization of individual parameters that control the relaxation mechanisms to improve the power absorption for each particular experimental condition. One way to reach this goal is using bimagnetic core/shell nanoparticles, which allows the systematic modification of the magnetic anisotropy, preserving the size, morphology and high values of magnetization. In this way, the magnetic relaxation time can be modified respect to the mechanical relaxation and the dominant Brown or Néel heating mechanism could be tuned.

With this in mind, we design bimagnetic core/shell nanoparticles synthesized by a thermal decomposition method, and we have studied them regarding the shell composition [1]. We report a simple and effective way to control the heat generation of a magnetic colloid under alternate magnetic fields by changing the shell composition of bimagnetic core–shell Fe_3O_4 / $Zn_xCo_{1-x}Fe_2O_4$ nanoparticles, and the effective anisotropy that can be tuned by the substitution of Co^{2+} by Zn^{2+} ions in the shell [2,3]. MFH experiments were performed with nanoparticles dispersed in hexane and butter oil. Increasing the Zn concentration of the shell diminishes the magnetic anisotropy, changing the relaxation mechanism from Brown's to Néel one. We demonstrate that tuning the Zn contents at the shell of these exchange-coupled core/shell nanoparticles provides a way to control the magnetic anisotropy without loss of saturation magnetization.

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Oral talks

Effect of molecular coating on magnetic properties of spinel ferrite nanoparticles: XAS study

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Molecular coating of magnetic iron oxide nanoparticles by organic molecules is attracting intensive research owing their possible biomedical applications such as magnetic drug targeting, cancer treatment (hyperthermia), enzyme immobilization, or magnetic resonance imaging [1]. Several authors have shown that the influence of different ligands bonded at the surface of magnetic nanoparticles (NPs) plays a significant role in the magnetic properties of the NPs. In this landscape Manganese Zinc ferrite NPs (MZFO) are chosen owing their high saturation magnetization and low resistivity. In addition, Mn-Zn ferrites are very important ferromagnetic ceramics, particularly for application at high frequencies. Encapsulating the MZFO NPs core with opportune ligand shells allows to modify the magnetic interactions between magnetic cores and the molecular shells providing new features valuable for specific applications, influencing both surface magnetic disorder and single ion magnetic anisotropy [2].

In this study, a set of core-shell magnetic NPs based on MZFO magnetic cores with averagely 7 nm diameter, is coated with three different organic molecule shells: Dopamine (dop), Oleylamine (ole) and Citrate (cit). The MZFO NPs crystallographic phase and morphological characterization has been carried out by x-ray diffraction and TEM. The chemical interactions of the core with the organic shells were accurately characterized by FTIR spectroscopy and TGA technique. The magnetic response of the MZFO NPs (bare and coated) as a function of magnetic field and temperature was characterized by DC magnetization (performed with SQUID). Magnetization curve versus field, zero field cooled (ZFC) and field cooled (FC) magnetization, isothermal remnant magnetization (IRM) and Direct Current Demagnetization remanence (DCD) have been performed. The results showed that the nanoparticles coated with Dopamine depict anomalous magnetic response with a lower blocking temperature and unsaturated magnetization suggesting smaller magnetic cores despite the same synthesis procedure for all the samples. Further details have been obtained by XAFS, which provided details about local atomic structure around Fe, Mn and Zn atoms of all MZFO samples [3]. The Fe, Zn and Mn K-edge XAFS data analysis revealed a strong chemical interaction between dopamine molecules and the NPs which removes the metals from the MZFO core, this effect being especially evident for Mn, also for the citrate molecules. Such interaction between organic molecules and MZFO NPs is responsible for the magnetic behavior modifications and must be carefully considered in these core-shell systems.

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Magnetocaloric effect in $Mn_{1-x}Fe_xAs$ in cyclic magnetic fields

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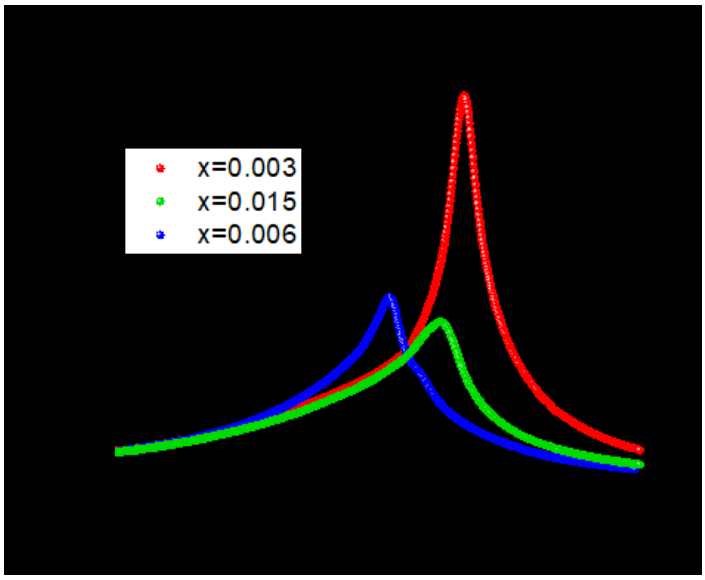
Magnetocaloric properties of the materials under single and repeated application of the cyclic magnetic fields can exhibit significantly different behavior. For practical applications materials with time-stable and no frequency dependence magnetocaloric properties are required.

In this report, we present results of studying the magnetocaloric properties in $Mn_{1-x}Fe_xAs$ compounds in cyclic magnetic fields with frequencies up to 30 Hz with an amplitude of 1.2 T and in high fields up to 8 T at 0.2 Hz. The dependency of the MCE on the frequency of cyclic magnetic field and the effect of prolonged action of cyclic magnetic fields on magnetocaloric properties of the materials are studied in detail.



Based on the field dependences of the adiabatic temperature change and magnetostriction results the lattice and magnetic contributions to the total magnetocaloric effect estimated. It was discovered that variation of the MCE with Mn substituting by Fe is mainly to the change in the lattice contribution. It was also found that the effect of degradation of the magnetocaloric properties as a decrease in the magnitude of the MCE under the action of a cyclic magnetic field is observed. An explanation of the observed behavior of the MCE in cyclic magnetic fields is given in the report. The degradation of the MCE imposes restrictions on the use of this material in magnetic cooling technology.

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Ab initio study of Mn_2ScZ Heusler alloys (Z = Al, Si, P, Ga, Ge, As, In, Sn, Sb) with switchable metal to half-metal behavior

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Modern electronics is rapidly approaching its physical limits, and therefore, research in the field of spintronics becomes relevant. The efficiency of spintronic devices is directly related to the efficiency of spin injection from electrodes to semiconductors, as well as the degree of their spin polarization [1]. One of the most common methods is spin injection from a ferromagnetic material, in particular, half-metallic Heusler alloys [1].

One of the families of half-metallic Heusler alloys is Mn_2XY. Typical examples are Mn_2VAl, Mn_2VSi, Mn_2FeZ (Z = Al, Sb), Mn_2CoZ (Z = Al, Ga, Si, Sb), Mn_2CuSb, Mn_2ZrSi, some of them are synthesized experimentally [2, 3]. The goal of this work is to predict new half-metallic materials based on the Mn_2ScZ family (Z = Al, Si, P, Ga, Ge, As, In, Sn, Sb) with an optimal composition for application in spintronic devices.

Geometric optimization of the lattice was goten within the framework of the Density Functional Theory using the plane augmented waves approach implemented in the VASP code [4]. Exchange-correlation effects are taken into account in the form of the GGA-PBE [5] and meta-GGA SCAN functionals [6].

For most alloys, except for Z = Si, Sn, Sb, the X_A lattice (No. 216) is preferable. The most interesting behavior is observed for Mn_2ScSi and Mn_2ScP in the ferrimagetic state. The energy landscape has two, almost degenerate, local minima, one of them has a low magnetic moment (LMS) that satisfies the Slater-Pauling rule, the second minimum has a high magnetic moment (HMS). The alloy has a direct $\Gamma - \Gamma$ energy gap in the majority spin channel, the value of which, within the SCAN framework, is 0.32 eV. Upon transition to HMS, the alloy becomes a metal. Thus, it is possible to switch metall-half-metall behavior by uniformly contracting / expanding the crystal lattice. This switching mechanism could be implemented for the design of spintronics devices like spin filters, sensors, switches, logic gates with femtosecond timescale [7].

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A new therapy for adiposopathy based on low frequency ac filed applications on magnetic nanoparticles

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One of the most promising areas of application of magnetic nanoparticles (MNPs) is biomedicine, where they have been actively investigated in various research fields such as imaging, detection, drug delivery and new therapies [1,2]. One of the most widespread pathologies in EU member states is adiposopathy [3], which is promoted by fat accumulation (adiposity) and sedentary lifestyle in genetically susceptible patients. At the present, this pathology is treated by invasive interventions, such as bariatric surgery or liposuction procedures, or by pharmacological treatments aimed at treating certain effects of adiposopathy, such hypertension or Type 2 diabetes, but not the disease itself. For this, we propose a new approach for the treatment of pathological adipose tissue, based on the application of MNPs and the induction of a magneto-mechanical stress applying an external LF-AC magnetic field that activates cell apoptosis, avoiding the undesirable side effects.

Here, we present the synthesis of iron oxide MNPs with different sizes and shape (spheres and rods) by colloidal chemistry (thermal decomposition and hydrothermal synthesis). The MNPs were characterized by X-Ray Diffraction (XRD), Transmission Electron Microscopy (TEM) and superconducting quantum interference device (SQUID) magnetometry. Also, we present a prototype of a LF-AC generator for inducing the magneto-mechanical damages. This device is easy to handle and transported, so to extend its use to other cell cultures and biological targets.

The collected data allow us to demonstrate the proof of concept of a novel approach and to establish which are the best MNPs for maximizing the effect.

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Absorption non-reciprocity on exciton-magnon-phonon states of the magnetoelectric antiferromagnet CuB_2O_4

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Depending on the propagation of light in a medium, optical effects can be divided into two groups. In the first group, the propagation of light in the opposite direction does not lead to any changes in the studied optical parameters, such as absorption, luminescence, refraction. Similar effects are observed in systems that are invariant with respect to time reversal operations. In the second group of nonreciprocal effects, the time-reversal symmetry is violated, which leads to different interactions with the matter of light in opposite directions. A magnetic field leads to a violation of time-reversal operations in any medium, which is the most famous example of nonreciprocal magneto-optical effects of Faraday and Kerr.

In this work, we carried out a comprehensive study of the optical nonreciprocity of absorption in copper metaborate CuB_2O_4. This compound has interesting optical and magnetic properties. It has a rich magnetic phase diagram [1], an unusual magnetically dependent absorption spectrum [2-3], it exhibits the effects of giant magnetic dichroism [4], giant nonreciprocal absorption [5], luminescence [6], magnetically induced generation of the second harmonics [7], etc. This work continues the study of nonreciprocal absorption in the context of various magnetic and crystal sublattices of copper and various geometries of the magnetic field. We found gigantic effects in almost all investigated geometries (Faraday, Voigt). Saturation magnetic fields (<0.1 T), optical transitions (components of Davydov doublets [4]) demonstrating nonreciprocity were determined, and the magnon peak in the dichroism and nonreciprocity spectra was investigated. It is shown that many effects depend on the magnetic structure, the direction of propagation of light, and the direction of the external magnetic field. This work will bring closer understanding of the microscopic reasons leading to nonreciprocity in this crystal.

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Packing magnetic nanoparticles into polymer microcapsules increases their cytotoxicity in presence of AMF

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Local hyperthermia is the most widespread method and applied mainly to solid tumors treatment nowadays [1]. There are many ways to supply heat to the required location - direct contact heating, perfusion of hot liquids, microwave radiation, and finally, magnetic hyperthermia [2]. Magnetic hyperthermia is based on the injection of magnetic particles into the tumor, followed by exposure to an alternating magnetic field. The advantages of microcapsules compared with nanoparticles can be a high degree of absorption by cells. In this work, we investigated the features of the cytotoxic effect of magnetite containing microcapsules in comparison with magnetic nanoparticles used in the synthesis of capsules.

The study was carried out on mouse fibroblasts L929 in which polyelectrolyte microcapsules with magnetite were internalized. Polymeric microcapsules were prepared by the «Layer by layer» method by alternately adsorption of oppositely charged polyelectrolytes (polyarginine and dextran sulfate) and iron oxide nanoparticles on spherical $CaCO_3$ cores. The cells culture was treated with AMF with an amplitude of 200 Oe and a frequency of f = 100 kHz during 0,5, 1, 2, 5, 10, 15 min. After treatment with AMF, L929 cells were transferred to a 96-well plate in 100 µl doublets and incubated for 24 hours. Thereafter, an MTT test was carried out to determine cell viability.

The studied objects were microcapsules with average size 4.2 µm, the magnetite content was 4.1 pg per capsule and magnetic nanoparticles (MNPs). The iron concentration was 3.2 mg/ml and 1.73 mg/ml for MNPs and suspension of microcapsules, respectively. Both the capsules and MNPs interacted with the cells, but capsules provided a greater accumulation of iron in the cell compared to MNPs. The treatment of cells with MNPs in combination with the action of an AMF did not lead to cell death. In contrast, incubation of cells with microcapsules followed by exposure to AMF resulted in dose-dependent cytotoxicity: in a series of 5 capsules per cell, the viability was 75%, in a series of 10 capsules per cell – 28% according to the MTT test. The cellular damage could be caused by thermal impact. At the same time, we did not reveal an increase in the temperature of the cell incubation medium during the entire observation time. The discovered phenomenon of cell damage without increasing the temperature of incubation medium can be of great importance in terms of the selectivity of the destruction of pathologically altered cells. If capsules are targeted to pathologically altered cells, treatment with an alternating magnetic field will lead to the death of these cells only without affecting neighboring cells, which can be extremely useful, for example, in cancer therapy.

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Influence of correlation effects on the electronic properties of Co_2MnGa Heusler alloy

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Since the discovery of Dirac and Weyl semimetals [1], topological semimetals have important role in condensed matter physics. Their unique topological properties are predicted to give rise to a wide range of exotic transport and optical phenomena. Recently the ferromagnetic full Heusler compound Co_2MnGa was predicted as a topological material which has both Hopf link and chainlike bulk band crossings and unconventional topological surface states [2]. From theoretical point of view usually the electronic properties of Heusler alloys are described *ab initio* in terms of generalized gradient approximation in PBE parametrization [3]. It is well established that the Heusler alloys are the strong correlated systems [4]. Because of the electronic properties of Co_2MnGa need better to describe in SCAN parametrization which is more precise method in comparison to PBE one.

In the present work, the electronic properties of Co_2MnGa alloy were investigated by using density functional theory implemented in the *ab initio* software program package VASP [5,6] within meta-GGA SCAN parametrization [6]. It is shown (see Fig.1) that in comparison with GGA PBE parametrization [2] meta-GGA SCAN one the conduction zone in down channel lied higher in energy and vice versa in up channel it displaces down.

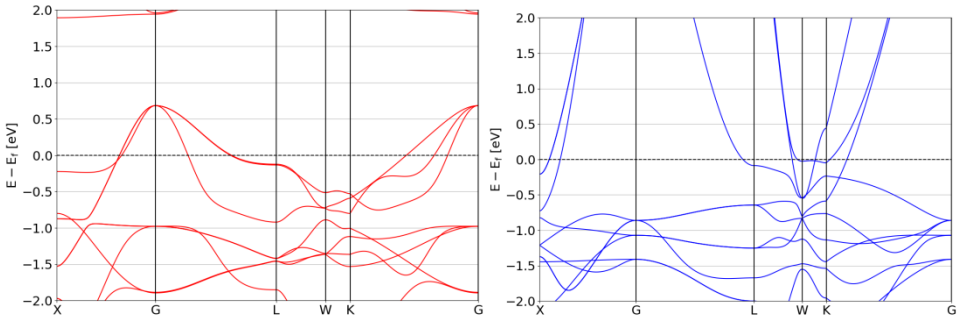

Fig.1 Band structure of Co_2MnGa for down (left) and up (right) states.

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Subpicosecond dynamics of magneto-optical Faraday effect in hybrid metasurfaces

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The phase, amplitude, polarization, and frequency of radiation can be effectively controlled by plasmonic or dielectric resonant metasurfaces. The presence of magnetic materials leads to enhancement magneto-optical as well [1, 2].

The interaction of femtosecond laser pulses with materials allows studying ultrafast change in the characteristics of light transmitted/reflected through the samples. Remarkable alteration of the polarization state inside a single femtosecond pulse reflected from the sample as a function of time is experimentally shown in plasmonic crystals [3]. In magnetophotonic crystals, the ultrafast temporal behavior of the Faraday rotation within a single femtosecond laser pulse under conditions of slow light is also demonstrated experimentally and numerically [4]. However, the ultrafast dynamics of magneto-optical effects in metasurfaces with Mie resonances has not been studied yet.

The sample is an array of silicon nanodiscs on a quartz substrate coated with a thin nickel film. Excitation of Mie resonance leads to an increased Faraday rotation [5]. The dynamics of optical and magneto-optical effects is measured by a cross-correlation scheme with a polarization-sensitive part based on a photoelastic modulator. The experiment shows that for the wavelength of the resonance, the evolution of Faraday rotation is monotonically increasing for 4 degrees, while for unstructured Ni film there is no time dependence of polarization plane rotation. The results are consistent with the numerical calculations performed by the finite difference time domain method.

In conclusion, the femtosecond dynamics of the Faraday effect in magnetophotonic nickel-silicon metasurfaces under the excitation of Mie resonances was discovered.

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Boson magnetism and quantum phase transitions in a system of strongly correlated cold atoms

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Quantum state of cold atoms in optical lattices in the Mott insulator regime when hopping is suppressed is basically governed by density-density and (pseudo)spin-(pseudo)spin interactions, U_0 and U_s, that, in turn, might be tuned *in situ*, contrary to strongly correlated electrons in solids. We show, on the same unified footing, for a number of cold atom systems, vector Fermions or Bosons, how tuning U_0 and U_s drives the sequence of quantum phase transitions (QPT) that involve (pseudo)spin state and particle ordering, Fig.1. These QPT originate from competing interactions. As an example, we analyze possible types of ordering in a boson-fermion model. The Hamiltonian is inherently related to the Bose–Hubbard model for vector two-species bosons in optical lattices. We show that such model can be reduced to the Kugel–Khomskii type spin-pseudospin model, but in contrast to the usual version of the latter model, we are dealing here with the case of spin S=1 and pseudospin 1/2. We show that the interplay of spin and pseudospin degrees of freedom leads to a rather nontrivial magnetic phase diagram including spin-nematic configurations. Tuning the spin-channel interaction parameter U_s gives rise to quantum phase transitions. We find that the ground state of the system always has the pseudospin domain structure. On the other hand, the sign change of U_s switches the spin arrangement of the ground state within domains from ferro to aniferromagnetic. Finally, we revisit spin (pseudospin)-1/2 Kugel–Khomskii model [1] and see inverse picture of phase transitions. We present new results for this system also when in addition to the standard parameters characterizing it, we are dealing with the 'degree of atomic nonidentity', manifesting itself in the difference of tunneling amplitudes and onsite Coulomb interactions. We obtain a cascade of quantum phase transitions occurring with the increase in the degree of atomic nonidentity. While in the system of nearly identical vector bosons, only one phase transition between two phases occurs with the evolution of the interparticle interaction, atom nonidentity increases the number of possible phases to six, while the resulting phase diagrams are so nontrivial that we can speculate about their evolution from the images similar to the 'J. Miro-like paintings' to 'K. Malewicz-like' ones [2, 3].

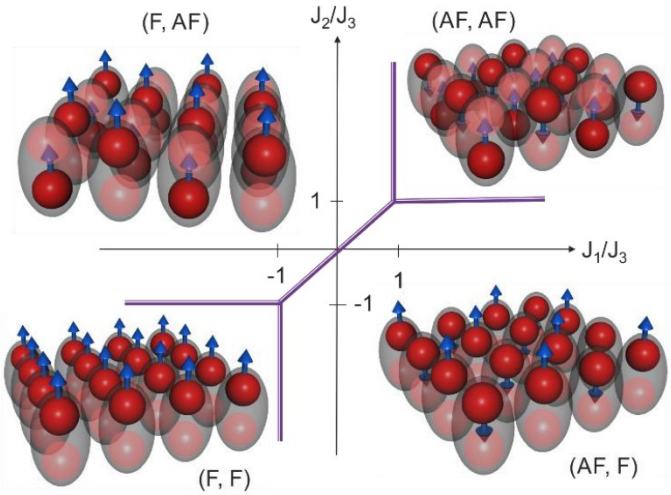

Figure 1. Phases of vector Bosons in optical lattice.

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Modelling of high magnetic field cryogen-free MRI

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We have developed: Compact, Liquid Helium-free 1,5 T MRI system for visualizing human extremities such as the knee, foot, ankle, wrist, and elbow;

The main breakthrough is the development of fundamental principles of visualization based on nuclear magnetic resonance in high magnetic fields which can be used for the fields up to 12 Tesla for MRI. The difference between the developed magnets and those that have existed so far is the use of the phenomenon of superconductivity to achieve high compact fields, as well as the world's first use of an economical conductive method of cooling superconducting magnets, which reduces production costs by 20%. The most important point is the development of the principles of Helium-free cooling, which became possible after the appearance of powerful pulsed cryocoolers, which allows temperatures of the order of 4K and below at maximum cooling power values. Cryocoolers using thermal bridges were used first for laboratory magnets with a field of 18 T, and then for MRI magnets with a field of 1.5 T. At the same time, in the future, on the basis of the developed technology, the potential for creating MRI magnets with a field of up to 10 T remains. In the course of the work, competitive software was created, which allowed us to obtain a spatial resolution of 0.5 mm that meets medical MRI standarts. At the moment, 38 volunteers have been scanned, 528 MRI studies have been obtained, and the possibility of studying the following areas has been shown: the brain, shoulders, neck, spine, knee and elbow joints. Domestic software (software) has been created, which is not inferior to foreign analogues. This software allows you to control the operation of MRI scanners, modify existing ones and create new sequences, which distinguishes the EGO from the "closed" type of software supplied with other MRI scanners. The results of the work are protected by more than 10 patents, and are also presented in more than 40 publications in peer-reviewed scientific journals.

FeNi and FeCo alloys nanowires: synthesis, structure and magnetic properties

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Samples. In this work, arrays of nanowires (NWs) from binary compounds (alloys) FeNi and FeCo were obtained by the matrix synthesis method. The synthesis process consisted in the galvanic filling of the pores of the track membranes. We used membranes with pores 100 nm in diameter and a pore surface density of 10^9 (manufactured by JINR, Dubna). The iron content in NWs varied from 15 to 85% due to changes in the concentrations of ions of the corresponding metals in the electrolyte. Galvanic deposition was carried out at potentials from 1 to 2 V. The process of filling of the pores was controlled by recording the current versus time.

Scanning microscopy (JEOL JSM 6000 plus) showed a slight increase in the NW` diameter as compared to the matrix pore diameter due to polymer stretching. Elemental analysis revealed that the composition of NWs from FeCo is close to the composition of the growth electrolyte and does not depend on the deposition potential (in the studied range). At the same time, for nickel-containing NWs, a strong increase of the iron content with a decrease in the potential and / or an increase in the concentration of iron ions in the electrolyte is observed. It is also shown that the composition of iron-nickel NPs in some cases can vary along the length of the NWs.

X-ray structural analysis (diffractometer RIGAKU Miniflex 600) of NWs samples with different ratios of elements and obtained at different growth voltages. showed that in most cases NWs are a solid solution with the fcc structure. The lattice parameters change regularly with a change in the ratio of metal concentrations. In a number of samples, a tetragonal phase was found, which requires additional research.

The magnetic properties of NWs were studied by Mössbauer spectroscopy (on ^{57}Fe) and vibrational magnetometry. Typical Mössbauer absorption spectra demonstrate magnetic splitting and are weakly broadened sextets with values of hyperfine parameters characteristic of Fe-Co and Fe-Ni solid solutions. The local field on the nuclei was determined, lying in the range of 28-36 T. In cobalt samples it is much higher than in nickel samples. It is shown that the field increases almost linearly with increasing iron content. Analysis of the results of magnetic measurements showed that all nanowires exhibit spontaneous magnetization of nanowires along their axes and strong anisotropy of magnetic properties.

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Switching of magnetoresistive light-emitting diode by external magnetic field

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The structures of semiconductor spintronics are considered as one of the options for the development of modern micro- and optoelectronics. Such structures utilize new principles of transmission, storage and processing of information as a tool to overcome fundamental quantum limitations on the number of elements in an integrated circuit [1]. From this point of view, the key property of spintronic devices is a compatibility with currently implemented technologies. Therefore, the most important task of modern spintronics is the technological integration of devices based on spin-dependent effects into "classical" micro- or optoelectronics.

In particular, a magnetoresistive element (spintronic device) and a light-emitting diode were shown to be structurally combinable in [2,3]. In such a combined device, the magnetoresistive element function is a control of the total current (by switching the series resistance by an external magnetic field), which in turn drives the radiation intensity of the light-emitting diode.

In this work, we consider the mechanism of operation of a magnetoresistive light-emitting diode, which is fundamentally different from the ones discussed in [2,3]. In the reported structure, the total current passing through the combined device is maintained constant, whereas the intensity control is achieved by manipulating the ratio between the minority and majority carrier currents in a Schottky diode. It was shown that despite the small amplitude of a magnetoresistive effect, a 100% change of intensity can be achieved, i.e. the operation of a magnetoresistive light-emitting diode in the "on-off" mode can be realized upon the introduction of an appropriate external magnetic field.

Furthermore the use of ferromagnetic layer for electrical injection in Shottky diode allows one to realize spin injection into semiconductor structure which leads to modulation of the polarization of the device emission. Thus, in addition to the magnetic field controlled intensity the magnetic field controlled circular polarization can be utilized within the same device.

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Synthesis and magnetic properties of Co nanowires/PVDF composites

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Magnetic nanowires (NWs) are promising candidates for applications in different kinds of modern technologies, such as memory storage devices, sensors, spintronic devices, etc. Thereby, there is a need in the development of synthesis methods allowing for realizations of the necessary functional properties of both NWs themself and composite materials. In this work we synthesized oriented and randomly oriented Co NWs/polymer composites, analyzed their magnetic properties, and evaluated different contributions to their magnetic anisotropy.

Composite's synthesis was performed in several stages: producing porous templates of anodic alumina, filling of substrates with cobalt by AC electrodeposition, dissolving the templates and transferring NWs to the polyvinylidene fluoride (PVDF) polymer. Morphology of the porous templates and arrays of NWs was studied by scanning electron microscopy: the length of the NWs was 3 μm, diameter – 35 or 50 nm, distance between centers of neighboring NWs – 105 nm. NWs/polymer composites were applied to glass substrates as thin layers with (oriented composites) or without (randomly oriented or disordered composites) uniform magnetic field applied parallel to the substrate's surface. Magnetic properties of NWs in anodic alumina templates and polymer matrix were studied by vibrating sample magnetometers.

After transferring to PVDF, NWs remained ferromagnetic, which was confirmed the high values of their magnetic moment and hysteresis properties. In contrast to disordered composites, a clear easy magnetization axis was observed in ordered composites. The observed anisotropy is a result of the two main contributions: magnetocrystalline anisotropy and shape anisotropy of the NWs. A comparative analysis of the hysteresis properties, performed on arrays of NWs in a polymer matrix and an anodic alumina templates in a temperature range 100 K to 400 K, showed the presence of a strong magnetoelastic contribution for samples with a rigid Al_2O_3 matrix and relatively weak but measurable contribution for NWs in polymer matrix. As a result, various contributions in magnetic anisotropy of composite materials were evaluated and a prototype ordered NWs-PVDF composite material was synthesized. These results can be useful for producing a composite multiferroic material, although further optimization of ferroelectric β-phase content in PVDF and magnetic properties of NWs is necessary.

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Ferromagnetic resonance investigations of exchange biased NiFe/IrMn/NiFe trilayer structures

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Investigations of magnetization dynamics in nano scaled magnetic structures are now of great importance for several reasons. The most important one is that in low-dimensional devices, such as sensors and spin valves based on the giant magnetic resistance effect, the rate of reorientation of the magnetization of the layer is a key factor. The dynamics is determined by the damping of the precession of the magnetization towards the equilibrium state. The value of the spin damping determines the width of the FMR line, which is an important property for the development of devices. In turn, the amount of damping depends on large number of factors, including the microstructure, presence and magnitude of exchange bias field.

Here we present our results on FMR study of NiFe/IrMn/NiFe trilayer structures with IrMn layer thickness t_{AF} varied from 2 to 50 nm. The set of experimental samples was obtained using magnetron sputtering in presence of a constant magnetic field of 420 Oe applied in substrate plain during the layer deposition.

It was shown that the dependence of the exchange bias on the AF layer thickness is non-monotonic. Thus, the exchange bias that appears at t_{AF} = 4 nm increases, then, at AF thicknesses of 8-12 nm, a sharp decline is observed, after which, the exchange bias increases linearly from 22 Oe at t_{AF} = 20 nm to 48 Oe at t_{AF} = 50 nm. The angle of non-collinearity of the uniaxial and unidirectional anisotropies has a maximum value at t_{AF} = 4 nm, which corresponds to the thickness of the AF layer at which the exchange displacement appears. With a further increase in the thickness of the AF layer, the noncollinearity angle decreases and becomes zero at t_{AF} = 15 nm. The dependence of the peak width of the FMR on the thickness of the AF layer for different orientations of the sample relative to the external field of the FMR has along with small quantitative differences a single qualitative form for all orientation angles. It was shown that with the appearance of the exchange bias at the AF layer thickness of 4 nm, there is a sharp increase in the width of the FMR peak. Further, as the AF layer thickness increases, the line width decreases nonmonotonically and does not change significantly after the AF layer thickness of 20 nm. It is worth noting that the maximum width of the FMR peak corresponds to small AF layer thicknesses of 4-10 nm, corresponding to the AF thicknesses at which a peak is observed depending on the exchange displacement of the AF layer thickness, as well as the non-collinearity of the unidirectional and uniaxial anisotropies. This can be explained by the weak magnetic ordering of the AF layer at small thicknesses, in which defects and local structural inhomogeneities play a significant role, leading to local disorientation of the magnetic moments. The angular dependence of the FMR peak width for a sample with an AF layer thickness of 4 nm, corresponding to the thickness at which the exchange displacement and the greatest angle of non-collinearity of the unidirectional and uniaxial anisotropies appear, is characterized by an asymmetric angular dependence of the FMR peak width and the greatest absolute change in the peak width with a change in the angle between external FMR field and easy axis of the sample. At the same time, a sample with an AF thickness of 15 nm is characterized by a symmetric angular dependence and a small (about 10 Oe) change in the width of the FMR peak when the sample orientation changes.

Solid solution AuFe nanoparticles synthesized by wet-chemistry methods and their transformation to Au/Fe Janus nanostructures

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In the present work, we show the synthesis of AuFe solid solution nanocrystals, for the first time in ambient conditions, by the methods of colloidal chemistry previously established for a Fe_3O_4-Au core-shell morphology [1]. These AuFe NPs preserve the fcc structure of Au with paramagnetic Fe ions incorporated. Interestingly, the solid solution is metastable at room temperature forming Fe-rich regions in the Au matrix during storage. By *in situ* annealing experiments up to 700°C in a transmission electron microscopy and vibrating sample magnetometry, we prove the segregation of metallic Fe from the AuFe solid solution finally forming Au/Fe Janus NPs. The ferromagnetic bcc Fe (estimated T_N = 1006 K) grows epitaxially on low index fcc Au planes. Therefore, this study provides new insights into the established synthesis of core-shell NPs suggesting completely different underlying mechanisms and final structures. It facilitates the reassessment of possible applications of such NPs leading to a new material for magnetoplasmonics.

We obtained preliminary data on the AuFe optical properties, which proves the presence of the expected plasmon resonance peak at 533 nm. Remarkably, the Fe dissolved in the Au matrix does not alter the Au plasmon peak significantly at similar sizes. We also tested the toxicity of AuFe NPs in human cancer cell lines LNCaP and PC-3. The results indicate that the NPs are non-toxic for these cells for the entire tested concentration range up to 150 µg/mL Au after 48 hours of co-incubation. While large-scale production of Janus Au/Fe NPs with segregated iron and gold phases still has to be optimized, we believe that this new preparation route will allow for a variety of theranostic applications such as magnetic hyperthermia combined with photothermal therapy as well as dual-mode contrast agents for magnetic resonance imaging and computer tomography.

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Nonlinear effects in Co-based ferromagnetic microwires associated with the magnetization reversal process

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The search for new approaches to the miniature magnetic sensor development highlights importance of nonlinear magnetic effects. The sensitivity of dynamic responses of Co-based amorphous microwires (magnetoimpedance [1], domain wall propagation [2]) to magnetic field, mechanical stresses and temperature makes these materials suitable for sensing elements that operate in a non-linear mode. The voltage signal that is generated during magnetization reversal of a bi-stable microwire or during the domain wall (DW) propagation can be decomposed into a harmonic spectrum. The amplitude of the higher harmonics depends on the magnetic structure, and, hence, on the external stimuli causing its change. In this work, the influence of mechanical stress and temperature on the harmonic spectrum of the voltage signal generated by the travelling DW is investigated.

The velocity of the DW was measured by the Siktus-Tonks method. A voltage signal is generated in the coil mounted on the wire when the DW passes through it under the action of an applied magnetic field. The system for studying the harmonic spectrum consisted of a set of coils (primary, generating the driving field, and pickup, detecting the signal due to local magnetization change) and a lock-in amplifier.

Chosen Co-based microwires are characterized by the predominant axial anisotropy although they have a negative magnetostriction. Then in the presence of a tensile stress the overall anisotropy decreases leading to the decrease in the DW surface energy. This will result in decrease of the spin relaxation and increase in the DW mobility, as was experimentally observed (Fig. 1a). It should be noted that this behavior is not typical and is associated with a unique combination of anisotropy and magnetostriction. However, the amplitudes of the odd harmonics decrease with increasing stress (Fig. 1b) which could be due decrease in the volume of an axial domain, which is propagating.

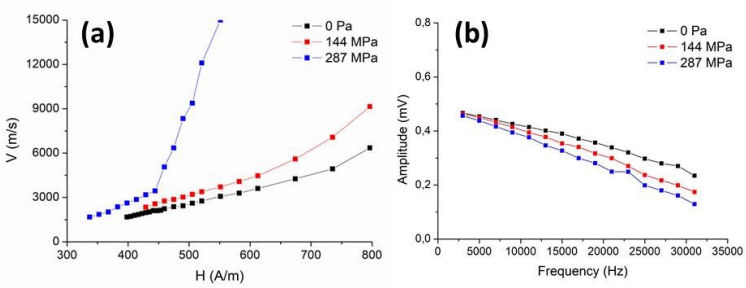

Figure 1. (a) Domain wall velocity of $Co_{71}Fe_5B_{11}Si_{10}Cr_3$ microwire (D/d = 29/25 μm) vs. magnetic field for different tensile stresses; (b) effect of the stress on odd harmonics (f = 1kHz, H_{ext} ~ 400 A/m)

We acknowledge support by RFBR, project number 20-32-90145.

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Colloidal heavily doped semiconductor nanocrystals as an excellent platform for active magnetoplasmonics

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The combination of external magnetic fields and light polarization to actively and remotely modulate the plasmonic response of nanostructures – i.e. magnetoplasmonics – triggered significant improvements in optical nanodevices for telecommunications and refractometric sensing. To this aim, a proper design of the composition and architecture of the nanostructure is needed to achieve a large modulation of the plasmonic response while maintaining a sharp plasmonic resonance. Within this framework, noble metal nanocrystals [1], nickel ferromagnetic nanodisks [2] or hybrid bimetallic nanostructures [3] have been proposed in the literature. A common drawback in the use of hybrid or ferromagnetic magnetoplasmonic nanostructures is the introduction of high optical losses due to the incorporation of a magnetic metal, which broaden the plasmonic response. On the other hand, the use of noble metals is hampered by their relatively weak magneto-optical signal.

To overcome these issues, we propose a paradigm shift in material choice, focusing the attention on a novel class of plasmonic materials: colloidal heavily-doped semiconductors. Employing colloidal dispersions of 9 nm ITO NPs, supporting a plasmonic resonance in the near infrared, we obtained a 20-fold enhanced magnetic modulation with respect to Au, as detected by Magnetic Circular Dichroism (MCD), while maintaining a sharp plasmonic resonance. We ascribed the enhanced magneto-optical response to the reduced effective mass (m*) of free carriers in ITO with respect to most metals, which in turn boosts the magnetic modulation. The latter is given in first approximation by the cyclotron frequency ω_C, which is inversely proportional to m* and directly proportional to the applied field [1,4]. A further enhancement of the magneto-optical response was achieved in F- and In- co-doped CdO (FICO) nanoparticles, which display a 2-fold reduced plasmonic line width with respect to ITO and comparable effective mass [5,6].

Finally, using FICO NCs in a proof of concept magnetoplasmonic refractometric sensing experiment we obtained a superior refractive index sensitivity with respect to the most promising magnetoplasmonic systems reported in the literature,[1-3] and performance competitive with the current state of the art of plasmonic refractometric sensing employing extinction spectroscopy [7], with the advantage of not requiring complicate curve fitting.

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Heating efficiency of magnetic nanoparticles with cubic anisotropy in a viscous liquid

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Nanoparticles with cubic magnetic anisotropy, such as particles of metallic iron [1] or biogenic magnetite [2], distributed in a viscous liquid show very high specific absorption rate (SAR) in an alternating (ac) magnetic field.

In this work a numerical calculation of SAR has been performed for dilute assemblies of spherical nanoparticles with cubic anisotropy in a wide range of diameters, ac magnetic field amplitudes and frequencies. The numerical approach developed takes into account that the spatial orientation of a particle with cubic anisotropy is described by a set of orthonormal directors ($\boldsymbol{n}_1$, $\boldsymbol{n}_2$, $\boldsymbol{n}_3$), in contrast to the case of uniaxial nanoparticle [3]. As Fig. 1 shows, the particles with cubic anisotropy in the range of optimal diameters demonstrate high heating efficiency in a viscous liquid even at small amplitudes of ac magnetic field, H_0 = 50 Oe. The SAR increases rapidly as a function of particle diameter for sufficiently large amplitudes of ac magnetic field. The viscous and magnetic magnetization reversal modes are found for nanoparticles with cubic anisotropy depending on the ac magnetic field amplitude. The range of applicability of the linear response theory for energy absorption is investigated.

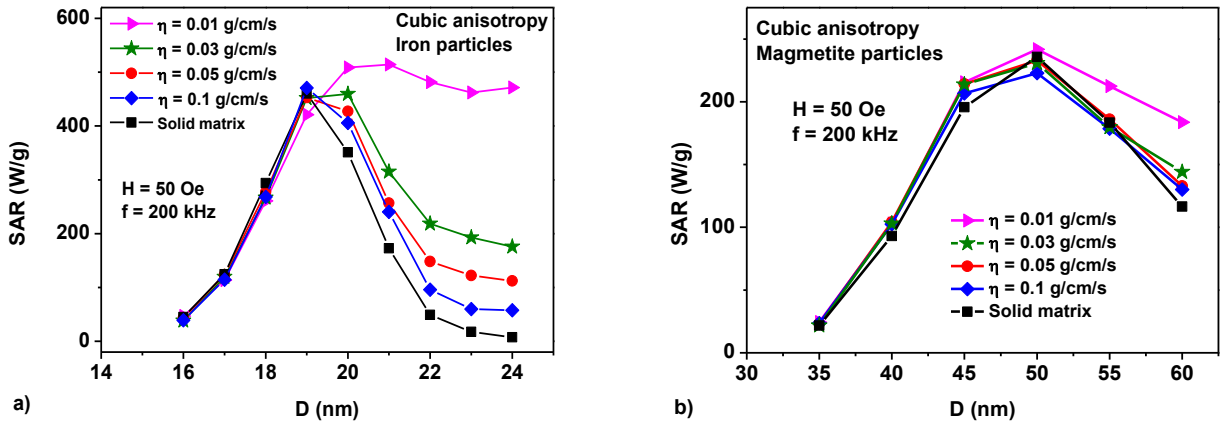

Fig. 1. Comparison of SAR of dilute assemblies of a) metallic iron and b) magnetite nanoparticles distributed in liquids with various viscosities.

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Forced diffusion of diamagnetic particles in the magnetic potential of arrays of ferromagnetic microwires

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Micromagnetic manipulators are widely used in biology and medicine to control the dynamics of nanosized biological objects with weak magnetic properties, as well as to control marked magnetic nanoparticles [1].

In this paper, we propose a system of amorphous microwires with magnetization along the diameter to manipulate diamagnetic particles [2]. An energy minimum is formed between two diametrically magnetized wires, which is characteristic of diamagnetic capture [3]. For a deeper study, diffusion was considered for a given configuration of microwires [3]. The obtained results show that the diffusion of diamagnetic particles (cells) is characterized by a time parameter which depends on particle susceptibility, diffusion coefficient/ and the strength of the magnetic potential for typical parameters of amorphous microwires with a diameter of 15-20 microns and diffusion coefficient of water the time parameter is in the range of 30-50 s. The distribution of diamagnetic particles after a characteristic time shown in Fig.1 demonstrates a sharp particle increase between the wires near the edges where the magnetic potential has a minimum. In the middle part where the potential has a plateau the concentration remains almost unchanged. As this wire configuration is suitable for the diamagnetic capture [2, 3], our result shows that the concentration of the levitating particles will be non-uniform. Thus, this microwire configuration can be used to control the movement of particles (cells).

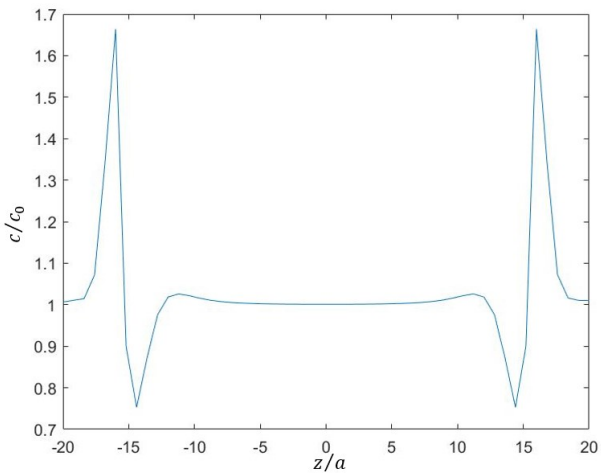

Fig. 1. Distribution of the concentration of diamagnetic particles after 30 s. (normalization to the initial concentration $c_0 = 10^{-2}$, magnetization of microwires along the diameter). Parameters for calculation: wire radius $a = 7\ \mu m$, distance between the wires $d = 2a$, wire length $2L = 32$a, magnetic susceptibility $\chi = -2 \cdot 10^{-5}$, particle volume $V = 10^{-21} m^3$, magnetization $M = 5 \cdot 10^5\ A/m$, temperature $T = 300\ K$.

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Low voltage resistive switching in nanocomposite based on $LiNbO_3$ with embedded magnetic nanoparticles

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Memristors are circuit elements that can change their conductivity under applied voltage bias and preserve resistive state even after external impact is over. Because of this property memristors can be used as synaptic weights in neuromorphic systems (NS). Spiking NSs are promising bio-inspired neuromorphic systems, that can demonstrate high energy-efficiency while solving different cognitive tasks.

One of widely used memristive materials is LiNbO3 with nano particles of metal inside. Its switching between resistive states is caused by forming and destruction of conductive filaments in isolating matrix. Magnetization of nanocomposite at low temperatures had paramagnetic component 3 times bigger, than ferromagnetic. SQUID magnetometry investigation showed that paramagnetic component is determined by dispersed Fe^{2+} and Co^{2+} ions [1]. Introduction of metal nanoparticles into isolator makes this process more pre-defined, decreasing both cycle-to-cycle and device-to-device variability of resistive switching. Nanocomposite memristors are shown to have good operating characteristics, such as: up to 10^6 switching cycles, 10^5s retention time, 256 resistive states; spike-timing-dependent plasticity, dopamine-like modulated plasticity [2], noise-assisted learning, etc. were demonstrated using them. However, they have major disadvantage – relatively high switching voltage (≈ 6V). It may be a result of relatively big voltage decrease on filaments. This issue can significantly increase power consumption. This is why we developed nanocomposite memristors with thin working layer – 30nm of pure LiNbO3 under 60nm of CoFeB LiNbO3 nanocomposite. In this work we demonstrate their switching properties (switching voltage ≈ 2-3V), evaluate endurance, retention time, device to device and cycle to cycle diversities, demonstrate basic and dopamine-modulated spike-timing dependent plasticity (STDP), examined possibility of noise-assisted learning in NSs with these memristors as synaptic weights. For latter experiments we developed self-made analog spiking neuron.

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The dynamic control of magnetic elastomer surface for biomedical applications

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Stem cells play a crucial role in rapidly advancing during the past decade the tissue engineering and regenerative medicine. One of the current challenges is the development of the strategy to induce the targeted differentiation of the stem cells by the control of their local microenvironment. Besides biochemical factors, physical factors such as the mechanical interaction of the cell with the extracellular matrix can modulate cell fate [1]. Magnetic materials, in particular magnetoactive elastomers (MAE), can act as active substrates or scaffolds for cell cultivation and targeted differentiation due to the application of mechanical forces affecting the mechanism of mechanotransduction of stem cells by modulating the morphological properties of the substrate under the action of an external magnetic field [2, 3].

In this work, we present the results of numerical modelling of surface parameters of MAE. Surface roughness as well as morphology and surface topology were numerically simulated. As well as change of these parameters under the influence of external magnetic field. Different types of external surface coating were simulated. The cases of uneven distribution of coating were considered and the influence of coating properties on the final morphology and surface properties were investigated

The effects are based on the assumption about the displacement of magnetic particles inside the elastic matrix under the external magnetic field and the formation of chain-like structures. Such displacement causes deformation and change in surface topology and roughness parameters.

MAE surface profile roughness parameters were calculated using mean square method. To calculate particle redistribution and corresponding change in surface molecular dynamic approach was used. To calculate particle positions, the Verlet integration was used. We considered dipole-dipole model for particle-particle interaction and “springs” model for particle-matrix elastic interaction.

In the model, the magnetorheological system consists of 10^4 magnetic particles which are considered as isotropic and anisotropic samples varying with concentration of magnetic filler, size and space distribution of particles, elastic properties of the matrix, linear dimensions of the sample.

For simulation of the presented model and visualization of the system tool was designed using C++ and Python programming languages.

The presented model allows a better understanding of the processes arising on the surface of MAE that is the key factor to design new materials with the optimal properties for actuation mechanotransduction mechanism in stem cell.

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Static magnetic response of multicore particles

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We present theoretical calculations [1] of the characteristics of the static magnetic response of multicore magnetic particles. A distinctive feature of these particles is that they contain a considerable number ($\sim 10^2$) of nanosized inclusions, representing magnetic single-domain nanocrystallites. We model these "cores" as uniformly magnetized spheres with uniaxial magnetocrystalline anisotropy, the energetic barrier of which is comparable with the thermal energy. So the nanocrystallite magnetic moment is not blocked, and thermal fluctuations result in the stochastic reorientation of the magnetic moment inside the crystallite. It means that we consider the model of a multicore magnetic particle as an ensemble of superparamagnetic nanoparticles, the position and the easy magnetization axis of which are fixed in some random arrays. Here the magnetic moments of a multicore particle are induced by an external magnetic field. The essential point is that the magnetic response of a multicore particle is dictated by the internal rotation of the magnetic moment within each nanocrystallite.

We calculate the field dependence of the crystallite magnetic moment for randomly given directions of the easy axis and arbitrary values of the magnetocrystalline energy barrier. Summing up the field-directed components of the nanoparticle magnetic moments, we get the magnetic moment of the multicore particles under the assumption that that magnetic intercrystallite interaction can be neglected. An important effect is observed here: the weak-field magnetic response of a multicore particle turns out to be independent of the anisotropy energy due to random orientations of the core easy axes.

Our theoretical analysis results in simple expressions for the multicore particle magnetic susceptibility, which can be effectively used for processing experimental data and estimating the magnetic characteristics of multicore particles and their suspensions. The possibility of the prediction of these characteristics is of major importance for applications of these objects in biomedicine and modern technologies.

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Magnetic GrO-Ferrite nanocomposites and core/shell nanostructures for biomedical applications: structure and properties

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The work is devoted to the study of the magnetic structure, phase composition of Graphene-Ferrite (G-F) nanocomposites (NC) and the Core/Shell (C/S) type nanostructures (NS). Interest in these materials is determined by the prospects of their use in biomedicine (see [1-4] and references therein). The main method used for research was Mössbauer spectroscopy (MS), because MS is a highly sensitive and effective means of studying the phase states and magnetic structure of both complex composites and individual components that make up complex magnetic structures as C/S. MS gives possibility to obtain information that is inaccessible to other methods.

The C/S type NS consist of a core, which can have high magnetic moment (for example, iron or others). The core is covered with a magnetic sheath with good biocompatibility. G-F NC consist of graphene and spinel ferrites (for ex. Fe_3O_4, $CoFe_2O_4$). Main advantage of such materials is their versatility, as well as the ability to optimize the physical and chemical properties of the material. Advances in nanotechnology make it possible to manufacture these multifunctional nanomaterials.

In this report describes the results of studies of graphene - various ferrites NC synthesized by the method of ball milling. As shown by Mössbauer studies the magnetic G-F NC synthesized by the ball milled method contain phases identified as spinels and as iron carbides and iron-depleted carbon clusters that were not detected by X-ray diffraction. Those G-F NC were able to retain the functional groups of graphene oxide. The efficacy of the magnetic nanocomposites for killing of cancerous cells is studied in vitro using HeLa cells in the presence of an Alternating Current magnetic field.

In the case of Fe_3O_4 / α-Fe_2O_3 NS of the C/S type, it was established that they consist of a magnetite (Fe_3O_4) core and a maghemite (γ-Fe_2O_3) shell. On the surface of the shell is formed a layer, in which the spin magnetic moments are canted relative to the moments in-side the shell. Between the core and the shell is formed an intermediate layer in the spin-glass state.

As a result of this research, the dependence of the properties of G-F NC and C/S NS on the synthesis technology and particle size was shown, the interaction of the components and their influence on each other, as well as the phase state and magnetic structure, which significantly affect the properties of G-F NC and C/S NS.

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Spectral features of magnetostatic waves optically excited in ferromagnetic anisotropic films

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Femtosecond laser pulses became a powerful tool for driving ultrafast magnetization dynamics with a number of significant advantages over conventional techniques [1]. Consistent evolution of modern magnetism brought femtomagnetism [1] in touch with magnonics [2], as the optical excitation of spin waves (SWs) was demonstrated in transparent dielectrics and metals recently [3, 4]. On the other hand, active optical control of SWs propagation is up-to-date task in magnonics [5]. But the rates of the control are far from ultrafast regime yet. Therefore, exploiting femtosecond laser pulses in reconfigurable magnonics is modern challenge for fundamental magnetism with potential impact on future data processing applications.

In the present study we use two-color optical pump-probe technique with spatial scanning to study the influence of femtosecond laser pulses on propagation of magnetostatic surface waves (MSSW) in ferromagnetic metallic films of iron and galfenol ($Fe_{0.81}Ga_{0.19}$). The feature of the films is pronounced in-plane magnetic anisotropy. We show that this feature provides the opportunity to excite MSSW via ultrafast thermal magnetocrystalline anisotropy changes [6]. Next, we examine feasibility of MSSW control with fs-laser pulses not only during excitation but upon propagation as well. Particularly, we demonstrate experimentally the narrowing of the spectrum of the laser-excited MSSW wave packet as it propagates away from the excitation area [7]. Moreover, we control whether the low- or high-frequency part of the spin waves spectrum is suppressed upon propagation by changing the orientation of external magnetic field with respect to the anisotropy axes. The theoretical description of the effect is given in terms of the spatial gradient of magnetization and anisotropy parameters of the film induced by the laser pulse. The concept of MSSW control by fs laser pulses is extended further by analysing properties of the MSSW optically excited near a Néel domain wall in the thin film. Micromagnetic modelling reveals the appearance of controllable resonance peaks in the MSSW spectrum and shows that the combination of femtosecond optical excitation with magnetic nonuniformity of the film, e.g. a domain wall, serves as a tuneable source of MSSW wavepackets [8].

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Magnetic microstructure and magnetic properties of micro-scale glass-coated wires

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Microscale magnetically soft ferromagnetic wires, have found application in various fields: from devices for reading and coding information to magnetic tweezers in biomedicine [1,2]. In accordance with a specific application, their magnetic and mechanical properties can be changed in various ways, both during the manufacturing process by the Ulitovsky-Taylor method, and during subsequent processing (creation or removal of external stresses, the use of heat treatment and other methods) [3,4]. However, there is currently no understanding of the formation of the magnetic microstructure in the entire vein and its change from the periphery to the center. Therefore, the problem of restoring the domain structure of a microwire is important, and its solution can increase the efficiency of devices based on such materials.

In this work, we have investigated an $Fe_{74}B_{13}Si_{11}C_2$ microwire, its domain structure inhomogeneity along the microwire's long axis and the effect of an external magnetic field on the propagation of domain walls (DWs) in the axially magnetized core and in the radially magnetized periphery. Integral hysteresis loops were measured by vibration and induction magnetometry and the results were used to estimate that the volume of the axial domain is only about 70% and the peripheral domains take 30% of metallic nucleus volume. The results show that the magnetization process in the periphery is crucial for the whole magnetic properties of such wires. The dynamics of the DW motion in the axially magnetized crust was investigated by the Sixtus-Tonsk method, and the field dependence of the DW length was estimated by analyzing the signal shape in the receiving coils. Using the selective sensitivity method [5] in magneto-optical microscopy based on the Kerr effect and the Magnetic Force Microscopy analysis, the surface domain structure was investigated. Based on the solution of the Landau-Livshitz-Hilbert equations, as well as on the energy conservation law, an analytical model was constructed that describes the dynamics of the domain wall of ferromagnetic microwires made of an Fe-based alloy for the regions of the microwire core with different directions of the easy magnetization axis. As a result, the contribution of the magnetization reversal process of each region to the integral magnetic characteristics of microwires was estimated. The micromagnetic simulation of domain structure in entire volume of Fe-based microwire has been performed by mumax software and the Landau-Lifshitz-like structure has been observed.

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Dzyaloshinskii-Moriya interaction in epitaxial Pd/Co films with artificial oxidized magnetic layer

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In this work we study the influence of interface parameters on the perpendicular magnetic anisotropy (PMA) and the interfacial Dzyaloshinskii-Moriya interaction (DMI) of Pd(111)/Co /CoO /Pd thin epitaxial films with different oxidation depths. The lattice parameters of bulk Pd and Co materials are mismatched by about 9,7%, which leads to the appearance of significant elastic strains on the bottom interface, which induced strong perpendicular magnetic anisotropy [1]. Epitaxial Si(111)/Cu(2 nm)/Pd(2 nm)/Co(1 nm) films were grown by molecular beam epitaxy in ultrahigh vacuum chamber. After deposition of ferromagnetic layer, films were exposed the procedure of artificial oxidation with dry oxygen. We varied the oxide thickness and this way we changed ferromagnetic thickness. Determination of the thickness of the magnetic layers carried out by measuring the saturation magnetic moment with vibrating samples magnetometry. Magnetic structure was investigated by a magneto-optical Kerr effect (MOKE) microscope. The MOKE microscope was equipped with a hand-made coil applying out-of-plane magnetic fields and an in-plane electromagnet. The out-of-plane coil was used in pulse mode and produced magnetic fields with an amplitude up to 600 Oe and a width down to 2 msec.

Artificial oxidation of magnetic layer leads to symmetry breaking on the bottom and top magnetic interfaces in epitaxial films, which reduces compensation of interfacial DMI. Moreover, including of oxide layer is eliminate the asymmetrical contribution of chiral dumping in comparing with symmetrical Pd/Co/Pd[2] structures, it following from symmetrical parabolic shape of domain walls velocity curves as shown on figure 1(b).

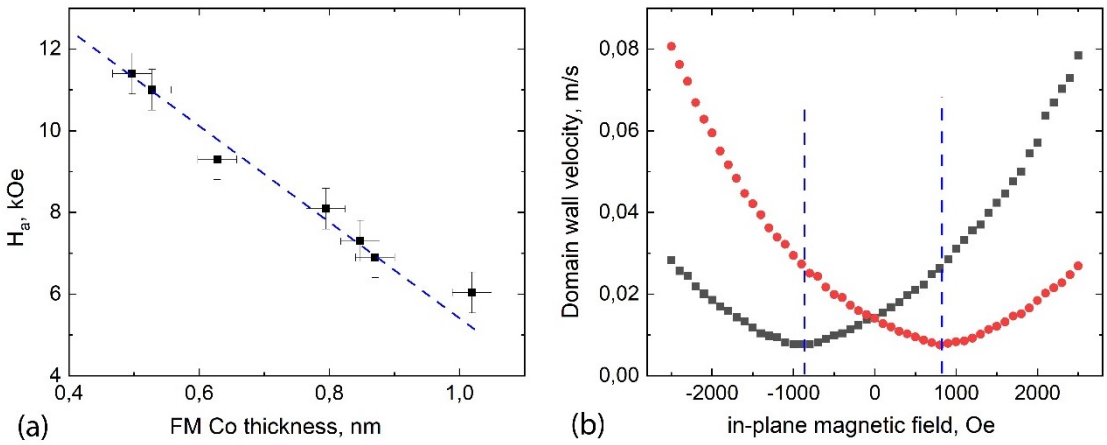

Figure 1: (a) Anisotropy field as a function of thickness of ferromagnetic cobalt layer, (b) domain walls velocity curves

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Magnetic phase transitions in the new multiferroic $SmCr_3(BO_3)_4$

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The rare-earth chromium borates $RCr_3(BO_3)_4$ (R = La, Nd, Eu, Sm, Gd, Tb) are ordered antiferromagnetically at temperatures of 6.5-10 K [1–5]. This family crystallizes in rhombohedral (structure of the mineral of huntite with space group $R32$) or monoclinic (space group $C2/c$) modifications [5]. X-ray structural data and FTIR studies showed that these crystals are characterized by the coexistence of two polytypes ($R32$ and $C2/c$) [5-6]. The authors of [7] presented the first spectroscopic data on $SmCr_3(BO_3)_4$, which indicated a phase transition at a temperature of about 5 K. In this work, an in-depth spectroscopic study of $SmCr_3(BO_3)_4$ was carried out, and its heat capacity and magnetic susceptibility were measured. Analysis of the phonon spectra in the IR region shows, that the sample is not a single phase.

From an analysis of the spectra of the Kramers Sm^{3+} ions, as well as from an analysis of the temperature dependence of the heat capacity and magnetic susceptibility, it was found that the $SmCr_3(BO_3)_4$ undergoes a cascade of phase transitions at the temperatures T_1 = 7.8 K, T_2 = 6.7 K, and T_3 = 4.3 K. From all the data received, we conclude that at the temperatures T_1 and T_2, antiferromagnetic ordering of the magnetic subsystem of chromium occurs in the $R32$ and $C2/c$ phases, while the nature of the phase transition at T_3 is still unclear. A noticeable displacement of the phonon lines at phase transition temperatures may indicate the presence of a spin-lattice interaction. This behavior is characteristic of multiferroics and has often been observed in other similar compounds $RFe_3(BO_3)_4$ [9,10].

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Optimal control of magnetization reversal by means of applied magnetic field

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We present a general method of finding magnetization switching protocols optimizing energy cost of the switching. Minimization problem is described in terms of the path taken by the magnetic system from the initial to final state with switching time as a freely adjustable parameter. Solution to that problem – called the optimal control path (OCP) – is used to calculate the amplitude and direction of the magnetic pulse realising the obtained trajectory.

We apply the method to a macrospin [1] and a nanowire [2] with easy axis anisotropy as well as a macrospin with both easy and hard axis anisotropy [1] and obtain nontrivial switching protocols. For a macrospin and short nanowires (which predictably behave like macrospin systems) with just the easy axis anisotropy the optimal switching is realised by chirped microwave pulse with smoothly changing amplitude. For longer nanowires, the pulse becomes non-uniform and the switching is assisted by spin waves generated in the system. For a macrospin with both easy and hard axis it is possible to utilize the internal dynamics to aid the switching process and lower the energy cost.

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The nucleation rate of domain wall reversal at plane ferromagnetic stripe: numerical and phi-in-quadro models comparison

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Following Brown 1D model [1] of the nucleation rate we extend the theory to 2D, adding the dimension Oy ($0<y<l$), orthogonal to the domain wall propagation axis Oz ($0<z<L$) at a narrow ($l<<L$) plane ferromagnetic stripe. The size of the whole sample is supposed to be small enough to be one-domain. The magnetization reversal in presence of a magnetic field goes via a saddle point corresponding to either π or 2π Bloch walls used as a model for a nucleus of the transition state. The dynamics of the transition is described by the Landau-Lifshitz-Gilbert equation, which is enriched by the source of fluctuations (Langevin term is taken into account). In the framework of a generalized Fokker-Planck theory we calculate the transition rate. The Fokker-Planck equation is approximately solved by the method developed in [2]. This method uses 1D phi-in-quadro kink ansatz along z direction and harmonic functions of variable y satisfying boundary conditions at the points 0 and l. The final expression for nucleation rate is derived in terms of Maslov (quasiclassical) functional integral.

The analytical result for the continuous model is compared with numerical estimation in harmonic transition state theory for the discrete Heisenberg model [3]. Transition rate in both approaches satisfies the Arrhenius equation. The equation contains two prefactors of dynamical and entropy origins. The prefactors in the two models are compared. The numerical results demonstrate limits of the analytical approach for the description of transition in the real magnetic stripes.

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Torsion mode of the magnetoelectric effect in a Metglas / GaAs layered structure

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When observing the magnetoelectric effect, different modes can be observed depending on the features of the excitation, fixation of the magnetoelectric (ME) structure, and the frequency of the alternating magnetic field. Such as longitudinal, bending, thickness, etc. Recently, interest has arisen in the study of the torsional mode. Recently, the torsional mode of the ME effect in a YIG / GaAs layered structure has been studied [1]. Also in [2], the delta-E effect was investigated on torsional and bending modes in a layered FeCoSiB / AlN ME structure on a polysilicon substrate. In this report, a layered ME structure Metglas / GaAs with dimensions of 20 mm × 5 mm × (625 + 58) μm was investigated. The calculation took into account the specificity of the torsion for the ME structure with a rectangular cross section based on the Saint-Venant hypothesis. When twisted around the length, the fundamental resonant frequency was of 162 kHz, the maximum ME voltage coefficient was of 11 mV cm^{-1} Oe^{-1}. When twisted around the width, the fundamental resonance frequency was of 649 kHz, the maximum ME factor in voltage was of 0.7 mV cm^{-1} Oe^{-1}. The results obtained can find application in the design of new ME devices.

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Optimizing the design of magnetically hard $SrFe_{12}O_{19}$ based nanocomposites

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Magnetic nanocomposites (NCs) have gained a lot of interest over the last years, due to the possibility to finely control and modify their features at the nanoscale, which allows to extend their applicability in a multitude of energy-related technological areas [1]. In this regard, exchange coupled hard-soft NCs have received significant attention, as a promising strategy to achieve high magnetic performances [2]: the main challenge is to develop systems which simultaneously show a large coercivity (H_C) and high magnetization. Hereby our focus is on the optimization of hard $SrFe_{12}O_{19}$ (SFO) ferrites´ magnetic performance, in order to be used as building block in bi-magnetic NCs [3].

This work is aimed at extensively studying the role of diamagnetic Al^{3+} in the tuning of the magnetic properties of a series of SFOs obtained by sol-gel self-combustion synthesis ($SrFe_{12-x}Al_xO_{19}$ with x ranging from 1 to 2.4). By means of X-ray powder diffraction (XRPD), transmission electron microscopy (TEM) and SQUID magnetometry we demonstrate that the magnetic behavior of the different samples is closely related to their size, morphology and elemental composition. The resulting partial occupation of diamagnetic Al^{3+} in specific Fe^{3+} sites of the hexagonal ferrite structure affects the magnetic moment as well as the magnetic order: by increasing its amount, the resulting magnetization is reduced, hinting at the modification of the magnetic collinearity, although the coercivity is hugely enhanced (up to 943 kA/m). Based on these results, we have designed and prepared bi-magnetic NCs by introducing a magnetically softer $CoFe_2O_4$ phase in different fractions (up to 20 w/w%). We address the sol-gel self-combustion chemical approach as a unique way to develop such NCs, compared to physically mixing [4], and our results clearly show that the synthesis strategy plays a critical role in the extent of magnetic coupling that can be achieved between the hard-soft phases.

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Magnetostriction in Fe-Ga alloys: effect of rare-earth elements doping

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The magnetostrictive Fe-Ga alloys are the most popular object for investigation in the last two decades. At present, the interest of researchers shifted toward the study of ternary alloys based on Fe-Ga system with a small amount of rare-earth elements [1-3].

In the present work, the effect of rare-earth elements on magnetic properties of Fe-Ga-Re (Re=Tb, Pr, Er) alloys was investigated by using density functional theory implemented in the *ab initio* software program package VASP [4,5] within the generalized gradient approximation PBE parametrization [6]. Geometric optimization and calculation of the magnetocrystalline anisotropic energy (E_{MCA}) were done for the $D0_3$ structure (#225 group of symmetry) with the 128 atom-supercell for $Fe_{81.25}Ga_{18.75}$ composition ($Fe_{104}Ga_{24}$ in terms of the supercell approach). The spin-orbit coupling was included in calculating the E_{MCA}. For ternary alloys, one atom of iron located at Ga-sublattice (4*a* positions) was replaced by an atom of Re ($Fe_{103}Ga_{24}Re_1$). Curie temperatures were estimated by means of Monte Carlo simulations of Heisenberg Hamiltonian.

Fig.1 shows that the Re doping changes the easy-axis of magnetization (bold data in square brackets in fig. 1(a)) and the sign of magnetostriction from positive to negative. The Curie temperature is decreased with an increase in the number of 4*f*-electrons.

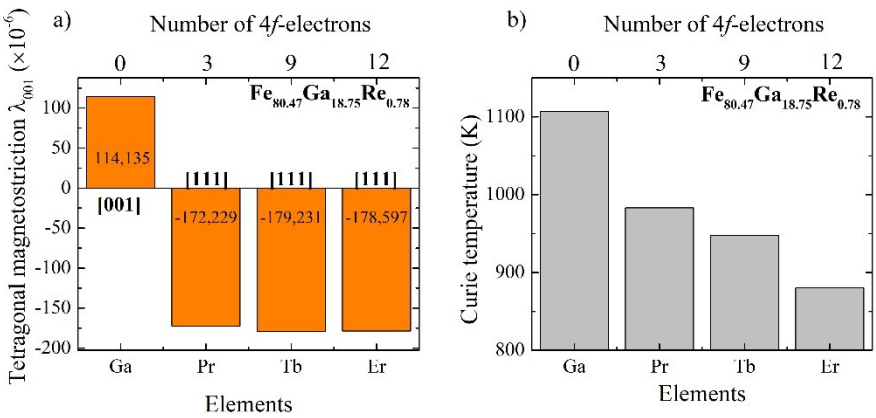

Fig.1 (a) Calculated tetragonal magnetostriction and (b) Curie temperature depending on rare-earth elements with the different number of 4*f*-electrons in $Fe_{81.25}Ga_{18.75}$ alloys.

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Layered crystal structure in Fe-Ni-Al Heusler alloys: effect on structural and magnetic properties

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Heusler alloys are intensively studied for the last several decades due to their distinguishing multifunctional properties such as large magnetic-field-induced deformation, magnetoresistance, magnetostrain, magnetocaloric and shape memory effect. These properties strongly depend on the composition, structural stability, and crystal ordering. In this work, we study from the first principles the structural stability at zero and finite temperatures as well as structural and magnetic characteristics of $Fe_2Ni_{1+x}Al_{1-x}$ (x = 0, 0.25, 0.5, 0.75, 1) Heusler alloys. The replacement of Al by Ni will lead to FeNi, which is of interest because its $L1_0$ ground state possesses a large uniaxial magnetocrystalline anisotropy energy (MAE). This makes it attractive as a low-cost permanent magnet [1, 2] but the $L1_0$ equilibrium phase is found in meteorites, only.

We performed full geometric optimization with the help of VASP using the PBE exchange-correlation functional within a supercell approach to reveal the effect of crystal ordering on the structural and magnetic properties. We considered new types of layered structures such as the tetragonal T^p and T^c [3] to find favorable structural motives at zero temperatures. Similar to our previous study on Ni-Mn-Ga Heusler alloys [4], we covered chemical and structural stability in combination with magnetic properties at finite temperatures. For this, we took into account the lattice contribution to the free energy derived from phonons calculations as well as electronic contribution and mixing entropy. Magnetic exchange interactions were calculated with SPR-KKR-CPA approach from which we obtain the Curie temperatures within the mean-field approximation.

We found that compositions with x = 0 and 0.25 have a T^p ground state with nearly cubic lattice parameters and are stable with respect to the tetragonal distortions, while the further increase of Ni content results in martensitic instabilities. T^p austenitic Fe_2NiAl has a large MAE of the same order as the one of FeNi tetrataenite. This makes T^p- Fe_2NiAl a promising candidate for a novel permanent magnetic material made of abundant constituents.

This work was supported by DFG TRR 270 (subproject B06), RFBR No. 20-42-740003, and the Ministry of Science and Higher Education of the Russian Federation within the framework of the Russian State Assignment under contract № 075-00992-21-00. Phonon calculations were performed on the MagnitUDE supercomputer of the University of Duisburg-Essen.

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Bound states in the continuum in magnetophotonic metasurfaces

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Control of light by an external magnetic field is one of the ways for modulation of its intensity and polarization. Magneto-optical effects at the nanoscale are usually observed in magnetophotonic crystals, nanostructured hybrid materials, or magnetoplasmonic crystals [1]. The quality factor of resonances in these samples is typical of order 50, limiting the value of magneto-optical effects. Recently, a new approach is introduced in nanophotonics. Asymmetrical shapes of nanostructures lead to the high-Q resonances with the order of 1000 [2]. The nature of these peculiarities is the interaction of "bright" and "dark" modes. Symmetry breaking allows realizing a regime of quasi-bound state in the continuum resonance (BIC) [3]. Such an approach seems to be promising for various applications like optical filters, lasers, sensors [4] and provides new opportunities for light control. To act as an active device, a structure should be sensitive to external influence. One of such stimuli may be a magnetic field. In magnetophotonic and magnetoplasmonic metasurfaces, near-field coupling between nanoparticles leads to an enhancement of the magneto-optical response upon spectral overlapping of resonances [5]. In this research, BIC is used to enhance magneto-optical effects [6].

The magneto-optical intensity and polarization effects are studied in all-dielectric metasurfaces with broken symmetry. A 2D array of asymmetric bismuth substituted yttrium iron garnet (Bi:YIG) nanodisks placed on a SiO2 substrate is considered. The garnet disk comprises an air hole that is displaced from the center of the disk. The degree of asymmetry is defined as the ratio of the air hole displacement to the disk radius. The quasi-BIC state leads to a high-Q resonance, which enhances both the magneto-optical intensity and polarization effects.

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Ultrafast optics of metal-dielectric magnetoplasmonic metasurface

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The recent advances in surface nanostructuring open the door for the novel sophisticated magnetoplasmonic systems, such as multi-resonance magnetoplasmonic metasurface [1]. Taking advantages of various resonances coupling, the multi-resonance metasurface creates new means of light properties modulation. In this regard, ultrafast control of the resonances of different nature offers the attractive possibility to tune light in the specific and fastest way. Here, we report on ultrafast modulation of optical response in multi-resonant magnetoplasmonic metasurface induced by 50 fs laser pulse.

The studied magnetoplasmonic metasurface is a square array of 100 nm gold nanospheres with a period of 600 nm embedded into 100-nm-thick Bi-substituted yttrium-iron garnet (Bi:YIG) layer placed on quartz substrate. The structure supports the excitation of electric dipole (730 nm) and quadrupole (610 nm) plasmonic resonances in gold nanospheres, as well as the resonance associated with the excitation of the quasi-waveguide mode (527 nm) in dielectric layer. The ultrafast optical response was measured in pump-probe experimental scheme in a transmission configuration and defined as a differential transmittance coefficient $\Delta T/T$. The pump pulse was resonant to dipole mode, the broadband probe pulse covered spectral range from 450 to 750 nm.

The differential transmittance spectrum measurements for the 500-femtosecond, 5- and 50-picosecond delay of the probe pulse reveals the different temporal behavior of the resonances. The attenuation of dipole resonance amplitude is significantly faster as compared to quasi-waveguide mode resonance. The ultrafast modulation of the optical response of a magnetoplasmonic metasurface is attributed to the pump pulse interaction with electron and phonon systems of the metasurface. The temporal investigation of the resonances associated with the electronic systems of gold nanospheres and yttrium-iron garnet allows us to distinguish the modulation of the optical response of metal nanospheres and the dielectric layer. According to measured transient differential transmittances, the pump-pulse-induced electron dynamics in yttrium-iron garnet is delayed in comparison to gold nanospheres.

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Specific absorption rate of magnetic ferromagnetic nanoparticles having a Biaxial Anisotropy

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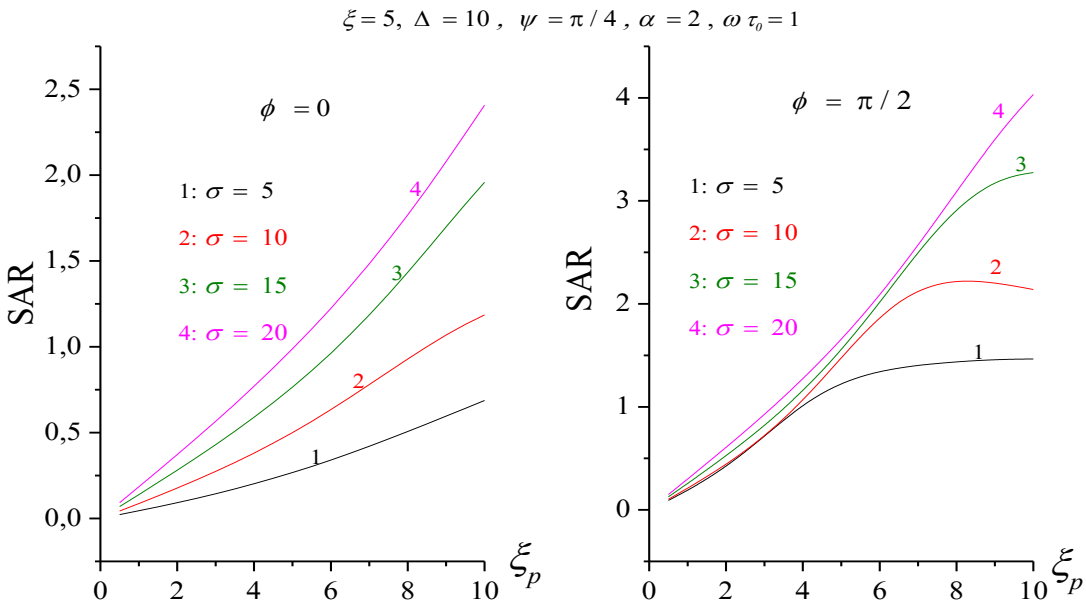
Hyperthermia therapy is the process of treating cancer by applying heat. It involves raising the temperature of the cells to between 40°C and 43°C [1]. If the temperature is raised above 43°C and held for 30 to 60 minutes, the heated cells erupt in a process known as necrosis, causing a reduction in tumor size [2]. In the context of magnetic hyperthermia, several physical parameters are used to optimize the heat generation and these include the particles concentration and the magnitude and frequency of the external AC magnetic field. Here we present numerical calculation of Specific absorption rate (SAR) of magnetic biaxial nanoparticles, we show that our calculation of the non linear magnrtic susceptibilty [3,4] and the SAR based on the matrix continued [5] fraction is consistant with the physiological emperical criterion that relies on an upper limit for H0f and we provid a physicist's rationale for it.



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Magnetic properties of the amorphous magnetic microsprings

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Amorphous magnetic materials have proven to be promising for various applications, including sensible elements and detectors, theft protection systems, and many others [1]. Nevertheless, rapid technological evolution requires the development of novel functional materials with advanced properties. For instance, amorphous ferromagnets with tunable anisotropy can be extremely promising for portable devices or filter systems. In this work, amorphous magnetic microsprings were investigated.

Amorphous magnetic microsprings were produced from Co-based microwires with metallic core diameter 50-100 μm. Two series of springs were considered. The first series included long springs coiled on the fiberglass or polyamide core with a winding diameter of 500-700 μm. Winding density varied from sample to sample. For the investigations, 15 mm pieces were cut from the samples. The second series included short springs with 3-5 spiral turns (length of 500-900 μm) without a dielectric core with a winding diameter of 500-900 μm. Two samples have an amorphous metallic core.

Magnetic properties of the samples were investigated at room temperature in the magnetic field range ±10 kOe using VSM Lakeshore 7407 at room temperature. The magnetic field was applied along the axis of the spring and in the transverse direction.

Magnetization field dependences (Figure 1) obtained for the long samples demonstrate the step-wise change of the magnetic permeability with field, which can be attributed to the change of the dominant magnetization mechanism. In the densely wound samples, the magnetization curve has the same shape in the both axial and transverse direction, what describes isotropic response of the sample. For the short samples, it was obtained, that the transverse direction corresponds to the easy magnetization direction. The shape of the transverse hysteresis loop is similar to those for a single microwire. For the wire with a ferromagnetic core, easy axial direction was obtained.

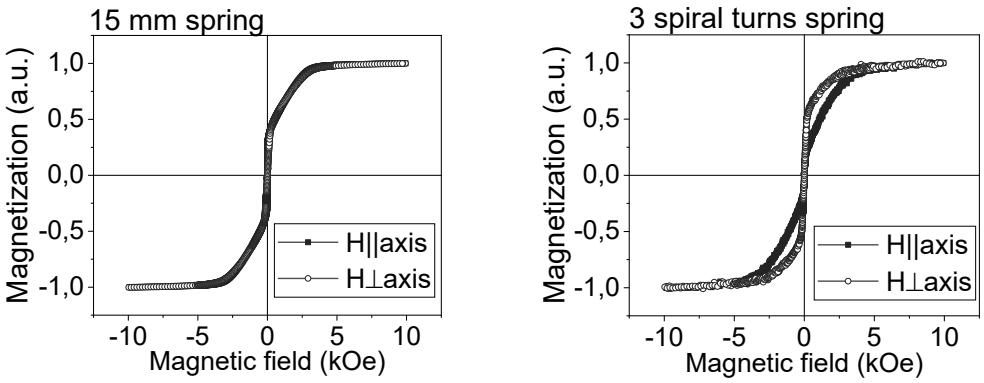

Figure 1. Hysteresis loops of 15 mm amorphous microspring (1st series) (a) and 3 spiral turns microspring (2nd series) measured in axial and transverse directions.

The results obtained prove the possibility of tuning the magnetic anisotropy in amorphous microspring structures.

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Cellular internalization of iron oxide magnetic nanoparticles induce oxidative stress in T-lymphoblastic leukemia cells

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Acute lymphoblastic leukemia (ALL) is a disease caused by the uncontrolled proliferation of malignant immature lymphocytes in the peripheral blood, bone marrow and other organs. ALL is one of the most common types of blood cancer in children (up to 75 - 80%), which creates the need to develop effective methods of treatment. Magnetic nanoparticles (MNPs) based on iron oxides are perspective objects for use in anti-leukemia therapy. However, information about their interaction with cellular structures is contradictory. In the experiments, we used (Fe_3O_4) nanoparticles with an average size of 9 ± 3 nm, obtained by the coprecipitation method. A T-lymphoblastic leukemia cell line (Jurkat) was used as a tumor cell model. Human peripheral blood mononuclear cells (PBMCs) were obtained from the blood of healthy donors by using gradient centrifugation method and were used as a model of healthy cells. The cell lines were cultivated in an amount of $5x10^5$ cells/ml for 24 h. The concentration of MNP was 100 µg/ml of the nutrient medium. An external static magnetic field (MF) of various strengths was used as an additional factor. Analysis using the cell dye WST-1 showed a significant decrease in the viability of Jurkat cells after cultivation in the presence of MNPs outside the MFs sources (data not shown). At the same time, the viability of MNCs was not inhibited. The application of an external magnetic field enhanced the cytotoxic effect of MNPs on the Jurkat cell line (data not shown). Further analysis using flow cytometry (dihydroethidium staining) showed an increase in free oxygen forms in Jurkat cells after cultivation in the presence of MNPs (Fig 1.). Granularity increase of Jurkat cells is associated with the internalization of MNPs into cells. This was also confirmed by microscopy using the Prussian blue dye (accumulations of intracellular iron were found in experimental cells). Thus, the studied MNPs cause oxidative stress through internalization in Jurkat cells, but do not have an inhibitory effect on healthy cells (PBMCs), which can be used in the future for the development of anti-leukemia therapy based on nanoparticles.

The research was supported by the 5 top 100 Russian Academic Excellence Project at the Immanuel Kant Baltic Federal University.

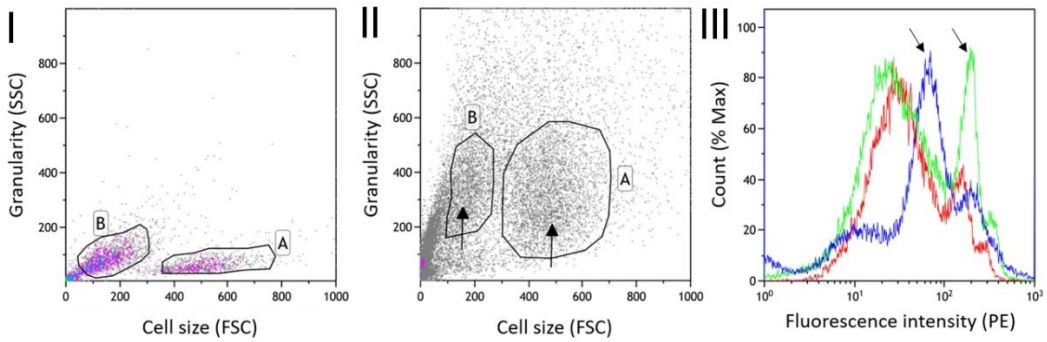

Figure 1. Granularity increase in Jurkat cells subpopulations (A, B) after 24 h cultivation in the presence of 100 µg/ml MNPs. I – control cells, II – treated cells. III – induction of ROS in Jurkat cells: red, green and blue curves indicate the cases of untreated cells, after 24 h incubation with 100 µg/ml MNPs, and after 24 h treatment with 100 µg/ml MNPs in the presence of permanent magnets, respectively. Data were measured by flow cytometry after PI staining.

Electric field as a “foaming agent” in micromagnetism: how to blow magnetic bubble domains and skyrmions

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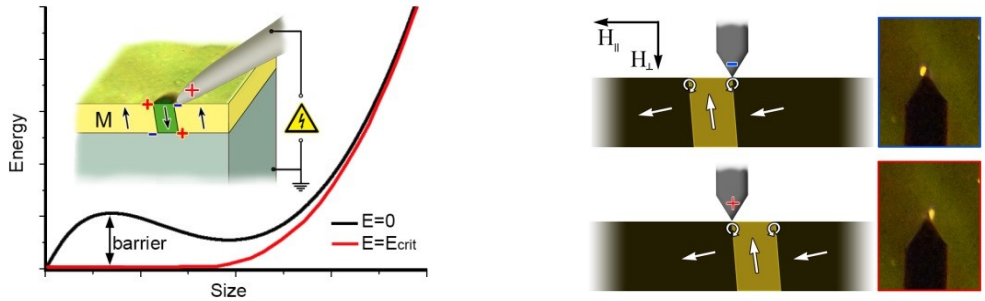
Recently there have been several reports on electric field-induced generation of magnetic topological defects: the magnetic skyrmions switching [1,2], the electric nucleation of magnetic bubble domains [3], and strain-mediated electric-field control of skyrmions [4].

In spite of the different microscopic mechanisms of these effects they have one thing in common: the surface energy of magnetic domain wall is modified facilitating the nucleation of the magnetic inhomogeneity.



a) b)

Fig.1 The electric field nucleation of the bubble domains: a) the composite experimental/schematic picture of 180^0-bubble domain generation by electric tip [5] b) the electric field-induced nucleation of 90^0-domain by AFM cantilever tip (schematics and corresponding magneto-optical pictures) [6].

The origin of magnetic bubble domain nucleation in iron garnet films will be discussed in details. The extensive experimental data on nucleation of bubble domains with 180º- and 90º-degree domain walls evidence for the mechanism proposed by I. Dzyaloshinskii [7].

The electric field has a dual effect on the magnetic structure: as a kind of “soap” lowering the surface tension of the domain walls and as a “blowing agent” acting with a pressure on domain walls and inflating the bubble due to the effect of electric field-driven magnetic domain wall motion.

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Contactless control of the dynamics of non-magnetic liquid and gas inclusions in a magnetic fluid

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Despite a significant number of works devoted to the dynamics of magnetic fluid systems containing gas and liquid nonmagnetic inclusions most of them address magnetic levitation in either uniform magnetic fields or inhomogeneous fields of a simple configuration. On the other hand, an interplay of interphase surface forces and magnetic forces induced by special field configuration can play the role of an efficient contactless controller for producing and manipulating gas/liquid drops. Such an approach, which is practically unexplored now, looks promising in the problems of microfluidics since magnetic fluids have certain advantages over electrorheological carrier conventionally fluids used recently due to more simple and efficient realization of governing conditions.

The principal scheme of the setup's configuration and results of the experiment are presented in Figure 1. The stages of evolution of the surface of a volume consisting of a nonmagnetic liquid levitating in the magnetic fluid carrier are considered when a drop is detached from the former relatively to the distribution of isolines of the external magnetic field intensity modulus. It is established experimentally that the skittle-shaped envelope of the volume containing the non-magnetic liquid of interest is well-coordinated with these isolines that makes possible a quantitatively accurate production of desired microbubbles.

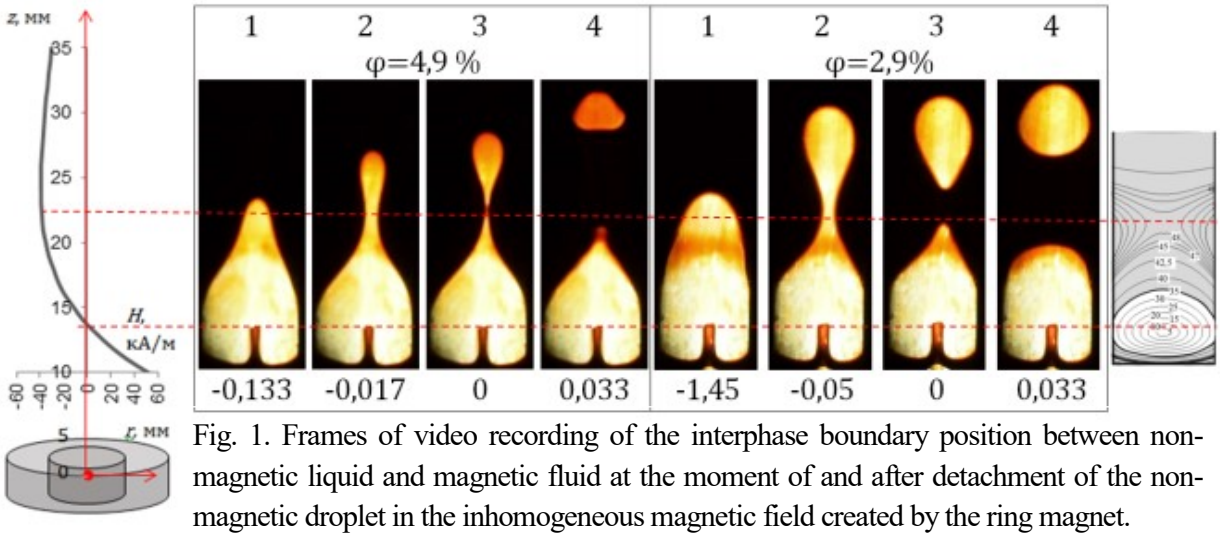

Fig. 1. Frames of video recording of the interphase boundary position between non-magnetic liquid and magnetic fluid at the moment of and after detachment of the non-magnetic droplet in the inhomogeneous magnetic field created by the ring magnet.

The dependence of the size of the non-magnetic liquid and gaseous inclusions on MF and MF parameters revealed and confirmed by a comparative analysis based on several methods. This makes such magnetofluid systems attractive not only for studying fundamental phenomena in the ferrohydrodynamics of multiphase systems but also for developing microdosers or gas counters for microfluidics applications.

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Specific absorption rate of elongated polydisperse assemblies of magnetic nanoparticles

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A polydisperse mixture of Fe_3O_4 nanoparticles with a diameter distribution in a range of 17 - 70 nm was obtained by splitting macro samples of magnetite in a flow of cavitation bubbles [1]. The specific absorption rate (SAR) measurements were carried out both for 3D assemblies of nanoparticles and for very elongated clusters (see Fig. 1a) obtained in high enough applied magnetic field in 4% agarose gel which rigidly fixes particles positions. As Fig. 1b shows, while for 3D assembly the SAR in ac magnetic field with amplitude H_0 = 250 Oe and frequency f = 393 kHz is only 140 W/g, it increases up to 600 W/g for the assembly of elongated clusters for the case when ac magnetic field is parallel to the long cluster axes. On the other hand, the SAR of the clusters is very small, 30 W/g, when the ac magnetic field is applied perpendicular to the cluster orientation. The experimental results obtained are qualitatively confirmed by means of numerical simulation of behavior of polydisperse assembly of elongated clusters based on solution of stochastic Landau-Lifshitz equation.

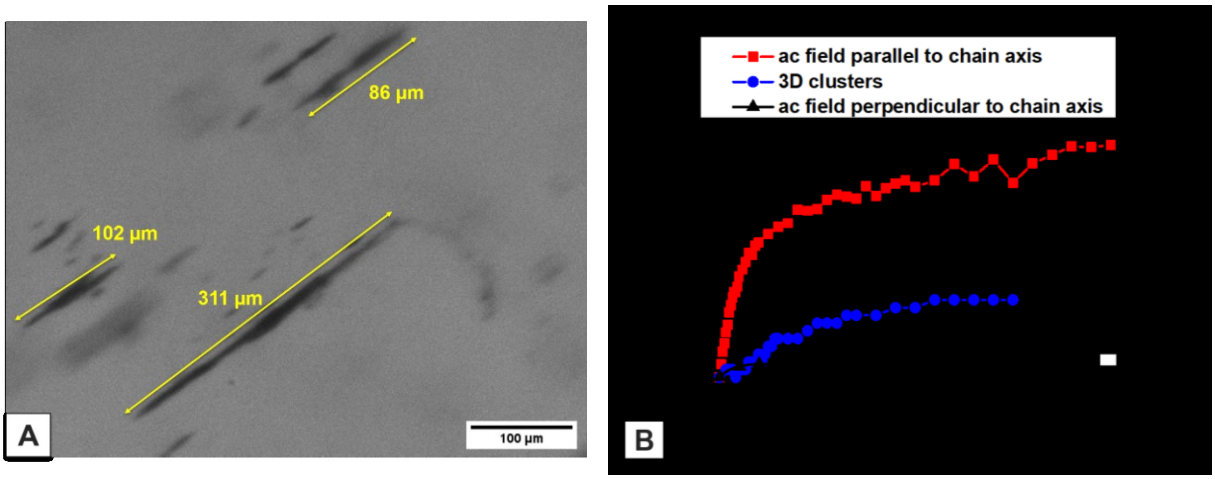

Fig. 1 a) Image of assembly of elongated micro clusters of magnetite nanoparticles in 4% agarose gel obtained in applied permanent magnetic field H = 1.2 T; (b) Thermal curves measured for 3D and for elongated polydisperse clusters of magnetite nanoparticles at H_0 = 250 Oe and f = 393 kHz.

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Tunable spin-wave propagation in the ensembles of magnonic stripes

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The recent advances in dielectric magnonics [1-2] push forward the integration of spin-wave computational paradigm towards the integration with CMOS-based materials [3]. In light of this. research has been directed towards the use of spin waves for signal processing at microwave and subterahertz frequencies due to the possibility to carry the information signal without the transmission of a charge current [1,2]. In the present work we demonstrate the experimental observations of the strain-mediated spin-wave coupling phenomena in different magnonic structures based on the asymmetric adjacent magnonic crystals, adjacent magnetic yttrium iron garnet stripes and array of magnetic stripes, which demonstrates the collective spin-wave phenomena. The voltage-controlled spin-wave transport along bilateral magnonic stripes was demonstrated (Fig.1). The model describing the spin-wave transmission response and predicting its value is proposed based on the self-consistent equations [4-6]. We also presents the results of investigation of the spin-wave propagation and spin-resonances formation in the metasurface formed from the meander-shaped ferromagnetic structure. It was demonstrated that the strain can be used to engineer energy-efficient complicated 2D and 3D piezoelectric material and heterostructures [7].

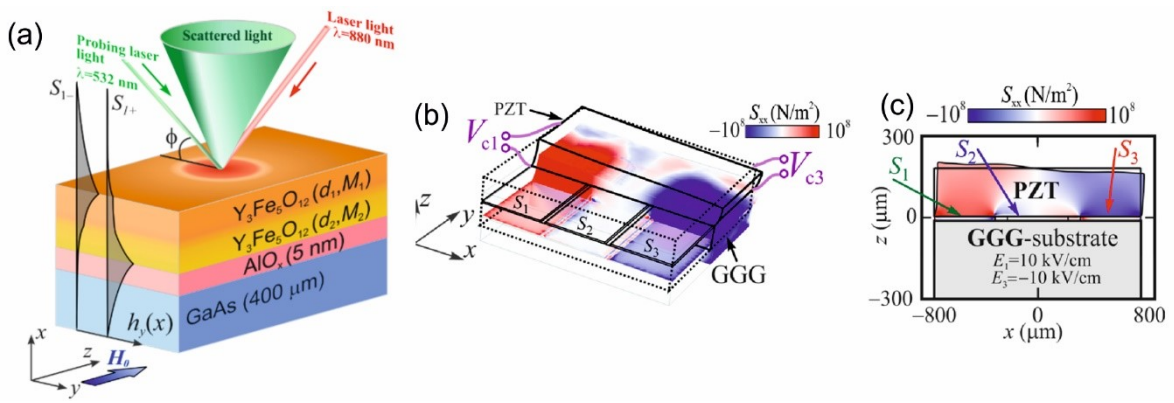

Fig1.(a) Schematic of the BLS experiment (b) Distribution of stress tensor component S_{xx} showing a local deformation of PZT layer; (c) induced stress in the YIG/PZT structures at the applied electric field E_1=10kV/cm.

This work is supported by the Russian Science Foundation (Project No. 20-79-10191) and Grant (MK- MK-1870.2020.9) of the President of RF.

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Influence of fiber diameter on magnetoelectric effect in flexible composite

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Magnetoelectric (ME) effect manifests itself as a change in polarization under the action of magnetic field. The effect in composite structures arises due to the combination of the magnetostriction of the ferromagnetic (FM) layer and the piezoelectric effect in the piezoelectric (PE) layer [1]. The largest ME effect was observed in flexible composites based on piezoelectric polymers and piezoelectric fiber composites [2]. Therefore, further development of flexible ME structures is of interest. In particular, the study of structures based on a magnetostrictive fiber composite (MFC), which is a magnetic analogue of a piezoelectric fiber composite [3].

In this work, the magnetoelectric effect was investigated in three flexible composite structures PVDF-MFC. MFC consisted of one layer nickel wires of 100, 150, and 200 μm in diameter placed parallel and tightly to each other and immersed in a polymer matrix. The dimensions of the PE and FM layers in the plane were 25 mm × 13 mm and 15×11 mm, respectively. The PVDF layer thickness was 28 μm. The layers were glued together using cyanoacrylate adhesive. The structures were placed in a constant magnetic field H up to 3 kOe, directed along or perpendicular to the wires. An alternating magnetic field $h\cos(2\pi ft)$ with an amplitude h up to 25 Oe was directed along the wires. ME voltage generated by the PE layer was measured by a voltmeter. The frequency, field, and amplitude dependences of the ME voltage were investigated. The effects of nonlinear frequency doubling and generation of combination harmonics were also investigated.

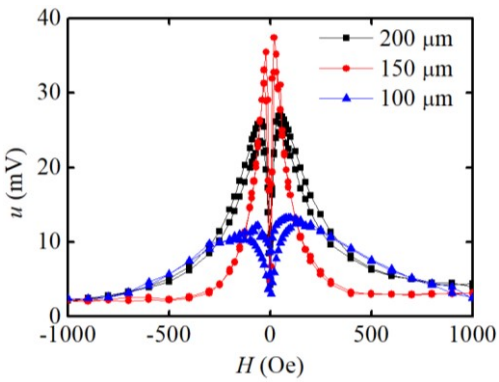

Figure 1. Magnetoelectric voltage dependencies on magnetic field of different PVDF-MFC composites.

Field dependences of the ME voltage of structures with different MFCs are shown on Figure 1. It can be seen that the highest ME voltage $u \approx 36$ mV was observed for a sample with an MFC of 150 μm in diameter. At the same time, the largest field H_m, where the ME voltage is maximal, was observed for a sample with a wire diameter of 100 μm. Its value was ~90 Oe, which is ~3 times higher than those for the other samples. The form of dependences is determined by the form of the first derivative of magnetostriction $\lambda^{(1)}$ with respect to magnetic field. The amplitude of the voltage generated by the ME structure was proportional to the effective contact area of the wires, as well as the magnitude of the MFC piezomagnetic coefficient.

The work is supported by projects of the RFBR (grants no. 18-502-12037, 20-32-90190).

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Magnetic mesoporous silica nanostructures: investigation of magnetic properties

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Magnetic mesoporous silica nanocomposites give the possibility of generating multi-functional objects for application in different technological areas [1]. In this work we focus on the magnetic properties of nanocomposites constituted by spinel iron oxide nanoparticles (MNPs, <D> ≈ 8-9 nm), prepared by co-precipitation method, embedded in a mesoporous silica (MS) matrix. The mesoporous structure of the silica matrix and the presence of the nanoparticles inside clearly emerge from Transmission Electron Microscopy (TEM) measurements. Low temperature (5K) field dependent magnetization measurements reveal saturation magnetization (MS) close to bulk value (MS Bulk ~90 emu/g) for both MNPs particles and MNPs/MS nanocomposite, indicating that the presence of silica does not affect magnetic features of the single MNPs. Moreover the dependence of the remanent magnetization on field (i.e. δM plots) at low temperature has shown a small but evident decrease of interaction in MNPs/MS sample with respect to MNPs samples, which may prevent aggregation phenomena. Finally, a partial orientation of the easy axis is observed when the MNPs are embedded in the silica matrix.

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Magnetic nanoparticles based immunotherapeutic agents for macrophage reprogramming

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Immunotherapy is a promising approach for treatment of different cancers. The conversion of tumor-supportive macrophages (M2) to tumor-suppressive macrophages (M1), inducing the functional reversal of macrophages, is pivotal for eliciting antitumor response. Despite some progress in this field the problem of specific delivery of pro-inflammatory stimuli to tumor associated macrophages still exists. Based on these facts it has been hypothesized that magnetic nanoparticles (MNP) can be used for tumor macrophages reprogramming.

In this work, MNP were synthesized by thermal decomposition of iron acetylacetonate (III) followed by human serum albumin coating (HSA). Nanoparticles ability to accumulate in macrophages was investigated using atomic emission spectrometry, flow cytometry, and confocal microscopy. Immunotherapy agents (CpG oligonucleotide, LCL-161 and IL12) were loaded onto MNP due to formation of electrostatic, hydrophobic, and covalent complexes, respectively. Physicochemical properties were investigated by dynamic light scattering method. Cytotoxic activity of developed nano-formulations was tested in MTT assay on both mice and human macrophages. The effectiveness of mice macrophages reprogramming was estimated by flow cytometry. Mice macrophages were obtained by subcutaneous implantation of 4T1 mouse breast carcinoma cells in BALB/c mice, which gave 100% metastasis to the lungs. After 14 days, macrophages were isolated from the lungs and cultured under standard conditions. M1 or M2 polarization was carried out by exposure with LPS or IL4/IL13 combination respectively. To develop a model for human macrophages polarization, the human monocyte cell line THP-1 was differentiated into macrophages by incubation with 150 nM PMA. Finally, three *in vivo* models for imaging of tumor microenvironment were developed (4T1, B16, CT26).

It was found that synthesized 35±3 nm MNP-HSA are able to accumulate in mouse and human macrophages *in vitro*, and this process depends on the incubation time. The data obtained also indicate a more stronger absorption of nanoparticles by human macrophages compared to mouse. Additionally, intravital microscopy revealed that MNP-HSA efficiently accumulated in mouse tumor macrophages *in vivo*. All nano-formulations with immunotherapy agents showed comparable or lower cytotoxicity compared to free substances on both mouse and human macrophages. Efficiency comparison revealed that MNP-CpG, MNP-LCL-161 and MNP-IL12 stimulated the reprogramming of mouse macrophages into the M1 phenotype more than free drugs.

Thus, as a result of these studies, promising MNP-based nano-formulations for cancer immunotherapy, as well as *in vitro* and *in vivo* models for evaluation the effectiveness of tumor macrophages reprogramming, were obtained and profoundly characterized for the first time.

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High frequency properties of P(VDF-TFE)/Mn-Zn ferrite/carbonyl iron/graphite composites

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During the past decade new composite materials are very demanding in engineering and scientific fields of knowledge because the usage of traditional single phase materials reached its limit of opportunities [1]. Polymer composite materials may be promising candidate for electromagnetic interference and radar absorbing applications because of the coexistence different absorbing mechanisms i.e. magnetic losses, dielectric losses and eddy current loss [2]. In the current research the radar absorbing and shielding properties of ferrite/polymer composite consisting of Mn-Zn ferrite branch 700NM, carbonyl iron, graphite and polyvinylidene fluoride copolymer P(VDF-TFE) is investigated. The experimental samples were produced by hot pressing method of powder mixtures. XRD, IR-spectroscopy and DSC analysis showed that no extra phases occurred during synthesis. The analysis of permittivity and permeability spectra in the range of 0.01-7 GHz on absorption characteristics was carried out. It is shown that even without high conductive inclusions obtained composites exhibit sufficiently high reflection loses (- 22 dB on 5.9 GHz with thickness 5.3 mm and 20 mass % of ferrite). The increased level of shielding effectiveness compared to bulk ferrite 700NM in 1-7 GHz region is explained by the increasing of magnetic and dielectric losses of ferrite particles and synergistic effect of ferrite and polymer matrix interaction. The influence of carbonyl iron, graphite addition on the permeability spectra and electromagnetic shielding effectiveness is discussed.

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Splitting of the magnetic loss peak of composites under external magnetic field

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Composites filled with ferromagnetic inclusions possess a combination of promising magnetic, electrical, and mechanical properties. The effective permeability of composites is a complicated function of frequency, the microstructure of the composite, and the properties of its constituents. Reliable techniques for determining physical mechanisms resulting in the appearance of magnetic loss peaks at microwave are not found in the archived literature.

A useful technique for studying the microwave magnetic properties involves coaxial measurements of frequency dependence of complex permeability under external magnetic bias [1]. The calibration techniques for the coaxial line have been well established, and an accurate permeability measurement is available in the frequency range of 100 MHz to 20 GHz. The measuring coaxial cell is placed inside a coil that creates magnetic bias parallel to the coaxial axis.

Making the measurement under various permanent magnetic field gives an opportunity for comparing the magnetic characteristics of a sample in both the demagnetized and magnetized states and for determining the physical mechanisms responsible for different peaks of magnetic loss. These data may be of importance for understanding the magnetic structure and dynamic magnetic properties of tiny magnetic particles.

The frequency dependence of permeability of composites filled with flake sendust (Fe-Si-Al alloy) particles is measured under external magnetic field. The measured dependences are fitted by the Lorentzian dispersion law [2]. It is found that the magnetic loss peak is split under external fields of more than 1.5 kOe.

To search for the reasons for the peak splitting, the influence of the skin effect on the permeability under external magnetic field is studied. The theoretical behavior of the permeability of platelet particles under magnetic field is described by Kittel's formula [3]. The skin effect is taken into account by a re-normalization of the theoretical intrinsic permeability of a conducting particle into the apparent permeability [4]. It is shown that the skin effect can lead to the splitting of the magnetic loss peak under magnetic field.

Another reason for the splitting of the magnetic loss peak may be a different magnetization of the particles due to the isotropic distribution. To study this effect, two anisotropic samples with the platelet particles oriented perpendicularly and parallelly to the coaxial axis are prepared. The particles in the samples are oriented by a strong uniform magnetic field. The frequency dependence of permeability of the anisotropic samples are measured under external field. The magnetic loss peaks of anisotropic samples do not split under external field.

It is shown that the splitting of the magnetic loss peak of the isotropic sample is caused by different orientation of particles in the sample.

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High moment FeB nanoparticles for magnetic hyperthermia

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Magnetic hyperthermia therapy based on the conversion of electromagnetic energy from an external AC magnetic field to heat by using magnetic nanoparticles. Although the most widely used material in this therapy is iron oxide nanoparticles, their low saturation magnetization lowers their performance. Iron-boride nanoparticles has been reported to be a good material to replace iron oxides [1,2]. However, further studies are needed on the determination of their particle size dependent magnetothermal properties.

In this work, we have demonstrated that iron boride (FeB) nanoparticles of high moment can be used efficiently for hyperthermia applications. The nanoparticles are produced by arc-melting of iron and boron chips followed by high-energy surfactant assisted ball-milling of the as-prepared ingot. Characterization of the nanoparticles are done by using X-ray powder diffraction (XRD), scanning electron microscopy (SEM), vibrating sample magnetometer (VSM) and magnetothermal measurements. We successfully produced nanoparticles with saturation magnetization as high as 120 emu/g at room temperature. In addition, we showed that specific absorption rate, which is a figure of merit for hyperthermia efficiency of nanoparticles is around 60 W/g.

Acknowledgment

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Study of the gyrotropic mode of magnetic vortex oscillations in a magnetic resonance force microscope

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The gyrotropic mode in magnetic vortices has attracted much attention of researchers in recent decades. This is due to the possibility of its use in memory elements, sources and detectors of microwave radiation. One of the methods for studying of the gyrotropic mode is magnetic resonance force microscopy (MRFM) [1], which has high sensitivity and high spatial resolution. However, the MRFM probe not only detects magnetization oscillations, but also affects the FMR spectra due to its scattering magnetic fields.

The array of ferromagnetic disks was fabricated by electron lithography and ion etching from a Permalloy film with a thickness of 40 nm. The diameter of each disks was 900 nm. In this system~~s~~ a vortex magnetic state is realized [2].

The study of the gyrotropic mode was carried out in a magnetic resonance force microscope created on the basis of the serial SPM Solver HV. Probes with a resonant frequency of 6.28 kHz and a stiffness of 0.003 N/m were used. A SmCo particle with a diameter of 10 microns was glued to one probe, and a cobalt film with a thickness of 100 nm was deposited on the other probe. The probes were positioned above the center of the probe.

For both probes, when the magnetic moment of the probe and the magnetization of the vortex core are co-directed, the resonant frequency of the gyrotropic mode increases as the distance between the MRFM probe and the sample decreases. For the case when the magnetic moment of the probe and the magnetization of the vortex core have opposite directions, the resonant frequency of the gyrotropic mode decreases as the distance between the MRFM probe and the sample decreases. However, for a probe with a large magnetic moment at a distance between the probe and the sample of less than 3 microns, the value of the resonant frequency increases sharply, which is explained by the magnetization reversal of the vortex core.

The work was supported by a grant from the Russian Science Foundation N 21-12-00271.

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Synchrotron-based studies of multicomponent systems: a case of single-phase Al_x-CoCrFeNi high-entropy alloys

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High-entropy alloys (HEA) are multicomponent systems with near equiatomic composition and continuously attract a lot of attention from different perspectives [1]. They exhibit a high mechanical and chemical stability under high-temperature and high mechanical pressure, and are also attractive for applications due to high saturated magnetization, low coercivity and, in some cases, high Curie temperature together with the absence of ductile-to-brittle transition and high strength. In addition to the initial interest from the metallurgy industry, nanostructured HEAs are also considered as novel electrocatalysts. Despite intensive studies of HEAs using high-resolution imaging and X-ray diffraction, element-specific studies on the local scale are still underrepresented, and, as a consequence, many fundamental questions are still shaded. Among them are the impact of the hybridization effects between constituents in homogeneous systems, the magnetic behaviour specific for each element in the alloy, absolute values of the magnetic moments and the presence of temperature-dependent magnetic phase transitions owing to a partial magnetic frustration.

Here we report the first results of our element-specific X-ray absorption spectroscopy studies of *fcc*-$Al_{0.3}$CoCrFeNi and *bcc*-Al_3CoCrFeNi single-phase HEAs [2,3] performed with hard- and soft X-rays at the K and/or $L_{2,3}$ absorption edges of all constituent elements at room temperature. The results of conventional magnetometry showing a very different magnetic behaviour of studied HEAs depending on the crystallographic structure are demonstrated as well.

EXAFS spectra recorded at the K edges of 3d constituents have revealed key peculiarities of individual atoms' nearest-neighbour arrangements on the atomic scale in the samples studied, and in conjunction with reverse Monte Carlo-based analysis have allowed us to estimate quantitatively a degree of local atomic structure relaxations and variations in a number of different nearest-neighbours depending on the crystallographic order. XANES spectra taken at the $L_{2,3}$ edges of the same constituents disclosed a presence of oxidized, partially oxidized and even metallic 3*d* elements in the sub-surface area of studied HEAs. XMCD technique employed for the *in situ* cleaned *fcc*-$Al_{0.3}$CrFeCoNi at low temperature has revealed the reduced magnetic moments of 3d metal constituents in the sub-surface region compared to their bulk values.

Extended to nanostructured versions of different multicomponent alloys such studies would bring new insights related to the effects of high entropy mixing on low dimensions.

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Resonant properties and Debye temperature of canted antiferromagnet $FeBO_3$

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Iron borate $FeBO_3$ is a rhombohedral crystal (space group $R\bar{3}c$) that has a lot of important applications [1]. In this work, the resonance, magnetic, and structural properties of $FeBO_3$ were investigated in a wide temperature range by Mössbauer spectroscopy and X-ray diffraction analysis.

The high-quality crystalline samples were synthesized by flux-growth technique [1].

Mössbauer spectra were described taking into account the combined magnetic and electric hyperfine interaction. Figure 1 shows the spectra obtained above the magnetic transition point (T_N ~ 348,3 K). In the case of the orthogonal orientation of the (001) plane of the crystal to the direction of γ-rays (vector ***k***, fig. 1a), the spectrum is strongly asymmetric, and it is aligned when this crystal plane is oriented at "magic angle" to the ***k*** (fig. 1b). This indicates that the main axis of the electric filed gradient ***Z´*** is orthogonal to the (001) plane. The Debye temperature calculated from the temperature dependence of the isomer shift is $\theta_D \approx 450$ K. The crystal structure was refined in a wide temperature range by single crystal X-ray diffraction. Figure 2 shows the temperature dependences of the atomic displacement parameters for Fe and B cations in the $FeBO_3$; there are no sharp fluctuations of the structural parameters. For each cation, this dependence was calculated in the extended Debye approximation [2]. The characteristic Debye temperatures calculated for the Fe and B cations are 440 K and 1063 K, respectively. These are in good agreement with the results obtained by Mössbauer spectroscopy. These results are important for the use of $FeBO_3$ crystals in new high-tech fields.

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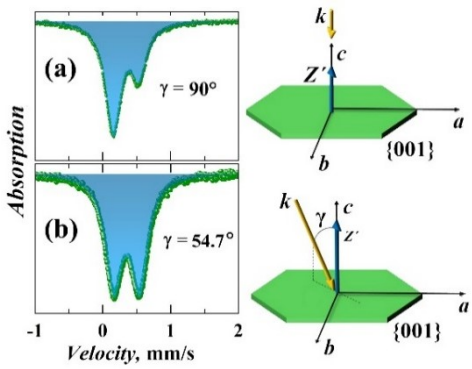

Fig. 1. Mössbauer spectra of $FeBO_3$ with different orientation of crystal plate, obtained at 350 K.

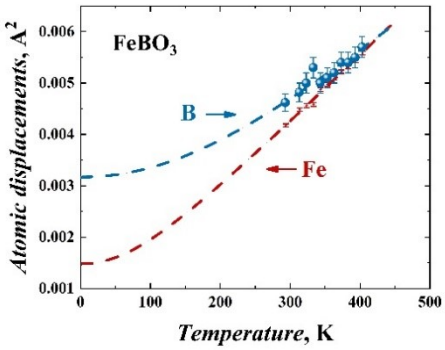

Fig. 2. Temperature dependences of the atomic displacement parameters of B and Fe atoms in $FeBO_3$. Points are experimental data and dashed lines are results of simulation.

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Optimized spark-plasma-sintering synthesis of bulk phase-pure $(Cr_{1-x}Mn_x)_2AlC$ MAX-phases

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MAX-phases are the family of atomically layered compounds with the common $M_{n+1}AX_n$ formula, where M is an early transition metal, A is an A-group element and X is either C or N. MAX-phases are familiar for the characteristic set of properties, combining both metallic and ceramic ones, such as high electric and thermal conductance, elastic stiffness, easy machinability, tolerance to high-temperature corrosion and harsh environments [1]. MAX-phases are being considered for a plethora of practical applications, from chemically stable electrical contacts to protective and shielding coatings and high-temperature applications [2].

One of the most intriguing goals is to obtain stable magnetic MAX-phase that will expand the application field of these materials toward spintronics and other practical uses. This can be possibly done via the chemical doping of existing MAX-phases with magnetic elements [3,4]. The promising candidate for this purpose - $(Cr_{1-x}Mn_x)_2AlC$ MAX-phase. The ability of this compound to possess tunable magnetic properties, controlled by the variation of the manganese content, is also of the great interest [5].

Recently we have established the protocol to successfully produce phase-pure samples of $(Cr_{1-x}Mn_x)_2AlC$ MAX-phase with dopant concentrations up to 15 at.% which is half times higher than the largest doping level, achieved previously [5]. The protocol requires complex optimization of the exploited synthesis method (arc melting technique) and further purification of the obtained samples via their chemical etching in the powder form. Spark plasma sintering (SPS) technique was used to compact phase-pure powders back to bulks. However, it turned out that the existing SPS protocol [6] works well only for the non-doped parental Cr_2AlC compound, while in case of $(Cr_{1-x}Mn_x)_2AlC$ it leads to the decomposition of the phase towards binary compounds and oxides.

In this work we have performed the complex optimization of the SPS synthesis route to promote the preservation of the obtained $(Cr_{1-x}Mn_x)_2AlC$ composition during the compaction and minimize the phase degradation of the samples. As a result, not only the protocol to synthesize bulk $(Cr_{1-x}Mn_x)_2AlC$ MAX-phase samples from powders in the whole range of studied Mn concentrations was studied but also the valuable conclusions concerning the change of MAX-phase chemical activity with the increase of Mn content were made.

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Field-induced pseudoplasticity of magnetoactive elastomers: a phase transition interpretation

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The term *magnetoactive elastomers* (MAEs) designates intellectual composites consisting of weakly-linked flexible-chain polymers filled with micron-size particles of a low-coercive ferromagnet, e.g., carbonyl iron. These materials are characterized, simultaneously, by a sufficient mechanical softness and a considerably strong magnetic response. Such a combination imparts to MAEs remarkable magnetomechanical properties: large field-induced deformations, drastic changes of the elastic moduli, turning into a plasticine-like substance under the action of the field and other peculiar effects.

In this work we focus on the phenomenon of the field-induced pseudoplasticity. It occurs when a highly-concentrated MAE (~25+v.% of iron filler) is subjected to a constant magnetic field. The material, which under zero field has been virtually elastic (responding to mechanical stresses with maybe just a little bit of irreversibility) becomes entirely ductile, and deforms virtually irreversibly under any external stress. As soon as the field is removed, the sample recovers its elastic properties in full and restores its initial shape.

The proposed idea exploits the similarity of the occurring transformation with a first-order orientational phase transition inherent to nematic liquid crystals. For a qualitative test we take a 1D model problem where the directions of mechanical stretching and the applied constant magnetic field coincide. Besides the standard set of thermodynamic parameters – specific density, deformation (here, elongation) and magnetization – we introduce an order parameter S that, under circumstances, is scalar. The implied physical meaning of S is the fraction of filler particles incorporated in global (i.e., spreading all along the sample) clusters.

Treating S in the same way as it is done in the liquid-crystalline theory, we construct a thermodynamic quasi-potential Φ in the form of the Landau-de Gennes expansion [1], i.e., retaining S up to cubic power. Minimization of Φ with respect to S under given field, renders the hysteretic dependence $S(H)$ and, accordingly, the hysteretic dependence of the sample strain ε.

The latter, in the proposed description, is split in two components: $\varepsilon = \varepsilon_e + \varepsilon_s$, where ε_e stands for the elastic and ε_s for the structure contribution, respectively. In this sum it is ε_s that is prone to pseudoplasticity behavior. When the stress is zero, ε_e vanishes. The constitutive equation for ε_s has the incremental (differential) form and depends on the direction of the cluster-formation process, i.e., on whether the structure builds up or breaks down.

In the talk we demonstrate that the afore-presented model is able to, at least qualitatively, reproduce the major features of the field-induced MAE behavior, namely, its magnetostriction, hysteretic magnetization curve, pseudoplasticity, drastic enhancement of the elastic modulus, etc.

The work was supported by the RFBR-DFG project 19-52-12045.

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Atomic-scale self-organization of monatomic transition-metal oxide chains

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Magnetic monatomic chains are an appealing option for engineering of devices. During the past two decades magnetic monatomic chains attracted a lot of interest because of their unusual magnetic and electronic properties [1,2]. Such systems can be produced using one of the three options: first, the atom-by-atom assembly [3], second, decoration of substrate step edges [4], and third, self-assembled growth [5]. Understanding the mechanisms that govern the growth of metal monatomic wires will be critical for engineering more advanced atomic structures with controlled properties.

Combining kinetic Monte Carlo and ab initio density functyeional theory calculations allows us to study the growth of monatomic transition-metal oxide chains on Ir(100). We show that for a large value of the bond energy, the antiripening mechanism and quantum effects do not affect the length of metal monatomic wires. The simulation of the cooling and annealing process allows controversies that exist in the field to be resolved. For instance, it has shown that in most cases, the experimental length distribution is not equilibrium. This is explained by the fact that the length distribution is obtained at a low temperature, and the time of the experiment is short. The time of transition from one state of thermodynamical equilibrium to another depends on the lifetime of one-dimensional islands. The lifetime, in its turn, depends on the ratio of diffusion barriers to temperature. The observed mechanism of wire growth will be useful both for explaining the experimental data and for creating atomic wires with a given length.

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Photoemission from 4f shell as a probe of crystal electric field and magnetism: a view on $TbRh_2Si_2$

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Controlling the spin orientation as well as the spin-splitting of two-dimensional electron states (2DESs) at surfaces and interfaces is the major challenge for spintronics. From this point of view, the crystalline materials with rare earth elements are particularly interesting, because 4f moments act as a tuning tool for 2DESs at the surface [1]. It should be expected that the crystal electric field (CEF) may vary greatly in the near-surface region of the crystal, which can lead to dramatic changes in the magnetic properties at the surface [2]. Hence, we need an effective methodology that could allow comprehensive analysis of CEF at the surface and its influence on the behavior of the 4f moments. We suppose that this methodology can be based on photoemission (PE) from the 4f shell.

Here, using experimental PE spectra from an open 4f shell we study the direction of Tb magnetic moment in different layers at the Tb- and Si-terminated surfaces of the antiferromagnetic $TbRh_2Si_2$ with the out-of-plane magnetic order in the bulk. To describe spectral features of PE spectra, we use ab initio calculations of PE intensity that include spin-orbit interaction, CEF, magnetism and photoelectron diffraction effects. Using theoretical apparatus developed we successfully simulated spectral, angular and temperature dependencies of the 4f signal from the Tb ion in $TbRh_2Si_2$ and have found a good agreement between the theory and the experiment. As a result, the PE spectra suggest that the magnetic moments of Tb ions are directed out-of-plane in the 4th layer on Si termination and in-plane for the 1st layer on Tb termination. The latter can indicate that CEF changes significantly at the Tb-terminated surface. To verify this assumption, we performed ab initio calculations of CEF parameters [3]. As a result, the calculated parameters fully confirmed the conclusions drawn from the PE intensity analysis and indicate significant modifications of the CEF at the Tb-terminated surface of the $TbRh_2Si_2$ that leads to strong canting of the 4f magnetic moments. Besides that, we have found that computed angular patterns of the PE signal exhibit a good agreement with experiment, indicating that such complex spectral structures as Tb 4f multiplet with can be used for the structural analysis by means of photoelectron diffraction. As an example of such analysis, we determine the lattice relaxation for the topmost atomic layer on the Tb terminated surface and show that it reaches unexpectedly high value.

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Epitaxial stabilization of $Fe_3Si(111)$-orientated thin films on Si(110) via self-organized growth of α-$FeSi_2$ nano-stripes: structural analysis and magnetic properties

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In this work we studied the formation process and magnetic properties of the ferromagnetic silicide Fe_3Si on Si(110) surface textured with α-$FeSi_2$ crystallites [1]. The Fe_3Si//α-$FeSi_2$ interface can initiate the growth of a certain orientation of ferromagnetic layers, which is impossible on silicon. Additionally, the formed heterointerface can act as a source of crystal lattice stress, which can be used as a tool to change electronic and magnetic properties. The finite small size of the Fe_3Si grains makes it possible to maintain such lattice stresses in contrast to the case of a continuous non-textured thin film, where induced stresses are removed by intergrowth of dislocations. The Fe_3Si films grown conserve the epitaxial strain, which was revealed from the reflection high-energy electron diffraction patterns (RHEED) (Fig. 1) Examination of hybrid heterostructures obtained (Fig.1) was carried out using X-ray diffraction, ferromagnetic resonance, transmission electron microscopy, atomic force microscopy, Kerr effect measurements, and ab nitio calculation methods.

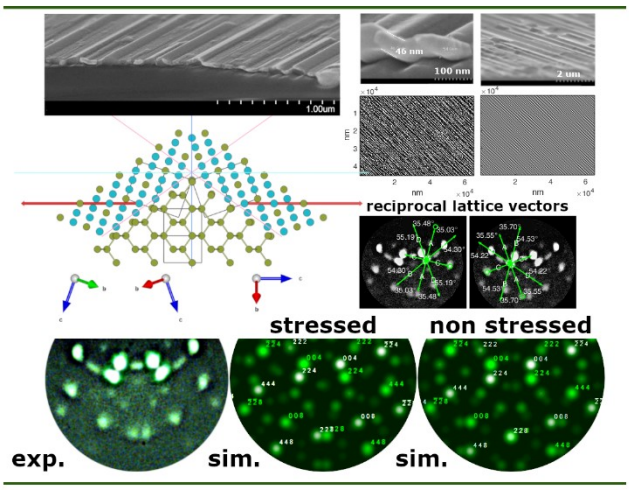

Figure 1. SEM images and experimental and simulated RHEED patterns of $Fe_3Si(114)$//Si(110) textured epitaxial thin films

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High-field magnetization study of R-Fe-H systems with a Laves phase structure

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The compounds of rare-earth and 3d-transition metals form a comprehensive class of materials widely known in science and technology. RFe_2-type compounds with a Laves phase structure are of particular interest due to their unique physical properties (magnetostriction, magnetocaloric effects and other). These materials are often used in hydrogen-containing environments. It is known that hydrogen penetrating into the crystal lattice of compounds can significantly change their magnetic properties. The purpose of this work is to study the effect of hydrogen on magnetization processes in multicomponent compounds $(R,Y,Sm)Fe_2$, where R = Gd or Tb.

Details of the synthesis of the parent compounds, their hydrides $(R,Y,Sm)Fe_2H_3$, as well as the certification of all obtained samples by X-ray analysis can be found in Ref. [1]. The study of the field dependences of the magnetization of the samples was carried out in static and pulsed magnetic fields up to 60 T.

It was found that the systems $(Gd,Y)_{0.8}Sm_{0.2}Fe_2$ and $(Tb,Y)_{0.8}Sm_{0.2}Fe_2$ and their hydrides have compensation compositions. The phenomenon of magnetic compensation in $(R,Y,Sm)Fe_2H_x$ is extremely sensitive to the hydrogen content in the samples. The calculations performed for the total magnetization at T = 0 K show that the collinear magnetic structure is characteristic only for the parent compounds. That why it was important to study the processes of magnetization in high magnetic fields for all hydrides $(R,Y)_{0.8}Sm_{0.2}Fe_2H_3$ with R = Gd or Tb.

As a result, it was found that a number of compositions demonstrate a sharp increase in magnetization and the ability to achieve a ferromagnetic state by an external magnetic field. The results obtained are discussed in terms of the model of a three-sublattice magnet with competing exchange interactions. It was found that hydrogenation has a significant effect on the exchange interactions between individual magnetic sublattices.

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Magneto-optical properties of metal oxide nanowire

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Recent experiments revealed the formation of novel 1D metal oxide wires on step edges of a vicinal metal surface [1]. The experimental evidences of low-dimensional oxides on vicinal metal surfaces made these fascinating nanostructures very attractive for further investigations of their electronic and magnetic properties of 1D systems. Moreover, oxide nanowires (NW) possess unusual optical properties such the most molecular systems. Thus, appears a new possibility of controlling the magnetic properties of magnetic nanowires using electromagnetic radiation. For this purpose, we studied the magneto-optical properties of cobalt nanowires formed at the step edges of platinum vicinal surface in the presence of oxygen impurities in low- (0.1 monolayer (ML) oxygen coverage) and high- (0.4 ML oxygen coverage) oxidized states.

All calculations in present work were made in two stages. At the first, the magnetic properties of Co oxide nanowires CoO for low-oxidized state and CoO_2 for high-oxidized state formed at the step edges of platinum vicinal surface were studied within the framework of density functional theory in first principle code VASp [2] and then the optical properties of these magnetic systems were investigated following the formulation proposed by Gajdos et al. using the VASP code and the LOPTICS method [3].

The study of the magnetic properties of metal oxides wires showed that at a low oxidized state the oxide CoO wire remains magnetic. However the ground state of the wire is highly dependent on the step edge geometry: CoO-Pt(332) system remains FM with magnetic moments of the Co atom 1.5μ_B, however, in CoO-Pt(322) surface, the ground state of oxide wire change to the antiferromagnetic (AFM) with a magnetic moment of Co 1.5μ_B. We found significant decrease of the magnetic properties, up to complete disappearance of magnetism in CoO_2 NW in the high oxidized state. The local magnetic moments of Co atoms decrease to 0.6μ_B in CoO_2-Pt(332) system and the wire remains FM. In CoO_2 - Pt(322) system we found the complete disappearance of the magnetic properties with magnetic moment of Co atom 0.2μ_B, but AFM configuration remains more energetically preferable

Then we have studied the optical properties of CoO and CoO_2 wires on Pt(322) and Pt(332). Reflectance difference spectra (RDS) and also surface dielectric anisotropy (SDA) were measured in our work [4]. We observed the formation of a singular peak at energy 6eV for clean Pt surface in SDA spectra, the position and polarity of this peak are not specific and do not differ for the two types of step edges. The formation of this peak we associated with the optical response of the step edges as heterogeneities of Pt surface. The singular peak for the unoxidized CoNW-Pt(332) system shifted by 0.1eV to the low-energy region relative to a clean Pt(332) surface; for the CoNW-Pt(322) system, no peak shift was found. Oxidation 0.1ML led to small changes in RDS and SDA spectra. Strong oxidation in 0.4ML in case of CoO_2-Pt(332) system did not lead to a significant change in the RD and SDA spectra. At the same time, for the CoO_2-Pt(322) system we found the reverse of the polarity of the SDA peak, the position of the peak does not change in compare to low oxidized states. Thus we have found the change of polarity of singular peak in SDA spectra which may be associated with transition to AFM state of CoO_2 on the Pt(322) surface.

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Effect of structure and electron configuration on the magnetic properties of $La_{0.7}Ca_{0.3-x}Sr_xMn_{0.95}M_{0.05}O_3$ manganites

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Perovskite-like manganites doped in *A* – and *B* – positions of perovskite ABO_3 cell attract considerable interest due to their interesting fundamental properties and promising different applications. Despite the number of relevant studies (see [1-4], for example, and references therein) some features of manganites, in which both position, *A* and *B*, are doped, remain unexplored until now.

We report on the properties of $La_{0.7}Ca_{0.3-x}Sr_xMn_{0.95}Al_{0.05}O_3$ manganites in which the Mn^{3+} ion is replaced by Al^{3+} ions and with continuous substitution of Ca by Sr. The substitution of manganese by aluminum damages the path of motion of itinerant e_g electrons leading to weakening of the double-exchange interaction and decrease in Curie temperature, T_C. The $\Delta T_C = \Delta T_{Cel} + \Delta T_{Cstr}$, where ΔT_{Cel} and ΔT_{Cstr} are the changes in *T*c caused by the difference in electron configurations and the ionic radii of the Al^{3+} and Mn^{3+} ions, respectively [4].

The ΔT_{Cel} caused by the change of electron configuration is negative. The ΔT_{Cstr} is positive because the ionic radius of Al^{3+} smaller than that of Mn^{3+}. The T_C is more strongly affected by the change of electron configuration than by the change in the local crystal structure thus the ΔT_C is negative. With increasing *x* the structural phase transition from orthorhombic to rhombohedral singony is observed casing the two step decrease in temperature dependence of susceptibility. Based on the results, the peculiarity of the phase diagram supposed in [4] are discussed.

The work was supported by the Russian Science Foundation (project RSF-No 21-43-00023).

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Application of the point-like contact model: resistance simulation of the single magnetic domain wall

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The present work is focused on the modeling of the single domain wall (DW) resistance ΔR in the magnetic nanowires (NWs) in framework of the adapted point contact model [1]. The original model describes diffusive, quasiballistic and ballistic regimes of the spin-resolved electron transport in metallic point contacts (PCs). The obtained result shows a rapid reduction of the ΔR with the NW's diameter d, which is accompanied by oscillations in range of d = 2.0 nm−10.0 nm. The origin of these oscillations corresponds to the non-uniform electron scattering when DW releases from a constrained state until d achieve a threshold t_0~ 10 nm. This constrained state is possible due to restricted geometry of a narrowed NWs, and PCs [2], where the width of the DW is approximately equal to the NW's diameter. It is assumed that NW can consists from homogenous material, e.g. Co [3], as well as from alloy, FeNi [4], or can be segmented one having two compounds, e.g. Co and Ni connected in series [5]. Several experimental points [3-5] for $\Delta R(d)$ and derived theoretical curves are shown in Fig.1. The ratios between spin-resolved electron mean free paths $\ell_\uparrow/\ell_\downarrow$ and k_F-wavenumbers $k_{F\uparrow}/k_{F\downarrow}$ are most important parameters for this system. Noteworthy that the same model of electron transport allows to find conductance, *I-V* curves and magnetoresistance of the different nanoscale systems.

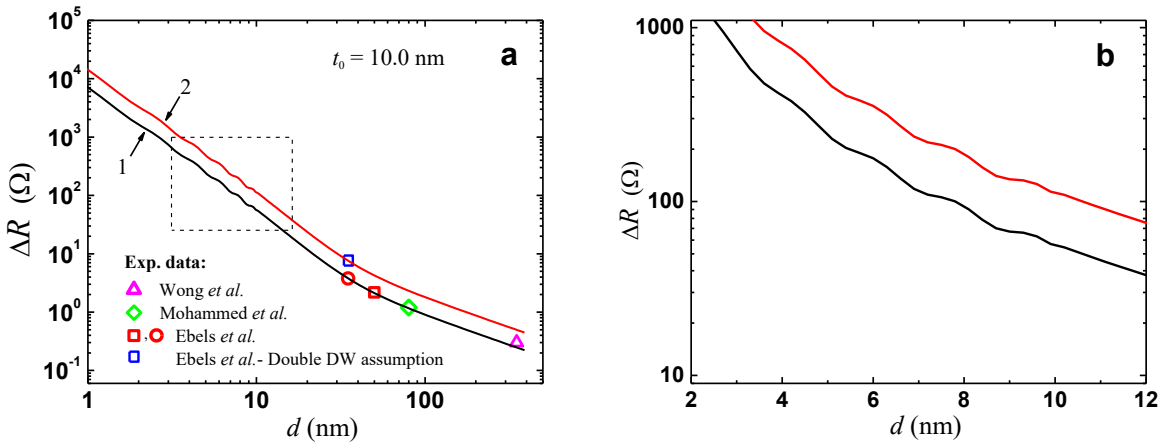

Fig.1. Domain wall resistance *vs* diameter of the NW; **(a)** Curves 1 and 2 show ΔR for a single and doubled DWs, respectively. Exp. points from Wong *et al.* [4] and Mohammed *et al.* [5] are located slightly higher than curve 1. Right panel **(b)** shows zoom of the selected window in panel (a), the depicted oscillations have a constant period ~ 1.73 nm, $\ell_\uparrow/\ell_\downarrow = 4.0$, $k_{F\uparrow}/k_{F\downarrow} = 0.56$, no oscillations at $d > t_0$.

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Role of anisotropy, frequency, and interactions in magnetic hyperthermia applications: noninteracting nanoparticles and linear chain arrangements

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The enhancement of the specific power absorption (SPA) of magnetic nanoparticles (MNPs) for magnetic fluid hyperthermia applications is currently focused on the design of MNPs with tuned properties or searching for the optimal experimental conditions for a particular system. However, the role of all parameters relevant to the relaxation still remains a matter of debate.

We modify a nonlinear model for the magnetic relaxation of single-domain magnetic nanoparticles with uniaxial effective anisotropy [1] and evaluate the influence of particle-intrinsic parameters as well as experimental conditions on the power absorption of both noninteracting and interacting systems (linear chain arrangements) [2]. These effects are assessed through the normalized enclosed hysteresis area a of the magnetization loops as a function of relative anisotropy h_K (the anisotropy field with respect to the amplitude of the ac field), i.e., the "area curve" of the system (see Figure 1). These curves can be divided into four regions (I-IV) with distinct magnetic responses and boundaries that depend on the particle size, frequency of the applied field, orientation of the anisotropy axes and interactions. Interactions change the effective anisotropy of the system and shift the area curve towards lower h_K values. For the low relative anisotropy range, dipolar interactions increase the area of the hysteresis loops (thus, the SPA) while they are detrimental or produce nonsignificant effects for the range of high relative anisotropy. Our study resolves seemingly contradictory results of interaction effects in linear arrangements recently reported in the literature.

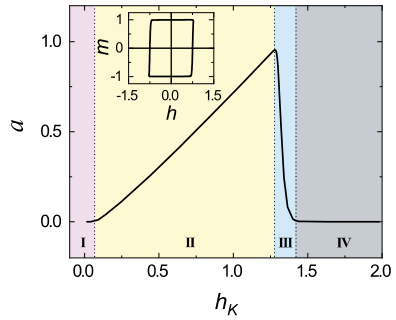

Figure 2. Area curve of a noninteracting MNP system with diameter of 60 nm and anisotropy axes parallel to the external field for a frequency f = 100 kHz. *Inset:* Normalized hysteresis loop for the maximum of the area curve (maximum SPA condition).

An analytical approach and the thermal interpretation of its validity range are detailed, both aimed at the design of nanoparticles and the choice of the experimental conditions for optimal heating. We conclude that systems with low-thermal-fluctuation influence are the best candidates for the application due to their high SPA values.

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In situ formation and thermographical analysis of nanoparticle chain-like arrangements in polyacrylamide phantom during hyperthermia experiments

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The formation and control of magnetic nanoparticle (MNP) arrangements during the hyperthermia experiment (HE) for viscosities similar to those of the intracellular environment is relevant for the enhancement of the specific power absorption [1]. A gel with adjustable viscosity such as polyacrylamide gel may work as a phantom to emulate intracellular viscosity [2].

In this work, γ-Fe_2O_3 MNPs with 25 nm diameter (σ = 7 nm) were prepared through the thermal decomposition method with a subsequent annealing. We determined the saturation magnetization (M_S = 68 emu g^{-1} at room temperature), the mean blocking temperature ($\langle T_B \rangle \sim 10$ K) and the effective anisotropy constant ($K \sim 1 \times 10^4$ erg cm^{-3}). The hydrophobic character of the as-synthesized nanoparticles was changed to hydrophilic by a post-synthesis glucose coating.

Two types of 4% polyacrylamide gel phantoms with dispersed MNPs were prepared: one conventionally jellified (dispersed MNPs) and another one jellified during the HE with an *ac* field with amplitude H_0 = 200 Oe and frequency f = 630 kHz, each one at MNP concentrations of 0.1 and 0.5 % wt. Images were taken with a cryo-focused electron and ion beam (Cryo-FIB-SEM) microscope, where the formation of chains-like structures was confirmed for gels exposed to the ac field (see Figure 1). Power absorption experiments were performed under ac magnetic fields with amplitude H_0 = 550 Oe and frequency f = 400 kHz. The temperature evolution was monitored through a thermographic camera and spatio-temporal profiles were obtained from the videos. Qualitative and quantitative differences were observed between the gel phantoms.

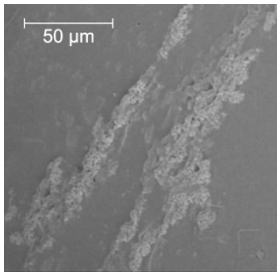

Figure 3. Cryo-FIB-SEM image of polyacrylamide gel with MNP exposed to the ac field.

To conclude, we obtained considerable temperature increments for MNPs dispersed in cytosol-viscosity emulating medium and confirmed the formation of chain-like arrangements for samples jellified *in situ* in the HE, which is of great importance to optimize the application in cells.

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Strength characteristics of 3D-printed samples determinate

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Introduction. Additive technologies are a simple and fast way to get a prototype or product of the required geometry. The most common printing method is FDM. This method makes it possible to achieve high results in manufacturing practically any parts from a wide range of thermoplastic materials — from widespread ABS, PLA, PETG, etc. to superstructural such as PEEK, PPSF, etc. However, this technology has disadvantages - the anisotropy of the strength properties of the resulting products depending on the printing direction and temperature.

Methods. The paper considers the influence of 3D printer settings when printing a test sample (ISO 527-2:2012, Type 1) on its strength characteristics. To avoid unnecessary deformation and possible damage of the samples when removing them from the 3D printer table, a 45° chamfer was added to the model. The sample is clamped at these locations, so this change has no effect on the test results.

Test samples was printed in PETG- plastic at 220, 230, 240 °C, printing speed of 30, 50, 70 mm/s with longitudinal printing direction, transversely printed direction and with "walls".

The obtained samples were tested for uniaxial tensile strength on an ITS 800 tensile testing machine at a gripping speed of 10 mm/min according to ISO 527-2:2012. The results of uniaxial tensile tests were processed statistically. Deviations of the strength value by more than 10% from the average value were not considered.

Results. Samples with longitudinal printing direction are characterized by brittle fracture with a higher strength value, in comparison with results for samples with transverse printing direction. This is due to the location of the print layers. In this case, the highest strength indicators were observed in samples printed at a speed of 70 mm/s at all the considered printing temperatures.

Samples with transverse printing direction are characterized by interlayer fracture with a lower strength value, in comparison with results for samples with longitudinal printing direction. This is explained by the adhesive nature of the fracture, as evidenced by the presence of kinks in the "Tense strength - grip moving" curves before the onset of sample destruction. At this point, interlayer adhesion plays a key role, the highest values of which are achieved mainly at low printing speeds. Can be concluded that it is advisable to print products with a preferential arrangement of the most loaded elements in the transverse printing direction at lower speeds (for example, 30 mm/s) and a temperature in the region of 230 °C.

When printing samples with a wall of 4 layers, their strength characteristics are generally higher compared to similar samples obtained under the same conditions, but the nature of their destruction is significantly different. This can be related to the distribution of stresses along the boundary layers of the sample during deformation.

Discussion. As a result of the work done, it was established: for 3D printing of products based on the investigated PETG plastic, it is recommended to adhere to a printing temperature around 230° C and a compromise is required between the strength and speed of printing products.. In this case, the decisive importance will depend on the complexity and location of the layers in the product when printing, and the minimum strength will not be lower than the strength of test samples with transverse printing direction in the absence of obvious stress concentrators in the product and maintaining the recommended temperature conditions. However, with all the printing modes studied, the strength of the samples was lower by more than 20%, compared with similar ones obtained by injection molding.

Synthesis aspects and magnetic moment alignment in ternary ordered Fe-Al-M (M = Ga, B, Sn) alloys

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Many experiments show that the introduction of some additives into Fe-Al-based alloys improves their physical properties. For example, boron addition can significantly refine such mechanical properties as ductility. A twofold increase in the total magnetostriction of polycrystalline $Fe_{80}Al_{20}$ was found with the addition of 2 at. pct boron compared with a sample without doping.[1] Another study [2] predicted the importance for technical applications of Fe-Al-based materials with gallium additives because of their magnetoelastic properties and good mechanical strength. Alloys of this kind are promising as materials for sensors and transducers, since, in addition to high magnetostriction values, these alloys are inexpensive and can be machined. In addition, ordered Fe – Al alloys with an Al content> 30 at. % turned out to be convenient model objects for studying the nature of the appearance and stabilization of magnetic nano-inhomogeneities in structurally homogeneous magnets, in particular, incommensurate spin structures.

First, we studied the possibility of synthesizing the ordered ternary alloys using a nanocrystalline metastable substance as the starting materials. X-ray crystal structure and local structure of the powders obtained by mechanical alloying from a mixture of elemental constituents were characterized and the phase transformations of the alloyed material during subsequent thermal treatment were analyzed.

The magnetic state of ternary ordered $Fe_{65}Al_{35-x}M_x$ (M_x =Ga, B, Sn; x = 5 at.%) alloys was examined based on an analysis of the structure, Mössbauer and magnetometric data and compared with the results of analogous studies of the $Fe_{65}Al_{35}$ alloy. The behavior of the magnetic characteristics and Mössbauer spectra of the binary alloy $Fe_{65}Al_{35}$ and the ternary alloy with gallium addition $Fe_{65}Al_{30}Ga_5$ is explained in terms of the phase separation into two magnetic phases: a ferromagnetic one and a spin density wave. It is shown that the addition of boron to the initial binary alloy $Fe_{65}Al_{35}$ results in the ferromagnetic behavior of the ternary alloy.

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Magnetic nanoparticles: from physical design to medical applications

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The application of magnetic nanoparticles (MNPs) in biomedicine and theranostics (diagnostics and therapy) is one of the most dynamic and promising fields of nanoparticles research. In this work, examples for the use of multifunctional hybrid MNPs in theranostics are presented. We designed, synthesized and tested various MNPs like ferrites [1-3], core-shell architectures [4], and magnetite-gold (Fe_3O_4-Au) hybrids [5-7] for optimized performance, e.g. in magnetic resonance imaging (MRI) and magnetic particle hyperthermia (MPH) for the localized treatment of cancer.

For MPH, the specific loss power (SLP) should be optimized for minimized side effects in patients. This is usually achieved by the choice of diameters [6], particle shape [7] or materials [4]. Another approach is the optimization of dipolar interactions between MNPs for maximized heating capabilities. We systematically studied dipolarly coupled stripe structures consisting of Fe_3O_4 MNPs as function of diameter and fixation fields [3,8]. The formed chains increase their remanent magnetization and coercive field which enhances the SLP up to one order of magnitude.

In another study, we show that controlled MPH provided by cobalt ferrite nanoparticles has different effects on tumor cells in vitro and in vivo, depending on temperature [9]. The cell death can be triggered by MPH. Interestingly, heating at 42-43°C (mild MPH) varies in different cell lines. In vivo data further shows that mild MPH is not effective for metastatic 4T1 tumor therapy, while it is efficient for curing non-metastatic CT26-bearing mice. MPH at 46-48°C and 58-60°C increases the long-term survival of 4T1-bearing mice providing primary tumor clearance and metastasis inhibition.

The results were obtained in collaboration with colleagues from the Aristotle University of Thessaloniki, Greece and the National University of Science and Technology MISIS, Moscow, Russian Federation.

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Structure and magnetic properties of layered nanowires made of 3d metals

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Layered nanowires (NWs) of various types were obtained using method of matrix synthesis - galvanic filling of pores in a track membrane - (diameter 100 nm, density 10^9 pores per square cm). Arrays of NWs with alternation of a magnetic metal (cobalt or nickel) with a non-magnetic (interlayer - copper spacer) are synthesized by a single-bath method. Another type of NWs - with alternation of two magnetic metals (or alloys) of different types, are obtained by a two-bath method.

TEM microscopy allows to estimate the thickness of individual layers - it was possible to reduce their thickness to 10 nm. Elemental analysis of the layers showed: in Ni / Cu NWs Cu layers contain several percent of Co impurity, while the concentration of Cu in the Ni layer reaches 20%. The growth of the layers with the control of the passed charge and the dilution of the electrolyte made it possible to obtain layers with the constant thickness practically along the entire length of the NWs.

Magnetic Properties: hysteresis loops were obtained using a vibrating magnetometer for layered NWs with different layer thicknesses for "in-plane" and "out-of-plane" geometries. Thus, it has been shown that in Ni / Cu NWs with layers 250 and 500 nm thick, the easy magnetization axis is directed along the nanowire axis. For NWs with "thin" layers (thickness 50 nm is less than the NW` diameter), the easy axis is already perpendicular to the NW axis. A sharp increase in Hc with a decrease of the NW diameter is also shown.

Magnetoresistance: for Ni / Cu NWs with a layer thickness of about 8 nm, the GMR effect was studied. The measurements were carried out by a two-probe method, with the resistance of the samples depending on the number of single wires involved in contact. For the initial samples it was about 200 Ohm. When an external magnetic field was applied (the maximum value was 2594 Oe), the resistance of the samples decreased by about 1%.

THz generation. In the samples of layered NWs (alternating layers of only magnetic alloys), experiments on the generation of radiation were carried out. It is known that when current flows through the first magnetized layer, its spin polarization occurs. When electrons pass into another magnetic layer subsequent relaxation occurs and electromagnetic radiation may arise. Radiation of the terahertz frequency was detected when current passed through the ensemble of NWs. A number of experiments (the threshold nature of its occurrence, the nature of the increase in signal intensity) prove its non-thermal nature. The geometry of the deposition of contact current-carrying layers was selected - in the form of narrow parallel stripes, providing conditions for the radiation output.

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Poster

Magnetocaloric and thermophysical properties of La-Fe-Co-Si compounds

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During the last time, increased attention has been devoted to the development of a new magnetic refrigeration technology, based on magnetocaloric effect (MCE), as a promising alternative to the conventional gas compression technique. From the view of practical applications, magnetic cooling needs to explore materials showing MCE behavior that can be operated near room temperature. Compounds based on the $La(Fe,Si)_{13}$ phase are among the most promising magnetocaloric materials. Many works are devoted to the study of the magnetocaloric effect of these materials. Analysis of the literature data indicates the scarcity of information on the thermophysical properties of these alloys, as well as the absence of direct measurements of the magnetocaloric effect.

This paper presents the results of magnetocaloric and thermal properties for the $LaFe_{11.1}Mn_{0.1}Co_{0.7}Si_{1.1}$ alloy. The C_P (T) dependences show pronounced anomalies associated with the ferromagnet-paramagnet phase transition. In a magnetic field, the maximum of the C_P (T) dependence is suppressed and shifts towards higher temperatures. Deep minima are observed at $\eta(T)$ near T_C, which are associated with the appearance of additional phonon scattering by fluctuations of the magnetic order phenomenon. The dependence of the electrical resistance in a field of H = 0 and 1.8 T with a maximum at T = 247 K. As can be seen near T_C, an anomaly in the ρ(T) dependence at H = 0. Below T_C, the resistance increases with increasing temperature, and then T_C the resistance increases with increasing temperature, but above T_C, the resistance increases in a narrow temperature range near the T_C, and then the metallic temperature course is restored. Application of a magnetic field 1.8 leads to an increase in the temperature of ferromagnetic ordering, while the anomaly in the ρ(T) dependence is retained. Thus, near the T_C, the application of a magnetic field leads to a positive magnetoresistance effect.

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Microstructure and macroscopic properties of the magnetic ellipsoidal nanoparticles system

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This investigation is a complex study of the system of magnetic ellipsoidal nanoparticles based on different theoretical approaches and computer simulations. We study the self-assembly in the systems of magnetic ellipsoids with various orientation of dipoles and semi-axis ratio.

The intensive development of modern technologies provides great opportunities to study soft magnetic materials at a new level, which is facilitated by the development of synthesis of new composite polymer materials with controllable properties and the creation of new magnetic nanoparticles with form anisometry [1] and anisotropic internal structure [2]. The thermodynamic properties of such systems can be controlled by external factors (temperature, electric and magnetic fields) and by the parameters of their microstructural units (shape, structure, topology).

In our work magnetic moments of anisotropic nanoparticles are directed parallel/perpendicular to the main axis of rotation. The computer experiments are based on the molecular dynamic method.

This research allows us to reveal the influence of particle shape anisotropy on the microstructure and macroscopic properties.

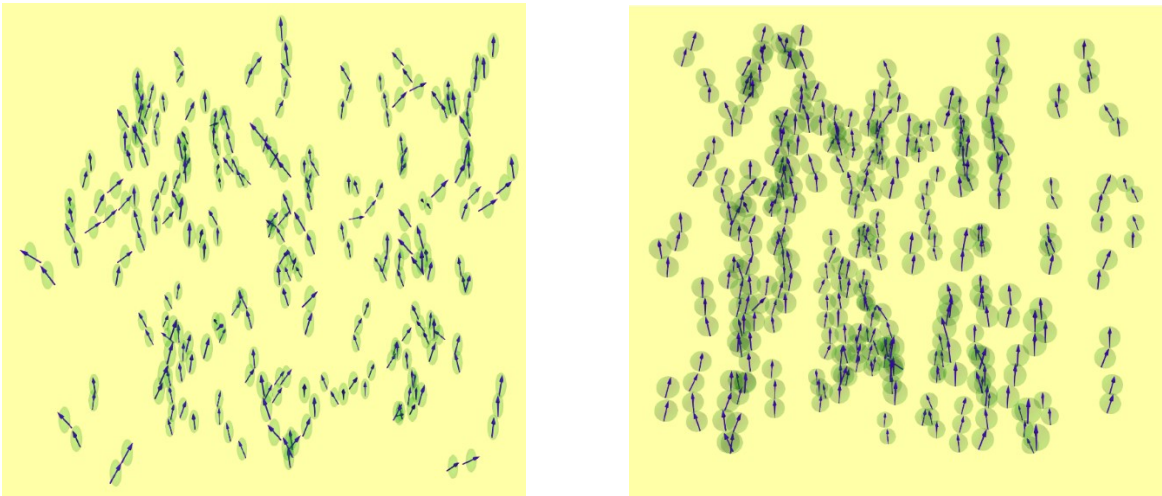

Fig. 1. Clasterization in the magnetic ellipsoidal nanoparticles system: comparison of elongated particles and almost spherical ones.

Thus, one can tune and design new smart materials with controllable microstructure and as a result various macroproperties via modifying particle parameters, such as shape and orientation of the magnetic moment and system characteristics. These results can be the basis for the development of theoretical models and the design of new systems with a magnetic response.

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Magnetization reversal in amorphous magnetic microwires

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Peculiarities of the magnetic properties of amorphous magnetic microwires have been the subject of numerous scientific works for decades. Mechanical stresses, which are induced during manufacture, lead to the appearance of magnetoelastic anisotropy and associated complex core-shell domain structure of the microwire, which depends on the magnetostriction of the particular alloy [1]. The fine micromagnetic structure of the wire affects its magnetic response, as it determines the magnetization mechanisms. Nevertheless, to define the micromagnetic structure, one has to use modified approaches, as its direct observation is limited. Several works devoted to microtomography using X-rays [2] described the obstacles, which first of all concern the sample dimensions restrictions. The magnetization reversal experiments allow conclusions about the internal structure by indirect investigations [3].

A complete description of the micromagnetic structure and the mechanisms of remagnetization processes in the microwires requires not only a comprehensive experimental study but also their numerical simulation, taking into account the obtained experimental data. Thus, modelling of magnetization reversal on a microlevel is necessary for the understanding of the main features of such processes and further prediction of the properties of the amorphous materials. In this work, the simulation of the microwires remagnetization by axial and circular magnetic field was carried out.

Micromagnetic modelling was carried out using the OOMMF package [4]. Calculations were carried out using rectangular mesh. Exchange stiffness A of $10^{-12} – 10^{-10}$ and saturation magnetization M_s in the range 100-800 kA/m were chosen as parameters. Magnetoelastic anisotropy was set as uniaxial with the spatial distribution of anisotropy constant K_{me} and easy magnetization axis direction. The magnetization reversal was considered in AC axial and circular magnetic fields. Equilibrium magnetization distribution in zero magnetic field was set as the initial state of the wire. Magnetization dynamics under the applied magnetic field were calculated by solution of the Landau-Lifshitz-Gilbert equation using the Runge-Kutta methods.

Equilibrium core-shell domain structures were obtained for both positively and negatively magnetostrictive wires. The axial remagnetization is associated with domain wall propagation in the core domain of the wire with positive magnetostriction. In the wires with negative magnetostriction, the inclination of the shell magnetization to the axial direction was observed. Local hysteresis loops in the wire sections were obtained for the axial and circular remagnetization.

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Neural stem cells activity on the polymer-based nanocomposites

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The ability of stem cells to differentiate into different types of cells makes them interesting for applications in tissue engineering and regenerative medicine. Nowadays, various growth factors are used to control the fate of stem cells, but this method has several disadvantages (the high cost of reagents and the limited time of exposure to cells). In recent scientific studies, it has been demonstrated that the fate of stem cells depends on their microenvironment, which can influence the mechanisms of mechanotransduction in cells [1]. The microenvironment of cells should be similar to the natural extracellular matrix and provide the action of various signals: mechanical, biochemical and electrical. The ability to provide these factors depends on the substrate material. The use of magnetoelectric polymer materials is most promising for these purposes.

Magnetoelectric polymeric composites — materials consisting of magnetic/magnetostrictive filler and piezopolymer matrix or polymer-bonded composites of ferroelectric and magnetic particles. In this class of materials, magnetoelectric coupling occurs through strain interactions (elastic coupling) of magnetic filler and piezoelectric particles or matrix [2]. Polymeric substrates demonstrate good biocompatibility, and this, along with multiferroic properties, makes them interesting for a number of biological applications. For example, the combination of these properties will make it possible to create substrates for stem cell cultivation, with remotely controlled physical parameters by applying an external magnetic field.

In this work, nanocomposites based on the polyvinylidene fluoride (PVDF) polymer and its polyvinylidene fluoride-trifluoroethylene copolymer (PVDF-TrFE) modified with magnetic nanoparticles ($CoFe_2O_4$ и $Zn_{0.25}Co_{0.75}Fe_2O_4$) and piezo particles BaTiO3 were designed. All samples were analyzed for physical and structural properties: X-ray diffraction analysis, analysis of magnetoelectric properties, magnetic microscopy and piezoresponse force microscopy. Two strategies have been identified for improving the magnetoelectric effect (α_{ME}): by ordering clusters of magnetic nanoparticles by an external magnetic field and by including piezoelectric particles in the composition of composites. The developed strategies allowed to increase the α_{ME} value from ~5 mV/cm E (PVDF composite with a random distribution of magnetic nanoparticles) to ~18.5 mV/cm E (PVDF-TrFE composite with the addition of piezoelectric particles). Samples based on PVDF were additionally tested on neuronal stem cells to analyze their effect on the activity of stem cells isolated at an early stage of mouse embryonic development [3].

This work was supported by the Russian Science Foundation No. 21-72-30032.

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Model of smart composite based on thermosensitive polymer for biomedical applications

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In medicine for cancer treatment, fragile chemical compounds or high toxic substances are often used. These materials can lead to patient intoxication or destruction of molecules before reaching disease location [1]. However, modern delivery systems are designed to make the use of toxic substances more safely. An example of such a system is a thermosensitive two-layer composite made of FeRh and PNIPAM layers. Performance of the system depends on the temperature control of the globule-to-solid PNIPAM phase transition occurring at 32 °C. Cooling of the PNIPAM layer occurs due to the negative magnetocaloric effect of the bonded FeRh layer placed into an external magnetic field. The thicknesses of FeRh and PNIPAM layers are crucial for the PNIPAM layer cooling to the phase transition temperature.

In this work, a model of the FeRh and PNIPAM layers composite was made to control the system's cooling process depending on the layers' thicknesses. The created model allows thickness selection of each layer by calculating heat distribution at a given point in time. The model is based on the stable and converging in the class of discontinuous functions difference scheme. Initial and boundary conditions were approximated for two cases: (i) Sample and environment don't exchange heat; (ii) Sample and environment exchange heat and environmental temperature is constant.

The model was implemented as a window application created in Qtcreator development environment and written in C++ programming language. Application allows calculation of heat distribution at a given point in time for two materials with specified coefficients of thermal conductivity, bulk density, heat capacity, initial temperatures and thicknesses.

To conclude, the program of fast heat distribution control in FeRh and PNIPAM-based composites depending on layers thickness was written. It can be used to design two-layer composites for systems with special temperature requirements. In further work, the COMSOL Multiphysics will be used to improve the model and consider more factors, like system lateral exchange of heat with environment and dependence of FeRh layer cooling intensity on the magnitude of a magnetic field.

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Superparamagnetic effect on the dynamic remagnetization of $CoFe_2O_4$ nanoparticles in a pulse field

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One of the essential manifestations of the magnetic properties of nanoparticles of magnetically ordered materials is the superparamagnetic state. The term "superparamagnetism" implies any effect that thermal fluctuations impose on the particle magnetic behavior well below the magnetic ordering temperature. When the fluctuations are intense, they might result in a complete disappearance of remanence provided the thermo-fluctuational (Néel) relaxation time is much shorter that the measurement time τ_m. So, some parameters of magnetic hysteresis depend crucially on τ_m. Here we present the results of study of magnetic hysteresis of cobalt ferrite nanoparticles both under the conventional quasistatic conditions and in pulse fields (dynamic re-magnetization).

$CoFe_2O_4$ nanoparticles with an average size $d \approx 6$ nm were synthesized by the method described in [1]. Dynamic hysteresis loops in pulse fields with amplitudes H_0 up to 130 kOe and pulse durations τ_P of 8 and 16 ms (in this case $\tau_P \sim \tau_m$) were measured using original technique [2]. It has been found that coercivity H_C increases with the magnetic field variation rate dH/dt, which is determined by the values of H_0 and τ_P.

A theoretical explanation is developed that ascribes this behavior to superparamagnetic effects. It is shown that the growth of coercivity with the magnetic field variation rate and its reduction with temperature fairly complies with the proposed model [3]. The obtained effective magnetic anisotropy constant K is $\approx 6 \cdot 10^6$ erg/cm^3, and this value is fairly independent on temperature in the range 80–300 K. The latter is indicative of the dominating role of thermal fluctuations (superparamagnetic effect) and might be considered as the thawing of magnetic anisotropy [3–5]. From the other hand, the K value notably exceeds that of bulk $CoFe_2O_4$ [6], and that points out the contribution of the surface magnetic anisotropy. Using well known expression for the combined (bulk + surface) anisotropy $K = K_V + 6\, K_S/d$ [7], at the bulk magnetic anisotropy constant $K_V = 2 \cdot 10^6$ erg/cm^3 [6], one obtains for the surface magnetic anisotropy constant: $K_S \approx 0.4$ erg/cm^2 [3].

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Magnetisation reversal of roughness modulated chemically homogeneous iron thin film

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Magnetic anisotropy variation can be achieved through the roughness modulation of a structure's interfaces. At an atomic scale, it may be used in spin-orbitronic devices due to the enhancement of interfacial Dzyaloshinskii-Moriya interaction and perpendicular magnetic anisotropy in thin 5d heavy metal/ferromagnet/4d(5d) heavy metal multilayers [1]. Micro- or nanoscale surface's roughness modulation significantly influences magnetic domain configuration even for samples with a single chemically homogeneous ferromagnetic layer [2].

The studied sample was fabricated by ion beam deposition of 100 nm of silver, 5 nm of iron, and 20 nm of silica nitride on top of a polymer substrate with trapezoidal diffraction grating period of 740 nm and stripes height of 100 nm [3]. The iron layer covers the grating profile non uniformly and causes an appearance of separate magnetic phases corresponding to the ferromagnetic material deposited onto different parts of the substrate profile. These phases are ferromagnetically coupled. The presence of the coupling leads to a hysteresis step-like behavior when the external field is applied along the stripes of the grating. Experimentally obtained and simulated hysteresis loops are shown in Fig.1.

This work describes the hysteresis behavior of a thin chemically homogeneous polycrystalline iron layer with surface roughness modulation using the experimental and simulated results of magnetic properties, first-order reversal curves diagram, and magnetic microstructure analysis.

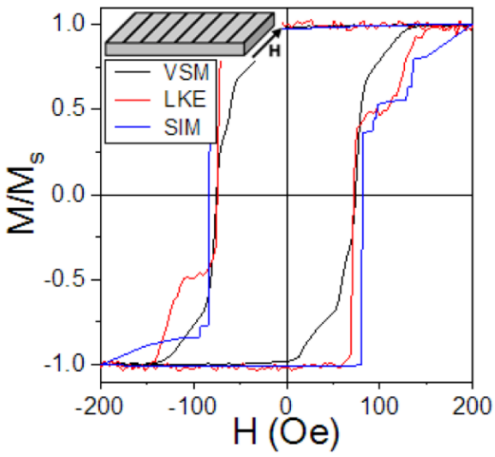

Figure 1. Integral (black), local (red) and simulated (blue) hysteresis loops. The inset shows the direction of the field in respect to the stripes of diffraction grating.

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Features of the magneto-optical effect in magnetic emulsions with low interfacial tension

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Ferrofluid microdroplet emulsions are a new class of functional nanomaterials with a wide range of potential applications. The improvement of existing methods and the development of new methods are based on a fundamental understanding of the behavior of magnetic emulsions under the influence of an applied external magnetic field. Under the influence of a magnetic field, the microdroplets of the magnetic fluid are deformed, which leads to the appearance of a significant anisotropy of properties, including optical ones.

We studied the influence of the duration of the action of the magnetic field on the parameters of the magneto-optical effect in a magnetic emulsion with low interfacial tension. The effect was estimated from the dependence of the relative change in the optical density of the sample on the time of exposure to the magnetic field at its various orientations relative to the light beam. A change in the sign of the effect was found with an increase in the duration of the magnetic field. That is, initially, with a short duration of action of the longitudinal field (less than 1.5 min), the action of the field led to a decrease in the transparency of the emulsion, and the transverse one – to an increase in transparency. With longer exposure to the field, the signs of the effects are reversed (see fig. 1a).

The interpretation of the effect is based on the approximation of anomalous diffraction (ADA) [1] since the emulsion droplets are optically soft; the relative refractive index is $m=n_1/n_0 \sim 1$, and the droplet size is much larger than the wavelength. Calculations in the approximation of anomalous diffraction show that a change in the sign of the optical effect is possible with an increase in the particle size (fig. 1b). Thus, prolonged exposure to the field leads to gradual coalescence of droplets and an increase in their size from 200-300 nm to 5-10 microns. By comparing the graphs and relying on the zero effect points, one can estimate the microdroplet size in the sample of magnetic emulsion.

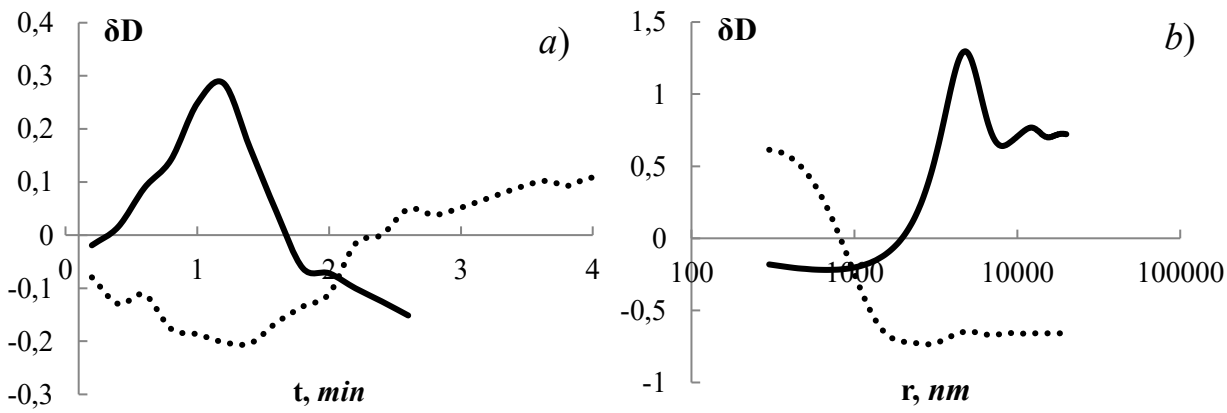

Fig. 1. Curves of the relative change in optical density depending on the time of exposure to the field (*a* - experiment) and the size of scattering particles (*b* - ADA calculation). Solid line - the field is directed along the ray, dotted line - the field is directed perpendicular to the light beam.

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Spontaneous phase transitions in the hard domain structure of Ferrite-garnet film

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The topicality of this study is that investigations performed in it can be used in constructing devices for transporting magnetically tagged microbiological particles. These devices can be used for sorting chemical particles according to their sizes at different temperatures.

The equilibrium and noneqilibrium bubble lattices of a ferrite-garnet film were studied. The investigations were carried out on a film with a developed surface <111> grown by liquid-phase epitaxy method on a gadolinium gallium substrate of the composition $(TmBi)_3(FeGa)_5O_{12}$, (T_N=473K, T_C=120K) where is the T_N– Neel temperature, T_C– the magnetic compensation temperature. The film at a room temperature has a quality factor Q>5. At such a value of Q in domain wall (DW), the action of a pulsed magnet field is perpendicular to the film plane and creates vertical Bloch lines (VBL) [1]. The domain structure is observed due to the Faraday Effect.

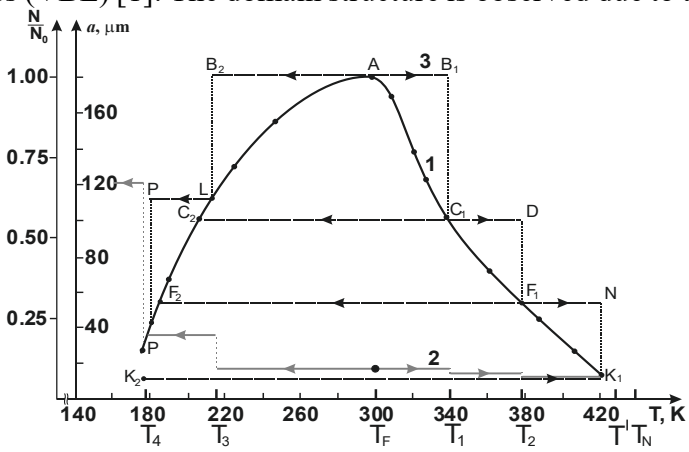

Fig.1. The temperature dependences of parameters of the bubble lattices: 1– N/N_0 VBL in the DW of equilibrium lattice; 2– period of nonequilibrium lattice; 3– N/N_0 VBL in the DW of nonequilibrium lattice.

It was experimentally determinate that the temperature change of film causes not only a change of domain phases but also structural transformations in the DW, which can be considered as a phase transitions. According to Fig.1 the temperature intervals of stability ΔT of nonequilibrium bubble lattices depends of a VBL number in DW. So, at the maximum number of VBL (point A on Fig.1) the ΔT is equal to (B_1–B_2). With a lesser VBL number (point C_1) the temperature interval of stability increases (C_2–D). The ΔT is a maximal at simple Bloch wall which creates under $T=0.98T_N$ [2].

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Automated search for low-dimensional magnets and its implementation: triangular magnetic clusters in $K_5Fe_3O(SO_4)_6 \cdot 10H_2O$

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Low-dimensional magnetism is a subject of great interest among condensed matter physicists. It is usually observed in compounds where magnetic ions form a sublattice of reduced dimension. The search for low-dimensional magnets is mostly carried out by the method of trial and error. Automatization of the search process would likely accelerate the progress in the topic and also help to find the "missed' compounds. The automated search could be realized through structural geometric, quantum computational methods or machine learning approaches. The first approach seems to be computationally inexpensive and become the initial stage in the search for low dimensional magnets with the desired properties.

Within the framework of this work an automated algorithm designed to search for low-dimensional magnetic compounds was created. The developed software was applicated for the search of the unexplored compounds with a magnetic subsystem of the following types: isolated triangular clusters, triangular plane, kagome plane, Cairo tiling. The algorithm selects the objective fragments (clusters or planes), which was limited by the difference between the distances to the nearest ion in the coordination sphere and the first one, not including to the environment. The application of the developed algorithm to the data available at open crystal structure databases (COD) allowed to find 257 isolated triangular clusters, 35 triangular planes, 36 kagome lattices, and 4 Cairo lattices.

Analysis of the data obtained made it possible to identify some unexplored low-dimensional magnets, one of which is an isolated triangular cluster in the α-Maus salt $K_5Fe_3O(SO_4)_6 \cdot nH_2O$[1], which was chosen as an experimental confirmation of the algorithm's correctness. Analysis of magnetic measurements showed that this compound really belongs to low-dimensional magnets, but further experimental work is required for its ground quantum state determination. Thus, in this work, the algorithm has confirmed its efficiency, allowing to obtain rapidly a set of unexplored low-dimensional magnets.

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Ferromagnetic microwire-polymer composite for sensor applications

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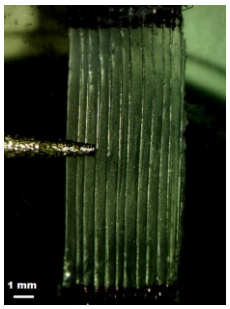
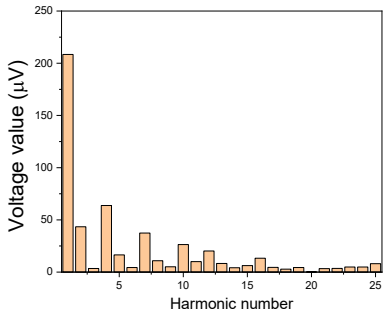
The development of magnetic/electric sensing materials with improved performance, microsize and wireless operation are increasingly critical for applications in structural health and environmental monitoring, security systems, biology, and medicine. Recently the concept of smart composites with magnetic sensing fibres has been extensively developing [1]. The present work devoted to the design and studies of smart composite materials with combined magnetic-electric effects based on Co-Fe ferromagnetic microwires (MW) embedded in polymer matrix of polyvinylidene fluoride (PVDF) polymer with piezoelectric response. These magnetoelectric smart composites (MESC) can be used as a sensitive element of sensory applications.

Magnetoelectric smart composite of MW/PVDF, consisted of Co-Fe based ferromagnetic microwires embedded in piezoelectric polymer PVDF matrix has been fabricated using solving casting method. For this procedure, PVDF granules (Alfa Aesar) were dissolved in dimethylformamide (DMF) (Sigma-Aldrich) with a weight ratio of 1:10. Complete dissolution of PVDF and obtaining a homogeneous solution was achieved using an ultrasonic bath for 45 minutes at a temperature of about 40 °C. Then ferromagnetic microwires were fixed, mounted parallel on template, coated by PVDF solution and dried at temperature 80 °C for 30 min. Coating by PVDF was repeated 4 times layer by layer to obtain the composite structure with fully embedded MWs in polymer matrix. The thickness of composite was about 0.5 mm with distance between microwires about 0.5 mm (Fig 1a). The harmonic spectrum of prepared samples has been studied by use of selective lock-in amplifier (SR830) with help of flat coil, which give an option of remote detection of voltage signal produced during remagnetizing of magnetic microwires.



(a)



(b)

Fig. 1. Image (a) and harmonic spectrum (b) of MW/PVDF MESC (MW-glass-coated amorphous $Co_{83}Fe_7C_1Si_7B_2$ microwires, PVDF- polyvinylidene fluoride).

We are presenting here a new method of monitoring internal stresses by using the stress-dependent harmonic spectra when the wire is remagnetized. The high harmonic spectrum of MESC of MW/PVDF are demonstrated in Fig.1 (b). The possibility of remote monitoring of effect of stress/strain, magnetic and electric field on properties of composite materials for sensory applications were demonstrated.

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Extended dispersive stiffness model of creep of domain walls

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The Dzyaloshinskii-Moriya interaction (DMI) has recently attracted considerable attention due to the possibility of using it in devices of a new type of magnetic memory. The interface DMI can stabilize chiral domain walls (DW's) of Néel type, which are effectively displaced by current pulses due to the transfer of spin moment, while the direction of propagation of the DW relative to the direction of the current depends on the sign of the DMI.

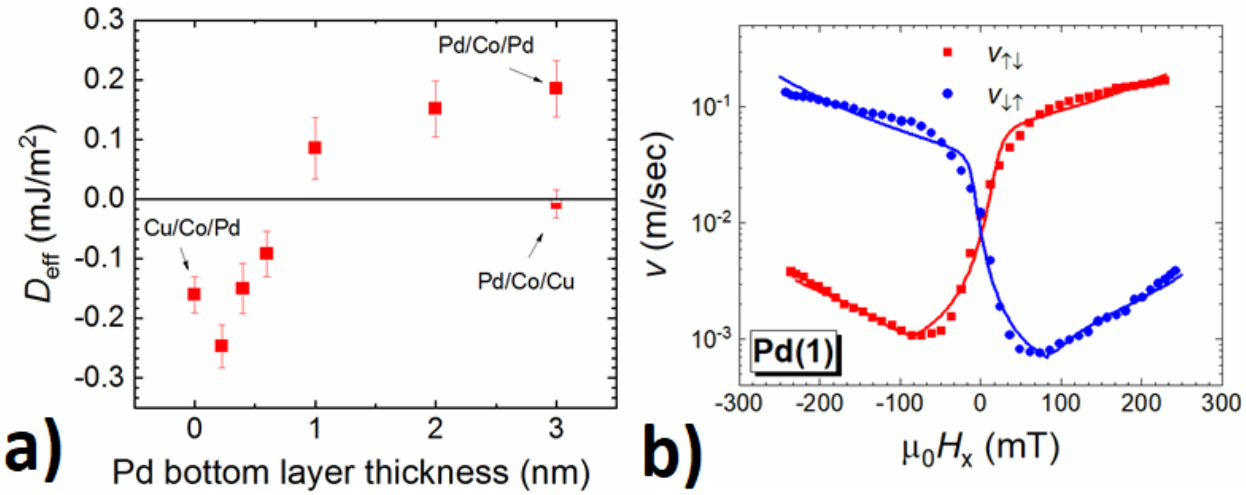

Fig. 1. a) Dependence of the effective energy of DMI on the thickness of the lower Pd layer; b) curves $v(H_x)$ for the right (red) and left (blue) domain boundaries measured in a sample with a lower Pd layer thickness of 1 nm.

In this work, using Kerr microscopy, we studied the creep of domain walls under the action of magnetic fields applied in the plane and perpendicular to the plane of the sample in a series of Cu(2 nm)/Pd(0-3 nm)/Co(0.7 nm)/Pd (3 nm) epitaxial films. The thickness of bottom Pd layer strongly affects the strains in the bottom Pd/Co and top Co/Pd inerfaces and hence, the value and even the sign of the effective DMI in the investigated system (Fig. 1(a)).

The extended dispersion stiffness model based on studies [1, 2] was proposed, which takes into account the dependence of the elastic energy of domain walls and the characteristic velocity factor in the creep law on the in-plane magnetic field (H_x).

In pioneer paper of Je et al. [3], it was proposed that DMI field may be determined from the position of the minima H_{min} on the $v(H_x)$ curves. However, the obtained results indicate that even a rough estimate of the DMI field by H_{min} (Fig. 1(b)) can lead to incorrect results. It is necessary not only to detect minima on the $v(H_x)$ curves, but also to reach saturation on the $v(H_x)$ dependences and use the extended dispersive stiffness model for fitting of experimental results.

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Model of perceptron based on spin-torque diodes with a ferroelectric/ferromagnetic bilayer controlled by a THz pulse of an electromagnetic field

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Nowadays, it is becoming increasingly difficult for modern computer systems based on von Neumann architecture to handle the processing of large amount of data, especially those presented in unstructured form (images, text, speech, etc.), which requires the development of completely new approaches. Previously, a group led by prof. Sharad proposed a concept of spin-based neuromorphic system, in which magnetic tunnel junctions (MTJs), which play the role of artificial neurons, communicate with each other through current-induced displacement of the domain wall in a ferromagnetic (FM) nanowire, which is responsible for the synaptic functionality [1]. On the other hand, significant progress has been made in the development of MTJ-based spin-torque diodes (STDs), which demonstrate a high microwave sensitivity up to 200 kV/W [2]. Here we propose the original concept of the perceptron, where STDs are connected as artificial neurons into a single network through a top ferroelectric (FE) microstrip, the domain wall of which can be shifted by the electromagnetic THz pulse and thereby switches the STD, due to magnetoelectric coupling between FE and FM layer (Figure 1). The total current creates a neuron response signal when the activation threshold is exceeded. Such magnetoelectric control of the STD network can be used in the development of high-performance neuromorphic systems, wirelessly controlled by an electric field [3]. The work was performed using the equipment of R&D Centre «MEMSEC» (MIET) and supported by the Minsvyaz RF and RVC JSC (№ 009/20, 0000000007119P190002).

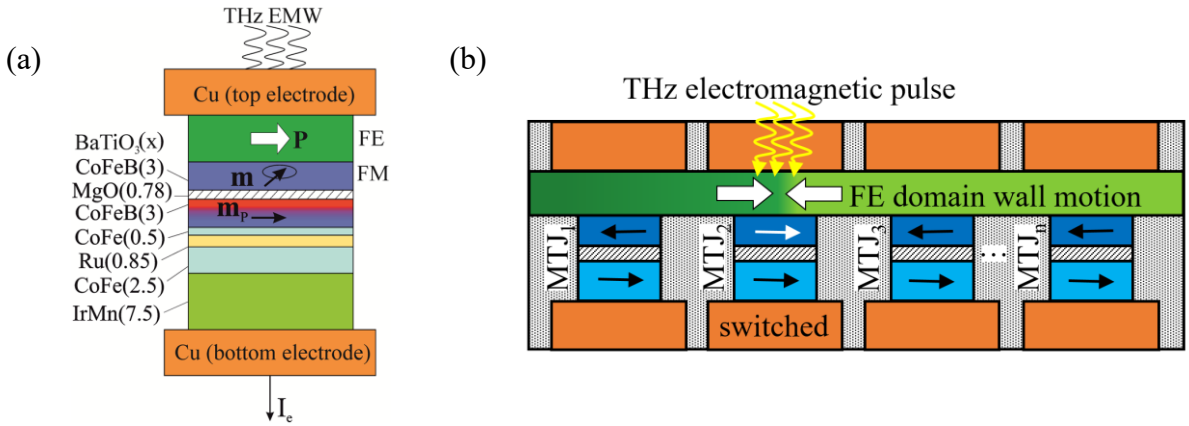

Figure 4. (a) Magnetoelectric control of the spin-torque diode based on MTJ with a ferroelectric (FE)/ferromagnetic (FM) bilayer driven by short THz electromagnetic pulse and (b) proposed concept of the perceptron.

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Circularly polarized luminescence of GaAs/InGaAs spin light-emitting diodes with CoPt/Al_2O_3/C injector

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Studying the processes of spin injection and spin relaxation in diodes based on semiconductor structures with ferromagnetic injectors is of interest from the point of view of introducing spintronic devices into modern microelectronics. One good example of such spin light-emitting diode (SLED) is an InGaAs/GaAs nanostructure with a CoPt injector considered in [1]. In this work, we present the results on the modification of semiconductor/ferromagnetic metal interface which consisted in the the introduction of carbon films directly on the surface of the GaAs structure. The presence of a carbon film at the metal/semiconductor interface significantly affects the processes of carrier current transfer, as well as the processes of spin injection and relaxation. In addition, the carbon film can act as a diffusion barrier during the process of the vacuum deposition of metal (Co).

The carbon films were fabricated using two different methods. The first unique method was thermal decomposition of carbon tetrachloride in a reactor for metal-organic chemical vapor deposition (MOCVD) [2]. The second method is a pulsed laser deposition (PLD) in vacuum [3]. A CoPt ferromagnetic injector was deposited by electron beam evaporation in a vacuum. In some cases, a 1 nm Al_2O_3 layer was formed prior to the CoPt. The diode diameter was 500 μm, the emission was extracted through the substrate to prevent multiple reflections and the influence of the MCD effect.

As a result, it was found that the deposition of carbon films using both of the technologies significantly reduces the operating currents of the diode, significantly increases the emission intensity of the SLED, and shifts the operating temperature of the diodes towards 300 K. The diodes demonstrate circulalrly polarized emission. A polarization degree was found to be nonlinear function of magnetic field with a saturation at 150 mT and maximal polarization being equal to 1 %. The most promising feature revealed is an operation at 300 K which is promising for constructing room-temperature spintronic devices.

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Green synthesis and magnetic properties of nanostructured FeCo-C and FeNi-C films

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Soft magnetic films have been widely used in the fields of magnetic recordings, magnetic sensors, microwave absorption [1–2]. As a kind of typical soft magnetic materials, FeCo and FeNi alloy films exhibit superior magnetic properties such as high Curie temperature, low coercivity, low magneto-crystalline anisotropy, high permeability, and high saturation magnetization. A variety of chemical and physical techniques could be used for the synthesis of Fe-based alloy films. However, these methods are fraught with many problems with the use of toxic solvents or high energy consumption. So, there is a growing need to prepare magnetic materials that do not produce toxic wastes in their process synthesis protocol. A promising approach to achieve this objective is to use polysaccharides (e.g. chitosan, cellulose) as an environmental alternative to conventional reducing agents [3]. Herein, we introduce a very promising eco-friendly processing technique based on the electroless deposition of FeCo-C and FeNi-C thick films with carbohydrates as reducing and stabilizing agents.

The FeCo and FeNi films were prepared by electrodeless reduction of metals from aqueous solutions of the corresponding salts at 800C on glass or copper substrate. We used several types of carbohydrates as reducing agents: arabinogalactan, corn starch, and sucrose. Mohr's salt concentration was adjusted to produce FeCo or FeNi deposits with various iron contents. The thickness of deposited films was in the range of 0.6-3 mm. The nanostructured thick films were characterized by electron microscopy, X-ray photoelectron spectroscopy (XPS), and X-ray diffraction. For FeCo film the bcc structure is found to be stable even for films with a very high concentration of Co (~0.94) beyond the thermodynamically stable bcc regime for bulk $Fe_{1-X}Co_X$ alloys. The average crystallite size calculated using the Scherrer formula for all film types was in the range of 10-27 nm. According to the results of XPS studies, carbon concentration in FeCo-C and FeNi-C alloys does not exceed ~ 2 at %. The saturation magnetizations, local magnetic anisotropy field, and coercivities of FeCo-C and FeNi-C films plated, under various processing conditions have been investigated to optimize soft magnetic properties. In cases, FeCo film reduced with carbohydrates the maximal magnetization values are 205, 235, and 240 emu/g for arabinogalactan, starch, and sucrose respectively, for FeNi films s_{max}~200 emu/g. The local magnetic anisotropy of FeNi alloys increases with a decrease in Ni content for all reducing agents. The positive linear correlation of Co content in Fe-Co alloy and the local magnetic anisotropy field is observed. It was found that surface relief, columnar microstructure, and hysteresis loops are controlled by varying reducing agent and Fe content.

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Dendritic growth in Co/Cu(111) surface alloy

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Dendritic cobalt clusters have pronounced ferromagnetic properties. They exhibit greatly enhanced magnetic coercivity in comparison with bulk cobalt [1], multiple dielectric relaxation and magnetic resonances, contributing to broaden the microwave absorption bandwidth [2]. Formation of the dendritic clusters in Co-Cu alloy was observed in experiments [3]. The magnetic properties of Co dendritic clusters depend on the their structure, while the structure of the clusters depend on the deposition conditions [4]. Thus, the study of the properties of dendritic Co-Cu clusters is of interest both from a practical and fundamental point of view.

It was previously shown that it is possible to study the formation of the fingerlike protrusions and dendritic clusters using the SlkMC technique [5,6]. In this study we investigate the formation of Co-Cu dendritic structures near the step edges on the Cu(111) substrate during the deposition of Co and Cu atoms. To analyze the structure of the clusters the fractal dimension is calculated. Note that cobalt and copper atoms do not mix at room temperature and, therefore, simultaneous deposition of Co and Cu atoms results in a formation of structures with a core consisting of Co atoms. As a result, the fractal dimension of Co-Co is lower than the fractal dimension of the whole cluster. An interesting feature of the presented work is a comparison of the fractal dimensions of the whole protrusion and the core consisting of cobalt atoms.

In a result of the study we investigated the formation of Co-Cu structures on the Cu(111) stepped substrate at different temperature regimes, amount of the deposited material, different deposition rates and relative concentration of cobalt atoms.

The research is carried out using the equipment of the shared research facilities of HPC computing resources at Lomonosov Moscow State University [7, 8]. The investigation is supported by the Russian Science Foundation (Project No. 21-72-20034).

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Base structural components of alloys for $(Sm,Zr)(Co,Cu,Fe)_z$ permanent magnets

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Advantages of $(Sm,Zr)(Co,Cu,Fe)_z$-based permanent magnets are due to their unique structure with the regular distribution of fine-grained phases in a highly anisotropic state. The high-coercivity structure of the $(Sm,Zr)(Co,Cu,Fe)_z$ alloy consists of Th_2Zn_{17}-type phase cells isolated from each other by a continuous $CaCu_5$-type boundary phase grid and is penetrated by thin Be_3Nb-type phase lamellas. The scale of structural morphology makes it difficult to analyze the processes leading to the formation of such a heterogeneity (Fig. 1 (5)).

It is shown in the present study that cast magnetically uniaxial $(Sm,Zr)(Co,Cu,Fe)_z$ alloy samples subjected to heat treatments demonstrate the ultimate hysteresis loops and domain-wall pinning coercivity mechanism and can be considered as model objects for the study of formation processes of high-coercivity state of these alloys.

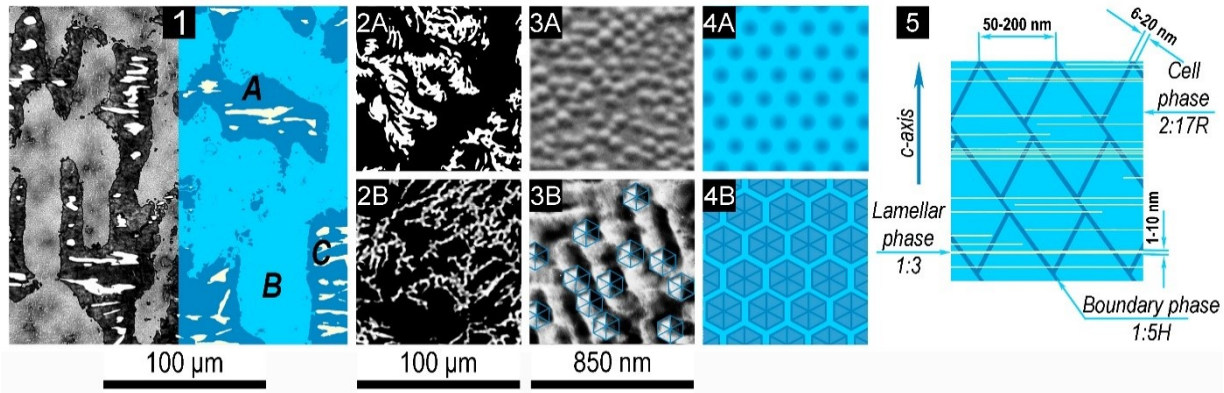

Fig. 1. (1) Base structural components A, B, and C observed on the prismatic plane of typical $(Sm,Zr)(Co,Cu,Fe)_z$ samples, morphology of (2) domains and (3 and 4) phases on the basal plane (SEM images and schemes, respectively) in A – (2-4)A and B – (2-4)B; (5) scale of the powder magnet structure.

Interrelations between the chemical composition of samples and their microstructure and coercive force are determined. It is shown that, over a wide composition range, the behavior of $(Sm,Zr)(Co,Cu,Fe)_z$ samples during the formation of high-coercivity state is determined by the relationship of volume fractions of two base structural components A and B, which correspond to 0.93-0.98 volume fraction of alloy (Fig. 1(panel 1)).

The domain structure in external magnetic fields (2B) and morphology (3B and 4B) of structural component B are analogous to those of sintered $(Sm,Zr)(Co,Cu,Fe)_z$-based magnets and represented by 2:17R cells surrounded by continuous cell boundary formed by phases belonging to $(Sm,Zr)_{n-1}(Co,Cu,Fe)_{5n-1}$ homology row. In turn, the domain structure (2A) and structural morphology (3A and 4A) of component A can be associated with the structures of quasi-binary $Sm(Co,Cu,(Fe))_x$ (x = 5-7) samples. It is likely that the structure of component A is analogous to that of cell boundaries in component B, i.e., it is based on $(Sm,Zr)_{n-1}(Co,Cu,Fe)_{5n-1}$ phases alternating along the "c" axis that is common for the anisotropic massive.

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Correlation of the structural transition temperatures and electronic characteristics in Ni-Mn-Sb-based magnetocaloric alloys

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It is well known that in the Heusler alloys based on Ni-Mn-Z (Z = Ga, In, Sb, Sn) systems the martensitic transition temperatures (MTT) are closely related to the structural state of the alloy, which, in turn, is closely related to magnetic properties. The main parameters influencing the MTT are number of valence electrons per atom *e/a* and the volume of the unit cell V_{cell}, however, their influence is not always unambiguous [1, 2]. It follows from the above that there is currently no universal parameter, which could unambiguously predict the behavior of the MTT, therefore, its search is a very urgent task. Apparently, there should be the relationship between the electronic structure of the alloy and the MTT. Taking this into account, the authors of this work proposed to consider electronic characteristics: the coefficients of the normal R_0 (NHE) and anomalous R_S (AHE) Hall effect, concentration of charge carriers *n* as such possible parameter.

The $Ni_{50}Mn_{35}Sb_{15-x}Al_x$ (x = 0, 1, 2) ingots were prepared by arc melting in an inert atmosphere. The elemental analysis was performed using an Inspect F scanning electron microscope (FEI Company, USA). The structural analysis was performed at the Collaborative Access Center «Testing Center of Nano-technology and Advanced Materials» of the Institute of Metal Physics, UB RAS. The magnetic and galvanomagnetic properties were measured at MPMS-XL-5 SQUID magnetometer and PPMS-9 setup (Quantum Design). The magnetic properties were measured in magnetic fields of up to 50 kOe in the temperatures range from 4.2 to 350 K. The Hall effect was measured by the standard dc four-probe method at temperature 4.2 K and in magnetic fields of up to 50 kOe.

It has been shown that for all investigated aluminum doping alloys the MTT is increase as the aluminum content in the alloy increases. Moreover with decreasing parameter *e/a* the MTT increases, although between them there should be a direct relationship. It was found that the NHE coefficient is negative, i.e., the main type of charge carriers are electrons, and the AHE is positive.

This work was partly supported by the state assignment of Ministry of High Education and Science of Russia (theme “Spin” No. AAAA-A18-118020290104-2) and by the Government of the Russian Federation (decision No. 211, contract No. 02.A03.21.0006).

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Nonlinear magnetoelectric effects in a periodic Ni-PZT heterostructure

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Linear and nonlinear magnetoelectric (ME) effects in the heterostructures containing ferromagnetic (FM) and piezoelectric (PE) layers, which arise due to combination of the magnetostriction in FM layer and the piezoelectric effect in PE layer, are actively studied because of its potential use in highly-sensitive magnetic field sensors and radio-frequency devices [1]. In this work we observed and investigated the nonlinear ME effects in periodic FM-PE heterostructures.

The heterostructure used is shown schematically in Figure 1. It is a set of 10 μm thick and w=100 μm wide nickel stripes, separated by T=20 μm, electrolytically deposited on a $PbZr_{0.52}Ti_{0.48}O_3$ (PZT) disk wafer, 23 mm in diameter and 240 μm thick. The heterostructure is placed in a tangential excitation ac magnetic field of the frequency f = 0-10 kHz and amplitude h = 4 Oe, and collinear dc magnetic field H = 0-1 kOe. The angle φ between the fields and Ni-stripes is changed by rotating the structure. The ME voltage generated between electrodes of the PZT-disk is measured for different values of f and H.

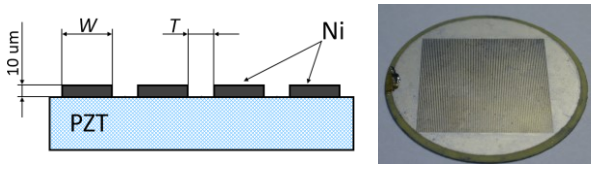

Figure 1. Schematic view and picture of the Ni-PZT periodic heterostructure.

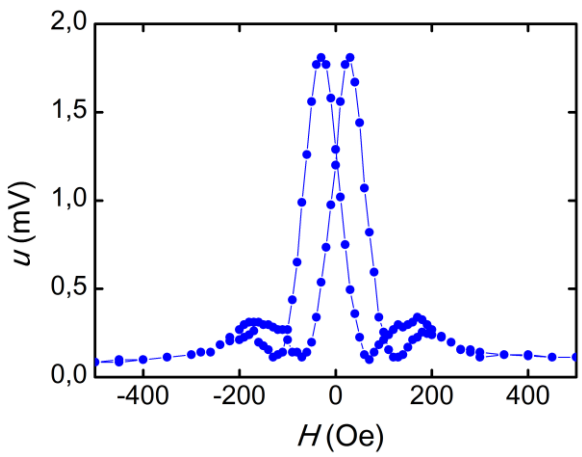

Figure 2. Amplitude u of the ME voltage 2[d] harmonic vs magnetic field H.

In the linear regime, at low h <1 Oe, the structure generated ac ME voltage with the frequency of the excitation field f. With increasing h, a nonlinear effect of ME voltage generation with a doubled frequency $2f$ was observed. Figure 2 shows the magnetic field dependence $u(H)$ of the second harmonic amplitude at f = 1.36 kHz and h = 4 Oe for H directed along the Ni-strips. The shape of the curve $u(H) \sim \partial^2\lambda/\partial H^2$ is determined by the field dependence of the Ni magnetostriction $\lambda(H)$ [2]. The hysteretic character of $u(H)$ upon field reversal is due to the hysteresis of the Ni magnetostriction as well. In addition, the nonlinear ME effect was highly anisotropic: the shape of the $u(H)$ curve strongly depended on the orientation of the H-field relative to the Ni strips due to demagnetization effects.

The structures fabrication was supported by the Council for grants of the President of the Russian Federation and measurements were supported by the Russian Science Foundation, grant 17-12-01435-P.

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Comparative study of melting pf Graphite and Graphene

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The melting lines of graphite and liquid carbon have been studied for a long time. However, numerous controversies still remain in this field; for instance, different experiments give different melting temperatures. In this work, we explore the melting lines of graphite and graphene by means of classical and ab-initio molecular dynamics. We show that the empirical models developed on the basis of experimental data (AIREBO potential, Tersoff potential and some others) fail to reproduce the properties of liquid carbon properly. The models fitted to ab-initio data (LCBOPII and GAP) give much better results. However, both types of empirical models and ab-initio simulations evidence the presence of smooth structural crossover in liquid carbon. We also show that the ”melting” of graphene discussed in previous works on computer simulation is indeed sublimation and propose a novel method to simulate the melting of graphene: simulation of graphene sheet in argon atmosphere. The melting temperature of graphene in argon atmosphere appears to be close to the melting temperature of graphite [1].

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Effect of phase transformations of a metal component on the magneto-optical properties of nanocomposites

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The study of magneto-optical effects in various types of granular alloys and composites demonstrated that they provide useful information about their properties due to the high sensitivity of magneto-optical spectra to the magnetic microstructure of the nanocomposites [1].

Complex investigations of the structural-phase transformations and magneto-optical properties of nanocomposites $(CoFeZr)x(MgF_2)_{100-x}$ (system1) and $(Co)_x(MgF_2)_{100-x}$ (system2) with a metal component in an oxygen-free dielectric matrix of magnesium fluoride on glass and glass-ceramics substrates have established the influence of the composition and phase transformations on their magneto-optical properties. By studying the spectral and field dependences of the transversal Kerr effect (TKE), it was found that the transition of nanocomposites from the superparamagnetic to the ferromagnetic state occurs in the region of x_{fm}~ 30 at% (S1) and x_{fm}~ 27 at% (S2), corresponding to the onset the formation of ferromagnetic nanocrystals of hexagonal syngony in amorphous dielectric matrix MgF_2. When studying the magnetic properties of these systems at $x = x_{fm}$, the appearance of nonzero values of the coercive force Hc was observed. With an increase of concentrations of the metal alloy $x>x_{fm}$, the features associated with structural transitions in magnetic granules are revealed in the TKE spectra. Comparison of the spectral and concentration dependences of the TKE for nanocomposites on glass and glass-ceramics substrates showed that the strongest differences occur in the region of the phase structural transition of CoFeZr nanocrystals (S1) from a hexagonal to a body-centered cubic structure at x=38 at% on the glass substrates and x=46 at% on glass-ceramics substrates, due to different diffusion rates and different size of metal nanocrystals on amorphous glass substrates and more rough polycrystalline glass-ceramics substrates.

The results obtained agree with the results of X-ray phase analysis of these samples. A relationship is established between the processes of self-organization during the growth of nanocomposites with increasing x and their magneto-optical properties.

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Simulation of anisotropic magnetoresistive sensor as a sensitive element of a smart glove for post-stroke neurorehabilitation

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One of the priority tasks of neurorehabilitation of patients after a stroke is the restoration of basic motor functions and an increase in the muscle tone of the fingers of the paretic limb. Modern research shows that the most promising method for controlling and stimulating neuroplasticity is currently the method of biofeedback, which consists in continuous tracking and subsequent analysis of motor activity [1]. This method is implemented through a system of miniature sensors that collect information about the state of the hands in a dynamic mode during a predetermined exercise cycle [2]. The main parameter that determines the motor skills of the hand fingers is the angle of rotation of each phalanx. High accuracy in measuring the rotation angle can be achieved through the use of a system of highly sensitive sensors attached to hand phalanges. The concept of a smart glove for neurorehabilitation of stroke patients based on a system of anisotropic magnetoresistive (AMR) angle sensors was considered in [3]. Such sensors based on the AMR effect have good sensitivity, increased reliability, combined with low cost. In this work, an original algorithm is proposed that allows using the micromagnetic distribution in AMR barber-pole structure in combination with a finite-element calculation of the current density to estimate the key parameters of the sensor (the resistance of the AMR structure, sensitivity, output signal, etc.). A numerical model of AMR sensor has been developed, which allows to determine the sensor performance for any topology of the sensitive element in relation to the angle of rotation of phalanges (Fig. 1). The sensitivity of the AMR sensor shows the possibility to detect a rotation angle of less than 0.1°. Based on the obtained results, the optimal topology of the AMR sensor was found. The work was performed in R&D Centre «MEMSEC» (MIET), supported by the Minsvyaz RF and RVC JSC (№ 009/20, 0000000007119P190002).

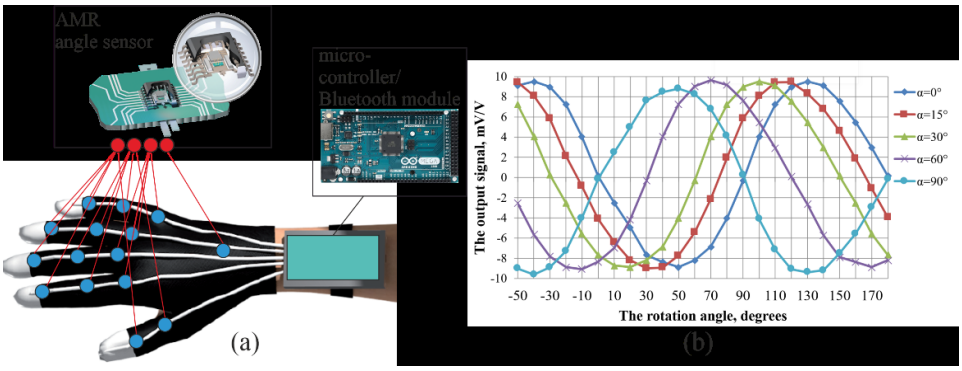

Figure 5. (a) Sketch of a smart glove based on the system of AMR angle sensors for post-stroke neurorehabilitation. (b) The output signal from the sensitive element of the sensor at different rotation angles.

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Determination of the direction of 4f magnetic moments in the near-surface atomic layers of rare earth compounds using photoemission

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Rare earth compounds have intriguing electronic and magnetic properties, including valence fluctuations, heavy-fermion properties, complex magnetic phases, unconventional superconductivity, Kondo physics, quantum critical phenomena, etc. They arise from the interplay between the valence electrons and the highly localized open 4f shell that provides a large magnetic moment influenced by the crystal electric field (CEF). Moreover, the properties may change drastically at the surface or interface. A prominent example is the recently discovered 2D ferromagnetism in a single atomic layer near the surface of $EuIr_2Si_2$ which is paramagnetic in the bulk [1]. In general, the near-surface magnetic properties of rare earth compounds remain rather poorly explored. Our data indicate that different atomic layers near the surface may have different, even orthogonal directions of magnetization.

Here, we propose a methodology allowing to determine orientation of the 4f magnetic moments in individual near-surface atomic layers based on photoelectron (PE) spectroscopy. On the one hand, this is a very surface-sensitive method of studying solids that allows one to obtain an imprint of electronic states. On the other hand, the photoemission matrix element is highly sensitive to the ground state of the 4f shell, which is directly related to the magnetic moment. Thus, it is possible to extract information on the magnetic properties of near-surface atomic layers of lanthanides from the 4f PE spectra.

Due to its localized nature, the 4f shell of a rare earth atom in the solid can be described similarly to the case of isolated ion. In our work, we calculated PE spectra for isolated ions of the lanthanide series for every possible magnetic quantum number M_J of the magnetically and/or CEF-split ground states. The results were compared with experimental data obtained for intermetallic compounds of the type $LnRh_2Si_2$ (where Ln = Sm, Eu, Tb, Ho, Tm). Such a comparison made it possible to establish the direction of the magnetic moments on the surfaces of different crystal terminations (Ln- or Si-). As a main result, we found that in most compounds the 4f ground states on the Ln-terminated surface suggest that the orientation of magnetic moments there is different from their direction in the bulk. It is noteworthy that our calculations provide a set of reference 4f PE spectra that can be used in the studies of a wide range of rare earth compounds.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation [Grant No. 075-15-2020-797 (13.1902.21.0024)].

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Effect of size distribution and surface roughness on the thermal dependence of coercivity and magnetic anisotropy in cobalt ferrite based nanoparticle assemblies

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The most common way to investigate the anisotropy of nanoparticles assemblies is by means of zero-field cooled-field cooled DC magnetization curves. However, depending on the characteristics of the investigated system, that experiment may not be successfully carried out. Such is the case of nanosystems based on the highly anisotropic cobalt ferrite, and analyzing the thermal dependence of coercivity arises as a more adequate experimental approach to assess the anisotropic properties. In this work, we investigate the thermal dependence of coercivity for cobalt ferrite nanoparticle samples synthesized by different methods and with different average diameters. Our analysis considers the size distribution and how it affects the thermally activated transition from the blocked to the superparamagnetic (SPM) state. Indeed, the fraction of blocked and SPM nanoparticles is constantly changing with increasing temperature, until the entire assembly becomes superparamagnetic. However, this is not sufficient to account for the experimental behavior observed [1]. Here, we expand on this investigation by also considering the thermal dependence of saturation magnetization and magnetic anisotropy constant[2,3]. Our approach enables us to obtain the anisotropy constant as a function of temperature, a quantity whose thermal variation is usually inaccessible in these kinds of systems since it's screened by the effects of SPM relaxation. The analysis of the anisotropy constants obtained and their thermal dependence allude to a convoluted interplay of types/sources of anisotropy affecting the coercivity.

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Tunable spin-wave propagation in planar YIG/PZT Mach-Zehnder interferometer

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The using elementary quanta of magnetic excitations (magnons) and spin waves (SW) in dielectric magnetic films sustain a signal transmission without moving charges and Joule heating, providing ultra-low power consumption and being a promising alternative to CMOS devices [1,2]. It is worth noting that, along with the transmission of information signals without the release of Joule heat, another advantage of using SW is the ability to encode a signal using amplitude and phase (logical "0" and "1") [3] to transmit and calculate information signals. The thin ferrite films are used as magnetic media, for example, yttrium-iron garnet (YIG), which show very low values of the SW dissipations [4].

Here, using numerical and experimental techniques based on the finite element method and Brillouin light scattering (BLS), the dynamics of propagation of surface magnetostatic waves in an irregular YIG waveguide with a piezoelectric layer was studied.

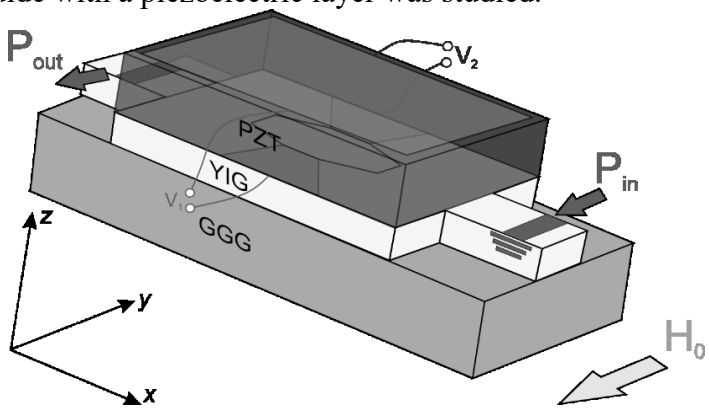

Fig. 1 The scheme of the considered structure.

Figure 1 schematically shows the considered structure, consisting of an irregular magnonic waveguide 10 μm thick, located on a gallium-gadolinium garnet substrate. Its represents the configuration of a Mach-Zehnder interferometer made by the laser ablation method from a YIG film. A piezoelectric layer of lead zirconate-titanate (PZT) is located on top of the magnonic waveguide. The structure is placed in a homogeneous static magnetic field H = 1500 Oe directed along the short axis of the microwave for effective excitation of the MSSW. On the bottom surface of the piezoelectric layer (on the side where the connection with the YIG film occurs) a trapezoidal 150 nm-thick chromium electrode is formed on both interferometer arms. On the top of the piezoelectric layer, a 250 nm-thick chromium electrode is formed. Using the BLS technique, the possibility of controlling local deformations by spin-wave interference in the proposed structure is demonstrated.

This work is supported by the RSF grant (#20-79-10191).

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Development of a method for diagnostic Crohn's disease using hybrid nanoparticles Fe_3O_4-Au

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Crohn's disease is an autoimmune disease with the gastrointestinal tract inflammation, with the intercellular distance increase in the epithelial layer of the terminal fragment of the small and large intestine [1]. Current diagnostic methods for the Crohn's disease include endoscopy, MRI, blood and stool analyses, etc. [2]. The symptomatology of the Crohn's disease is similar to that of ulcerative colitis that makes difficulty to provide a correct diagnosis and effective treatment. In the proposed method, wild-type mice of a group of healthy mice and a group of mice with intestinal inflammation, simulating the symptoms of Crohn's disease caused by using the Dexstran Sodium Sulfat Sigma Aldrich solution, were used. The separation in groups was done in order to compare an amount of nanoparticles excreted with feces in healthy and sick mice. Nanoparticles of different sizes were taken in order to estimate the size of gaps in the intercellular distance in the intestinal wall. The method goal is to determine a time and quantity of nanoparticles excreted from feces. Both type of mice received Fe_3O_4-Au nanoparticle solution by the gavage with the concentration of 200 μg/ml. Three types of nanoparticles were used depending on the Fe_3O_4 diameter d= 5 nm, 15 nm, 25 nm. Feces samples were taken from both groups at the different time after the nanoparticle administration: after 0 hours, 8 hours and 24 hours.

Magnetic properties of the samples were investigated using vibration magnetometry. Feces samples from mice which have not received a dose of nanoparticles show typical for biological tissues diamagnetic behavior. Magnetic moment of a feces sample mass unit was determined. For the group of healthy mice, the highest magnetic moment per unit mass, and probably the volumetric concentration, of nanoparticles with diameter d= 5 nm in the feces is observed at 8 hours after their administration, while of nanoparticles with diameter d= 15 nm - after 24 hours. For the samples with d= 25 nm the highest moment per unit mass is observed after 24 hours. The nanoparticles were also found in the feces of sick mice. On average, magnetic moment per unit mass is 2-5 times higher in healthy mice than in sick ones that may indicate a penetration of nanoparticles into the intercellular space of the intestine wall. It was concluded that the proposed experimental method of diagnosing Crohn's disease by means of the hybrid Fe_3O_4-Au nanoparticles could be further applied.

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Fabrication of 2D magnetoplasmonic crystals NiFe/Si_3N_4

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Advanced magneto-plasmonic crystals in the form of periodic 1D and 2D arrays are of wide scientific interest due to their applicability in magnetic field sensors [1], optoelectronic devices [2]. Technological profit of such systems is in the possibility to enhance a magneto-optical response and controlling plasmonic properties via an external magnetic field. Fabrication a 2D magneto-plasmonic crystal in nanometer scale requires a precise control of a grating period and a grating dot shape that is why this is a quite challenging technological process. Recently, it was proposed the use of the 2D Au/NiFe array with the grating period of 2.84 μm, to modulate the surface lattice resonance [2]. The structure was fabricated by the nanoimprint lithography method, and the dots were formed in the shape of a rectangle with rounded corners. In the other work [3], for example, the 2D magneto-plasmonic crystal was made of subwavelength holes in the NiFe continuous film, using deep ultraviolet lithography. In this case the grating period was 400 nm with the holes diameter of 265 nm. In this work, the electron beam lithography was used to fabricate diffraction gratings with the total size of an array of 500*500 μm, onto carbon substrates, spin-coated by the PMMA resist and then backed in oven at 180°C for 30 sec. The resist was preliminarily diluted with the anisole in the 2:1 ratio, respectively. The electron beam direct writing was performed with various doses 400, 500, 600 μC/cm^2. After the resist development the Ag (100 nm)/$Ni_{80}Fe_{20}$ (70 nm)/Si_3N_4 (20 nm) multilayered thin films were deposited using magnetron sputtering method. Resulting diffraction gratings were obtained with the period d= 610 nm ± 20 nm and height h= 80-90 nm (Fig. 1). As the dose decreased, the squareness and a size of the dots increased, as well as a diffraction gap depth increased. An increase of the mean dot size was followed by a slight red shift of the diffraction minima.

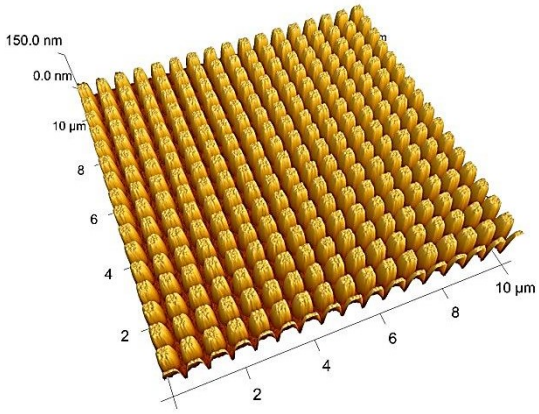

Figure 6. Atomic force microscopy images of the diffraction gratings.

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Phase resolution of spin wave propogation in YIG film with linearly varying width

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The creation devices based on the principles of magnonics is of great interest for areas, included the development storage and information signals processing [1]. Using Brillouin spectroscopy of light scattering (BLS) technique, it is possible to detect the propagation of a spin wave (SW). In the classical BLS system we detected the intensity I_{BLS} of SW [2]. By adding an optical phase modulator to the BLS system, the phase of the propagating SW can be resolved [3].

In this work, we study the propagation of SW with a phase resolution in a yttrium iron garnet film (YIG) with linearly varying width [3] was fabricated by the laser scribing technique. The described structure (see on fig. 1) represent YIG film with a thickness t_{YIG} = 10 μm with a saturation magnetization of $4\pi M_0$ = 1750 G, formed on a gadolinium-gallium garnet (GGG) substrate with a thickness of t_{GGG} = 500 μm. A structure with a linearly varying width width of w = 2 mm and a length l=8 mm was placed in an external magnetic field M0=1830 Oe to excite a magnetostatic surface spin wave (MSSW).

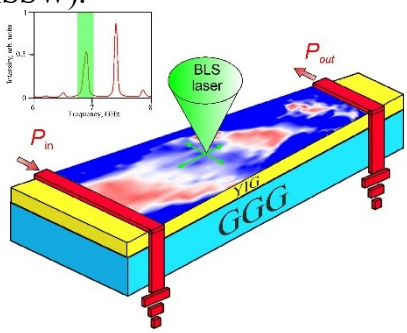

Figure 1.: a)Scheme of the structure with a superimposed map of the SW phase.

BLS method will be used to study the formation the phase front of a spin wave in a YIG film. Using micromagnetic modeling, agreement with the experimental data will be shown, the intensity and phase of the SW will be compared and the optimal parameters for the propagation of SW in the YIG film are revealed.

This work was supported by the Russian Foundation for Basic Research (project No. 20-37-90020, project No.18-29-27026).

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Investigation of magnetic elastomers: structural and magnetic properties

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Nowadays the design and application of smart materials attract attention of scientists from all over the world. These materials are sensitive to changes in their environment. Magnetic elastomers - hybrid materials composed of a rubber-like carrier with magnetic particles embedded into it - are one of such materials. Magnetic elastomers change their shape, mechanical and magnetic properties under external magnetic field which makes these materials very attractive for numerous technological applications [1],[2].

This paper is devoted to the study of self-assemble of magnetic raspberry type particles in shear flow after quick increasing of viscosity.

With the help of Lattice-Boltzmann hydrodynamic solver and the simulation package ESPResSo [3] we perform molecular computer simulations. To obtain comprehensive information about system under study we analyze structural and magnetic properties of the elastomer in the channel. We also perform cluster analysis using graph theory.

The work was supported by RFBR 21-52-12013.

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Planar superconducting film magnetic field concentrator

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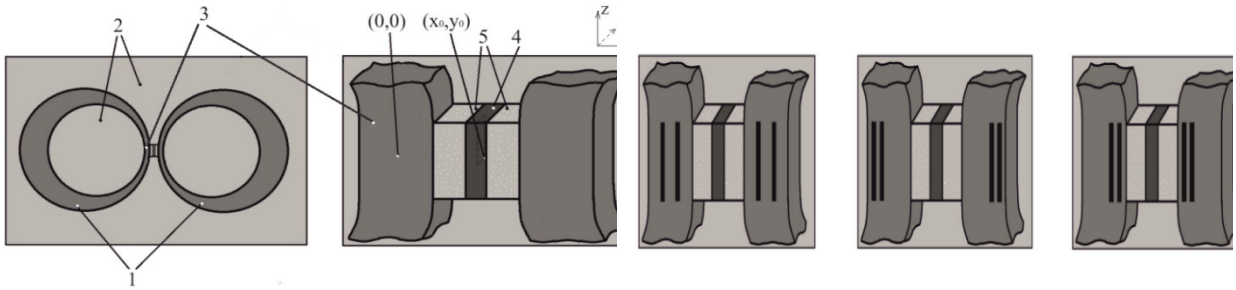
Most magnetic field sensors (MFS) have high resolution, i.e. low threshold sensitivity δB_0 ≤1 nT, achieved through the use of superconducting film magnetic field concentrators (MFC). They decrease in the MFS, in which various structures can serve as magnetosensitive elements (MSE), such as Josephson junctions, Hall sensors, sensors based on spintronic effects, etc. [1-4].

In this work, we study a planar structure (see Figure), in which the MFC and MSE are on the same plane and do not intersect with each other. The above structure had the following parameters. Figure *a, b*: receiving rings 1 – outer diameter 2 mm, ring width 0.8 mm; 2 – substrate; 3 – active bands (AB), 30 μm wide; 4 – MSE having a width of 10 μm; 5 – the width w_a of the gap between the AB and MSE varied in the range 0.2 ÷ 5 μm; $(0,0)$ – coordinate system; (x_0, y_0) – coordinates of the AB. All elements deposited on the substrate have the same thickness of 20 nm. Figure *c, d* and *e*: parallel sections in the AB are located uniformly across the width, unevenly far from the MSE and close to the MSE, respectively.



a *b* *c* *d* *e*

The concentration factor F of the magnetic field is defined as the ratio of the average magnetic field at the MSE to the value of the external registered field B_0. It has been established that the MFC made from a film of a low-temperature superconducting material (LTSC, the penetration depth of the magnetic field is λ ~ 50 nm) concentrates the magnetic field on the MSE, which has a degree of inhomogeneity of more than 20% in the range $B_0 \leq 1$ μT. MFC from a film of high-temperature superconducting material (HTSC, λ ~ 1000 nm) concentrates the magnetic field on the MSE, which has a degree of inhomogeneity of less than 10%. It is shown that parallel cuts with coinciding widths w_a increases the value several times, especially strongly for the case shown in Fig. *d*. In this case, for LTSC films, higher values of F are realized as compared to HTSC films. The results obtained will improve the efficiency of the existing MFS in the form of a decrease in their value of δB_0.

This work is supported by the Ministry of Science and Higher Education of the Russian Federation (project No. 075-03-2020-216 of December 27, 2019).

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Influence of the magnetic field gradient on the optical density of an aqueous dispersion containing biological material and carbon nanotubes

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Composite nanomaterials containing matrices of biological materials and filler made of carbon nanotubes (CNTs) are promising. They can be used in various implants, for example, in bone or cartilage tissues, and their aqueous suspensions, the so-called biological solders, are suitable for laser welding of biological tissues [1]. Since CNTs contain catalytic ferromagnetic or so-called superparamagnetic nanoparticles, they can be used for non-invasive monitoring of nanotubes. Thus, carbon nanotubes can be regarded as a kind of magnetic particles (MPs). In our experiment, we investigated the change in optical transmission under the action of the magnetic field of aqueous dispersions containing biological materials and single-walled CNTs (SWCNTs).

Aqueous composite nanomaterials contained a matrix of either bovine serum albumin (BSA) or microcrystalline cellulose (MCC) and a filler of SWCNT. BSA/SWCNT and SWCNT aqueous dispersions were prepared in the same way as described in [1]. They consisted of: 15 wt.% BSA and 0.01 wt.% SWCNT; 3 wt.% MCC and 0.01 wt.% SWCNT and 0.01 wt.% SWCNT, respectively. The relative optical density T of aqueous dispersions was measured in the optical range $\lambda = 200 \div 1100$ nm. For each variance, measurements of the T data were repeated three times, which made it possible to check the stable repetition of the obtained $T(\lambda)$ curves. To record the $T(\lambda)$ dependences, the variance was prepared as follows. Two identical cuvettes were filled. A neodymium magnet was attached to one cell, which created a magnetic field gradient of the order of ~ 1 T/m. The dispersion was retained in the cells for up to 72 h. After the end of the exposure of the dispersion in a magnetic field, optical measurements were carried out on a spectrophotometer.

At $\lambda = 550$ nm, the values of T were compared for various aqueous dispersions. It turned out that the values of T are approximately by ~ 10–15% lower in dispersions exposed to the action of a magnetic field, compared to the dispersion on which a magnetic field was not affected. The effect of the magnetic field on T is especially noticeable at $\lambda \leq 400$ nm. For example, in the variances BSA/SWCNT and MCC/SWCNT, the changes in T values reached ~ 25%.

Confocal microscopy showed that, under the influence of a magnetic field, SWCNTs aggregate to form linear chains on which light is strongly scattered and decreases T. It is proposed to use this effect to determine the size of SWCNT aggregates in aqueous dispersions of the composite nanomaterials under study, and also consider a non-invasive method for their registration (similar MP) using magnetic field sensors with a low threshold of magnetic sensitivity $\leq 10^{-9}$ T.

The authors are grateful to E.S. Davidova and V.M. Podgaetsky for help in the experiment and discussion of the results. This work is supported by the Ministry of Science and Higher Education of the Russian Federation (project No. 075-03-2020-216 of December 27, 2019).

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Length dependence of magnetization properties of amorphous FeCo-based microwire with nearly zero magnetostriction coefficients

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Studies of magnetic properties of glass-coated amorphous microwires attracted significant attention during last few years [1-2]. The reason for this is the unique magnetic properties, such as magnetic bistability, enhanced magnetic softness, Giant magnetoimpedance (GMI) effect, and fast domain wall propagation, which are suitable for a lot of applications [2-4]. The purpose of our study is to find length dependence of magnetization properties of amorphous FeCo-based microwire with nearly zero magnetostriction coefficients, λ_s.

We investigate glass-coated microwire $Co_{83}Fe_7C_1Si_7B_2$ ($\lambda_s < 10^{-8}$) with inner core diameter d = 38μm and total microwire diameter D = 44μm. Figure 1 shows hysteresis loops of $Co_{83}Fe_7C_1Si_7B_2$ samples with different length. As we can see, the coercive force and residual moment decrease along with the length of the wire. The reason of this dependence is increasing relative volume of closure domain structures at the ends of the inner core with reducing microwire`s length. Critical minimum length of $Co_{83}Fe_7C_1Si_7B_2$ is about 4 cm. For example, critical minimum length of $Fe_{65}Si_{15}B_{15}C_5$ is < 2 mm, as was found earlier [5]. Such significant difference in critical length can be explained by effect of both nearly zero magnetostriction coefficient and small stresses inside a wire for $Co_{83}Fe_7C_1Si_7B_2$.

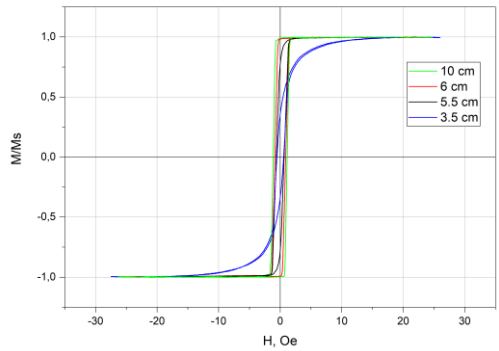

Fig. 1. Hysteresis loops of the $Co_{83}Fe_7C_1Si_7B_2$ wire of different length.

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Selective toxicity of nanoparticles with redox-sensitive coating towards cancer cells

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The use of stimulus-sensitive systems allows control and change the processes occurring in the organism [1], [2]. A promising approach is the use of redox-sensitive drug delivery systems based on drug immobilization in nanoparticles via disulfide bonds (S-S), the dissociation of which in the reducing medium results in drug release. We implemented this concept on a model system by covalent immobilization of a polyethylene glycol (PEG) stabilizer on the surface of magnetic nanoparticles through disulfide bonds. We synthesized iron oxide nanoparticles by thermal decomposition, with NH_2-PEG-COOH polymer grafted through 3,3'-dithiodipropionic acid. The obtained magnetic nanoparticles had a reverse spinel structure, which corresponds to magnetite or maghemite. The average nanoparticle size was about 6 nm, saturation magnetization was about 63 $A \cdot m^2/kg$. The chemical structure of PEG conjugate with disulfide and 2-nitrodopamine linker was confirmed by Nuclear Magnetic Resonance. Redox-sensitive nanoparticles in a reducing medium lost their colloidal stability and aggregate, while the control PEGylated nanoparticles without an S-S bond retain their stability. Also, concentration dependence was shown, nanoparticles with disulfide aggregated faster, when the concentration of reducing agent increased. In a tumor cell, the severity of redox response depends on the intracellular environment of nanoparticles after they are captured. In cell, the role of main reducing agent is played by tripeptide glutathione (GSH), the concentration of which varies depending on the type of cells and cellular compartments [3]. Cytotoxicity studies on cell lines PC3, U87 showed that both the control nanoparticles and with the S-S bond demonstrate the non-toxicity, while for 4T1 redox-sensitive nanoparticles turned out to be much more toxic in concentration range 50-800 μg/mL per iron oxide. Thus, in this work, we show that our redox-sensitive system works *in vitro*.

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Characteristics of the magnetization-vector precession and switching in the spin-valve free layer with perpendicular anisotropy

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In this work, we simulated the dynamics of the magnetization vector **M** of a free layer of a spin-valve structure with perpendicular layers anisotropy. The spin valve placed in the magnetic field of arbitrary direction. Four hardmagnetic alloys ($Co_{50}Pt_{50}$, $Fe_{50}Pt_{50}$, $Fe_{50}Pd_{50}$, $Fe_{50}Ni_{50}$) and six softmagnetic materials (cobalt, iron, $Fe_{70}Co_{30}$, $Fe_{60}Co_{20}B_{20}$, $Co_{93}Gd_7$ and $Co_{80}Gd_{20}$) are considered as materials for the free and fixed layers of the valve. The critical characteristics of the switching and precession of the vector **M** for the read head of the hard disk (HMDD), magnetoresistive random access memory (MRAM), spin-transfer nanoscillator (STNO), and the stochastic neuron p-bit used to implement probabilistic spin logic (PSL) are calculated.

For the manufacture of a magnetic element included in the MRAM and p-bit architecture, it is necessary to use hard magnetic material, since in magnetically soft materials without support of an external magnetic field the equilibrium states corresponding to the recorded “0” and “1” are unstable [1]. Thus, the most suitable material for the manufacture of MRAM is $Fe_{50}Ni_{50}$ because it has minimum switching current from parallel to antiparallel among magnetically hard materials. HMDD uses a switching mode in which a change in the direction of the vector **M** occurs under the influence of a magnetic field parallel or antiparallel to the anisotropy axis. Therefore, $Fe_{60}Co_{20}B_{20}$ is the optimal material for the manufacture of HMDD read heads, since it has the best ratio of the GMR coefficient of the minimum switching field and the relatively short switching time of the magnetic field.

The main mode of operation of the spin valve as a PSL element is switching with two probable outcomes. With this switching, the vector **M** changes its direction from the perpendicular axis of anisotropy to parallel to the probability of P_{AP} or antiparallel to it with probability P_P. To derive the magnetization vector to its initial position, a magnetic field is applied along the anisotropy axis. Among the materials considered, the most promising for the production of p-bit is $Fe_{50}Ni_{50}$, since the spin valve based on it has the greatest energy efficiency.

The maximum precession frequency is observed for $Fe_{50}Pt_{50}$-based STNO in the magnetic field perpendicular to the anisotropy axis. However, the $Fe_{60}Co_{20}B_{20}$-based spin valve in this case has 4 times less power consumption and 1.5 times greater oscillations amplitude. Therefore, this material is the optimal material for STNO technology.

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Effect of pulsed laser annealing on the properties of (Ga,Mn)As layers

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This work is devoted to the study of the possibility of modifying the properties of a magnetic diluted semiconductor (Ga,Mn)As by laser annealing. Such layers are used as injectors in the LEDs demonstrating circularly polarized radiation [1].

(Ga,Mn)As layers were formed by pulsed laser deposition at 330°C on top of a GaAs buffer layer fabricated by MOCVD on *i*-GaAs substrates. In this research, the thickness of the layers was varied from 30 to 170 nm, the Mn content was ~ 15 at. %. Samples of the fabricated structures were exposed to a defocused beam of an LPX-200 pulsed excimer laser (working mixture KrF, wavelength 248 nm, pulse duration 30 ns, energy density 300 mJ/cm^2). The structural and magnetic properties of the layers were studied. For magnetization study we used a magnetometer with a variable field gradient at room temperature. Galvanomagnetic measurements were carried out using a closed-cycle helium cryostat (in a magnetic field up to ± 3600 Oe) at temperatures from 10 to 300 K.

According to the results of X-ray diffraction studies, the presence of phase inclusions (semimetal MnAs) was established, both in the initial and in the annealed samples (Ga,Mn)As. Analysis of the magnetic field dependences of magnetization containing a hysteresis loop showed that the response from the MnAs phase, which is ferromagnetic at 300 K, increases with rising thickness of the (Ga,Mn)As layer and decreases after pulsed laser annealing.

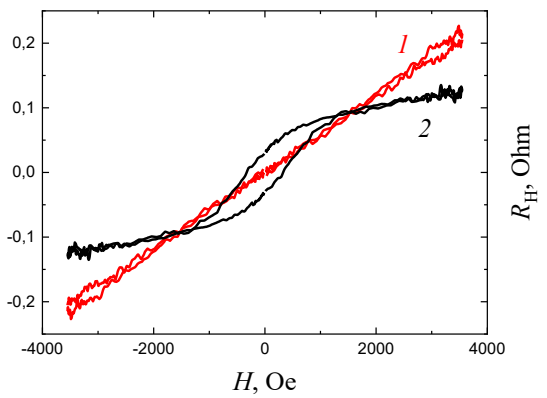

Figure.1. Magnetic-field dependences of the Hall resistance at 100 K for an initial GaMnAs sample with a thickness 170 nm (*1*) and after laser annealing (*2*).

The Curie temperature of the "semiconductor matrix" - heavily doped (Ga,Mn)As - in the initial samples was 30 - 40 K. In this case, the samples demonstrated a nonlinear dependence $R_H(H)$ with a hysteresis loop and negative magnetoresistance. For higher temperatures, the $R_H(H)$ dependence became linear (figure.1). It was found that pulsed laser annealing leads to an increase in the Curie temperature to values of no less than 120 K.

The results obtained may be of interest for the technology of spin optoelectronic devices.

This work was supported by the Russian Scientific Foundation, project no. 19-19-00545.

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Study of mechanically-induced twins in 10M modulated Ni-Mn-Ga martensite

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Study of materials with magnetic shape memory based on Ni-Mn-Ga is a intresting and promissing task. Its urgency is due to the possibility of creating unique micromechanic devices based on the effect of reorientation of domains under the influence of a magnetic field. Twin boundaries play the crucial role in the reorientation of domains, and the most important characteristic of this process is the mobility of twin boundaries.

In this work, we studied samples of the $Ni_{50.0}Mn_{28.4}Ga_{21.6}$ single crystal. Using scanning electron microscopy, we determined the presence, position and shape of twins caused by indentation or transverse bending of the sample (Fig.1 – ***a*** and ***b***) and determined the mobility of twinned and magnetic domain walls from the effective modulus of elasticity using a composite piezoelectric oscillator (Fig.2).

As a result of the study, a correlation was found for such characteristics as the modulus of elasticity and the decrement of vibration damping from the twin structure inside the sample.

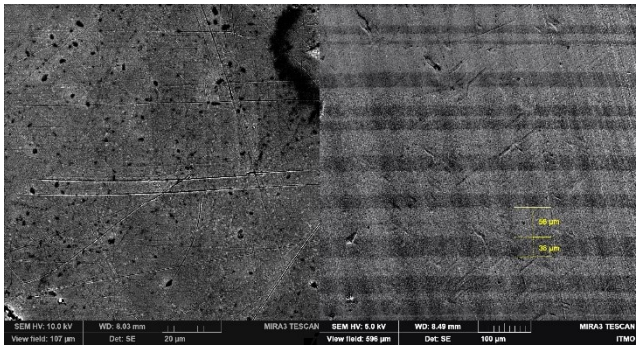

Figure 1. Microimages of twins

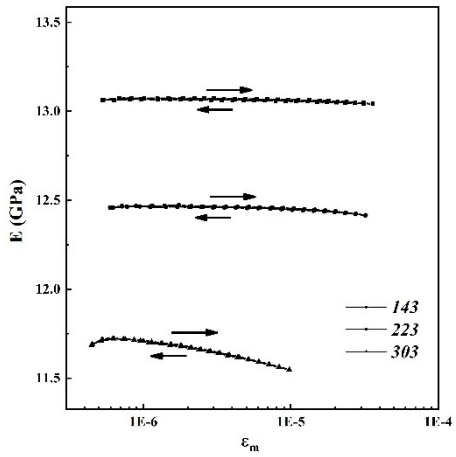

Figure 2. Effective elastic modulus

The reported study was funded by RFBR, project number 20-32-90195.

Non-contact methods for magnetocaloric effect measurements

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A big problem in magnetic research is the accurate measurement of the temperature of materials, especially in high pulsed and alternating magnetic fields. The disadvantages of contact temperature sensors are the effect of electromagnetic noises on their indications, which is proportional to the time derivative of the magnetic field, and the long response time of the order of 0.1 ms (for micro-thermocouples and film thermistors). The described difficulties can be avoided by using non-contact methods for measuring the material's temperature in magnetic fields.

We present a non-contact method for direct experimental measurement of the magnetocaloric effect (MCE) in pulsed magnetic fields by using the temperature probe based on IR fiber-optical sensor [1, 2]. The new system demonstrates the fast response (better than 0,1 ms) and high noise immunity. This method was compared with the systems based on micro-thermocouples and thin film thermistors.

The other using non-contact method for temperature measurements is the IR-thermography. It was applied for MCE measurements in prospective materials in steady magnetic fields up to 14,5 kOe.

This work is supported by the Russian Science Foundation (project No. 18-79-10176).

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Features of magnetization processes in nanowires based on Fe-Co and Fe-Ni alloys

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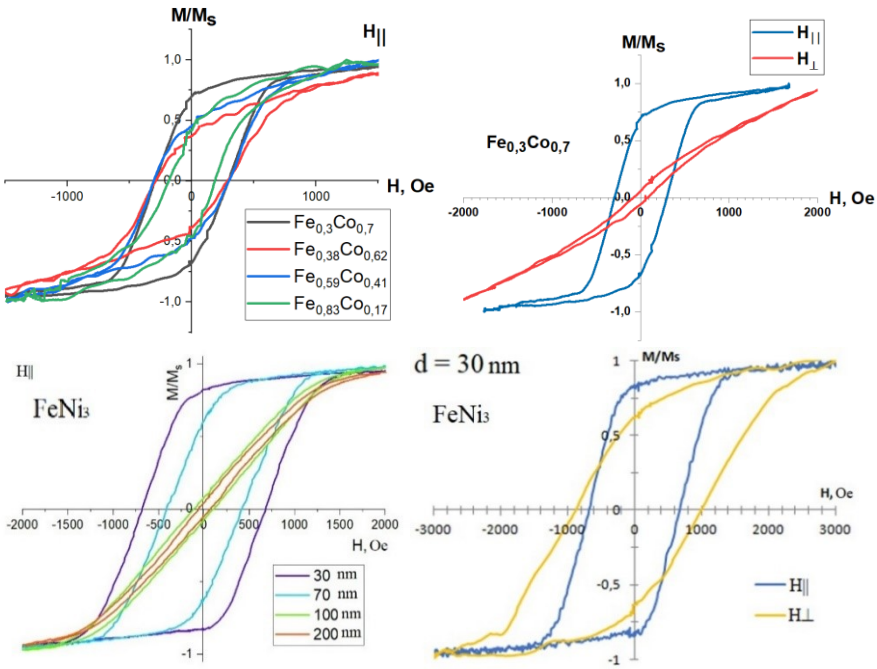
Electrodeposited ferromagnetic 1D nanowires (NWs) are perspective materials for magnetic memory devices and sensors [1] including flexible electronics. Bulk FeCo and FeNi alloys have high magnetisation saturation [2] and low coercivities. It is assumed that nanostructuring of such materials in an elongated shape can lead to the enhancement of magnetic anisotropy due the shape anisotropy. Then, a noticeable increase in coercivity is expected.

Nanowires were electrodeposited using PETE ion track membranes with track pores perpendicular to the membrane's surface and having different diameters (30 - 200 nm). The length of NWs varied from 3 to 6 µm. The structural properties of materials were studied using X-ray diffraction and scanning electron microscopy. Vibrating-sample magnetometer was used for measuring the hysteresis loops which are shown in Figures below.

The coercivity of FeCo NWs has a nonlinear dependence on the amount of Fe in the alloy, decreasing at the high concentrations of Fe in the structure. Maximum of H_c (360 Oe) was found in $Fe_{0,3}Co_{0,7}$ alloy in parallel magnetization. The decrease of the diameter of $FeNi_3$ NWs has led to the increase in coercivity up to 45 and 700 Oe for the diameter of 200 and 30 nm respectively. Such an increase in H_c is explained by the axial texture, shape anisotropy and remagnetization by coherent rotation.



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Spin-wave beams formation in 3D magnonic arrays

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Magnons, being the quanta of spin-wave excitations, can be used as the signal carriers at frequencies that are lying between a few GHz to hundreds of GHz [1]. Magnonic networks(MN) comprised of coupled YIG spin-wave stripes can be used to process information and at the same time providing the technologically relevant integration to the present CMOS architecture [2]. Recently, it was shown, that the three dimensional (3D) meander shaped magnonic crystal [3] can provide vertical spin-wave transport by using the vertical sections of magnonic waveguide. In the present work we use the dipolar stray fields of magnonic stripes to perform the vertical and lateral spin-wave transport and transfer of the signal between the magnonic stripes.

Figure 1 schematically shows the structure under consideration, consisting of 12 magnetic microwaveguides, which was fabricated from YIG film with thickness of d = 10 μm. YIG was epitaxially grown on a gallium-gadolinium garnet substrate. The distance between the magnetic microwaveguides is a = 20 μm and b = 15 μm. The length along the long side of the waveguides was l = 4 mm, the width of the waveguide was c = 200 μm. The excitation of spin waves was carried out using 1 μm-thick and 10 μm-wide microstrip antennas located on two central waveguides. The structure is placed in an external static magnetic field, H = 1200 Oe, directed along the X-axis.

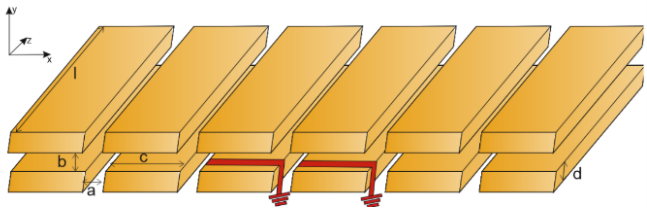

Figure 1.: a) Array of magnetic microwave guides.

By the means of spatial resolved Brillouing light scattering (BLS) technique the spatial profiles of the spin-wave modes, propagating along the stripes, was obtained. In particular, the study of the peculiarities of the processes of formation of spin-wave beams in homogeneous and inhomogeneous systems of coupled microwaveguides, as well as the study of isofrequency characteristics for a system of coupled microwave guides was performed. The features of the spin-wave propagation in 3D array of YIG films are revealed. The resuls of numerical simulation (MM and FEM) are in good accordance with experimental BLS data. The observed phenomena of tunable spin-wave beam formation in 3D magnonic structure can provide an in-depth insight into the physics of lateral and vertical spin-wave transport in array of micro- and nanoscale structures.

This work was supported by the Russian Foundation for Basic Research (project No. 20-37-90020, project No.18-29-27026).

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Magnetism and structure of oxide chains of binary alloys of Co and Ni on Ir(100)

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The morphological evolution of chains during heteropitaxial growth has recently been a topic of extensive experimental and theoretical [1,2] studies in part due to its fundamental interest, but also because of possible applications to the formation of self-assembled nanostructures. The self-assembled growth is limited to certain choices of materials, but one can produce one-dimensional structures to high perfection and with high surface density. This opens the opportunity to employ spatially averaging methods to determine their properties.

Using kinetic Monte-Carlo method, the formation of oxide chains of binary alloys of Co and Ni on Ir(100) is investigated on an atomic scale. The atomic processes responsible for the formation wires are identified. We show that for a large value of the bond energy, the antiripening mechanism and quantum effects do not affect the length of metal monatomic chains. The conditions under which wires with non-equilibrium and equilibrium length appear are determined. The observed mechanism of wire growth will be useful both for explaining the experimental data and for creating atomic wires with a given length. The magnetic properties of the structures forming are calculated using density functional theory. The spin and orbital magnetic moments and the magnetic anisotropy energy of these oxide chains are obtained. These alloy oxide chains represent a well-controlled ensemble of mixed one-dimensional ferromagnetic magnets with nonmagnetic separators. We believe that alloy oxide chains can potentially behave as a linear array of spin-memory bits.

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Effect of electron delocalization on the "recoil-free" absorption of γ-quants in $Fe_{1.75}V_{0.25}BO_4$ warwickite

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Mössbauer spectroscopy is used to study the characteristic features of the crystal lattice dynamics in powdered single crystals of $Fe_{1.75}V_{0.25}BO_4$ warwickite in the temperature range of 4.2–505 K. The Debye temperature (Θ_D = 260 K) is determined from the temperature dependence of the probability of the Mössbauer effect in the thin absorber approximation (Fig.1) [1,2]. It is found that the electron delocalization related to the fast electronic transfer between neighboring Fe^{3+} and Fe^{2+}cations take place in the temperature range of 260−505 K. As a result, iron cations exhibiting the mixed valence ($Fe^{2.5+}$) arise. This process correlates with a change in the elastic properties of the lattice. Such correlation leads to a sharp decrease in the recoil-free absorption of γ-quants by the crystal lattice in the range of 260–400 K.

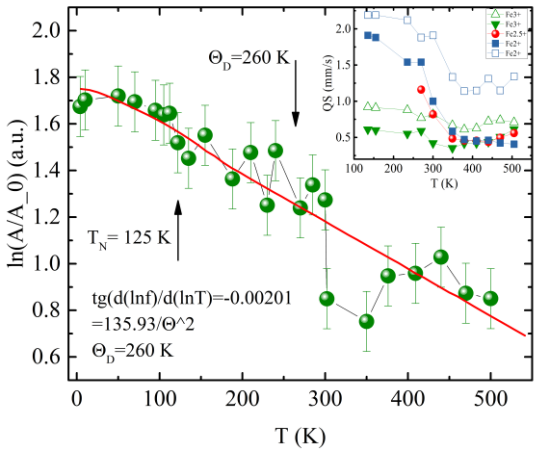

Fig.1. Temperature dependence of the probability of Mössbauer effect plotted on a logarithmic scale. The solid curve corresponds to the Debye model. The Θ_D value is determined from the slope of the solid curve. The temperature dependence of the quadrupole splitting of the spectral components is shown in the inset.

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Magnetic hysteresis scaling analysis for Fe_3O_4 spherical particles

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The magnetic hysteresis scaling of minor loops has been widely studied for evaluating material's quality [1]. This scaling law with an exponent of 1.3-1.5 universally holds true for bulk ferromagnets where irreversibility of Bloch wall movement dominates and the coefficients are proportionally related to the defect density of such as dislocation, precipitates [2]. However, the information extracted from the coefficient for nanometer-to-submicron particles where rotation mechanism is effective was not fully understood. In this paper, we report results of the hysteresis scaling analysis for Fe_3O_4 spherical particles with controlled interparticle distance or particle size to elucidate intrinsic features of the coefficient for ferromagnetic spheres.

We used 12-nm size Fe_3O_4 spherical nanoparticles, whose surface was polymer- or SiO_2-coated to control interparticle distance; d = 12, 18 and 34 nm. Hollow Fe_3O_4 particles with a shell thickness of ~100 nm, with varying 400-700 nm diameter, were also used. Magnetic measurements were performed in the temperature range of 10-300 K using a SQUID magnetometer. A set of symmetrical minor loops with different amplitudes were measured with increasing the amplitude step-by-step up to 2 kOe.

Fig. 1 shows a typical example of a hysteresis scaling for 12 nm size Fe_3O_4 nanoparticles at T = 10 K. The relation between hysteresis loss and remanence of minor loops follows a power law with an exponent of ~1.3, irrespective of interparticle distance. The same scaling was also observed for hollow particles, indicating the universality for spherical particles. Although coercivity does not show a systematic morphological dependence, the coefficient for d=34 nm is nearly one-third the value for d=12 and 18 nm at all measuring temperatures (inset in Fig.1). The lower coefficient for d=34 nm may reflect a wider particle separation that lowers interparticle dipolar coupling. The coefficient can be therefore a sensitive indicator that evaluate the morphology for spherical ferromagnetic particles.

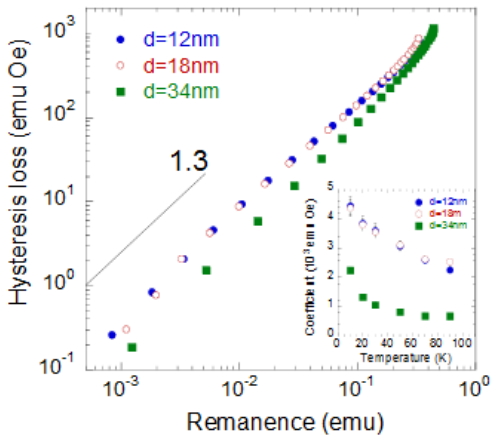

Fig.1: Double logarithmic plot of a relation between hysteresis loss and remanence at T=10K, for 12 nm sized Fe_3O_4 nanoparticle with different interparticle distance. The inset shows a minor-loop coefficient as a function of temperature.

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Simulation of the hysteretic characteristics of hard magnetic materials based on $Nd_2Fe_{14}B$ and $Ce_2Fe_{14}B$ intermetallics

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The $Ce_2Fe_{14}B$ intermetallic, like $Nd_2Fe_{14}B$, has the tetragonal $Nd_2Fe_{14}B$-type structure (space group$P4_2/mnm$), in which Ce has the mixed valence state characterized by the coexistence of trivalent $4f^1$ and tetravalent $4f^0$ electron states. The saturation magnetization I_s, magnetic anisotropy field H_A, and Curie temperature T_C of the $Ce_2Fe_{14}B$ intermetallic are 1.17 T, 2.6 T, and 424 K, respectively. These values are substantially lower as compared to those for the of$Nd_2Fe_{14}B$ (1.61 T, 7.3 T, 585 K) and $Pr_2Fe_{14}B$ (1.56 T, 8.7 T, 565 K), respectively. Nevertheless, the $Ce_2Fe_{14}B$ intermetallic retains the capacity of using it in manufacturing rare-earth permanent magnets. Studies of (Nd, Ce)-Fe-B alloys, which are intended to the improvement of the service characteristics-to-cost ratio, are very relevant in this respect.

At room temperature, the magnetic properties of $Ce_2Fe_{14}B$ are substantially lower than those of $Nd_2Fe_{14}B$, however, at low temperatures, the anisotropy field of $Ce_2Fe_{14}B$ is higher than that of $Nd_2Fe_{14}B$. It is of importance that, below the magnetic ordering temperature, $Ce_2Fe_{14}B$ does not undergo the spin-reorientation transition. It is assumed that the partial substitution of Ce for Nd in $Nd_2Fe_{14}B$ can lead to the marked improvement of hysteretic characteristics of permanent magnets based on the quasi-ternary $Nd_{2-x}Ce_xFe_{14}B$ intermetallics.

The model and algorithm for calculating the hysteresis loops of uniaxial hard magnetic materials with allowance for the K_1 and K_2($K_2 > 0$ and $K_1 > 0$ and $K_1 < 0$) magnetic anisotropy constants were developed and allowed us to obtain data on their effect on the characteristics of hysteresis loops in the wide temperature range.

The simulation and analysis of hysteresis loops of the quasi-ternary $(Nd_{1-x}Ce_x)_2Fe_{14}B$ (x = 0 … 1) intermetallics and mixtures $(1 - \upsilon)\cdot Nd_2Fe_{14}B + \upsilon\cdot Ce_2Fe_{14}B$ (where υ is the volume fraction of the $Ce_2Fe_{14}B$ phase ($0 \le \upsilon \le 1$) were performed for a temperature range of 0-300 K.

The simulation results indicate that the alloying of the $Nd_2Fe_{14}B$ intermetallic with Ce to x = 0,90-0,95 (1) does not completely eliminate the negative effect of spin-reorientation phase transition on the residual magnetization of the $(Nd_{1-x}Ce_x)_2Fe_{14}B$ intermetallic and (2) slightly decreases the slope of magnetization reversal curve and almost does not make the hystreresis loop back more rectangular.

The obtained data show that the increase in the $Ce_2Fe_{14}B$ content in the mixture of considered phases can favor the increase in the temperature stability of hysteretic characteristics of permanent magnets prepared in the form of bonded magnets from the $(1-\upsilon)$ $Nd_2Fe_{14}B$ + $\upsilon Ce_2Fe_{14}B$ mixtures and ensures their operation at low temperatures without losing the magnetic properties only at sufficiently high values $\upsilon \ge 0{,}90$.

This study was supported by the Ministry of Science and Higher Education of RF, agreement no. 075-15-2019-1871 (unique identification number RFMEFI60419X0244).

An improved kinetic Monte Carlo model for computational and analytical investigations of the magnetic properties of finite-size atomic chains

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Nowadays, the investigations of magnetic properties of atomic chains are under the great interest because of its potential applications in the nanoelectronics and spintronics [1]. In particular, atomic chains can be used for the creation of the next generation mass storage devices. The possibility of engineering of the memory elements from the atomic chains appeared after the discovery of the giant magnetic anisotropy energy (MAE) of Co atoms on the Pt(997) surface [2]. Another interesting possibility is use of finite-sized antiferromagnetic Fe chains on Cu_2N/Cu(001) surface as bits of information [3].

The theoretical investigations show that quantum tunneling is the main switching mechanism at extremely low temperatures below the mK range [4]. However, we can neglect the quantum nature of the atomic magnetic moments at higher temperatures. In this case the magnetic properties of atomic chains can be described in the framework of the classical Heisenberg Hamiltonian. The parameters of the Heisenberg Hamiltonian can be calculated from the first principles. Further investigation of the magnetic properties of atomic chains can be performed with the kinetic Monte Carlo (kMC) simulations [5]. Based on the kMC model [5] it has been developed of the simple analytical method for the investigation of the magnetic properties of the finite-length atomic and biatomic chains [6,7,8].

Here, an improved kMC model for computational and analytical investigations of the magnetic properties of finite-size atomic chains is presented. The improved model takes the possible uncollinearity of magnetic moments into account. The remagnetization of Co chains on the Pt(997) surface and Fe chains on Cu_2N/Cu(001) surface is investigated in the framework of the new model. The results are compared with the results of the kMC model [5].

The research is carried out using the equipment of the shared research facilities of HPC computing resources at Lomonosov Moscow State University [9, 10]. The investigation is supported by the Russian Science Foundation (Project No. 21-72-20034).

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Magnetic, Mossbauer and Raman spectroscopy study of iron-yttrium garnet nanostructured particles with functional heat generation ability

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A variety of magnetic fine particles that can transform electromagnetic energy to heat upon excitation in alternating magnetic field have been developed to achieve improved efficiency in biomedicine and fabrication of smart heat responsive composite materials. Application of magnetic iron oxide nanoparticles is presently and intensely investigated by a multidisciplinary field of research. Garnet particles of micrometer-range sizes are reported to exhibit greater magnetic heating than other ferrites do, but a lot of effort has been made to synthesize and research these compounds in nano-particulate form. It was found that $Y_3Fe_5O_{12}$ nanostructured particles with the garnet crystal structure demonstrated the highest heat ability among the reported materials at the same sizes and magnetic field conditions. In spite of controversial data relating to $Y_3Fe_5O_{12}$ particles' biological compatibility with living cells compared to several industrial important ferrite compositions, the investigation of the different effects influence on the functional magnetic properties of this compound attracted great attention. For this purpose, combination of different analytical methods which are greatly sensitive to dimensional and local structure parameters of the particulate sample were applied.

We have synthesised $Y_3Fe_5O_{12}$ particles by different wet and solid phase chemistry techniques to obtain the applicable magnetic and magnetocaloric properties of this compound. The influence of synthesis parameters on functional peculiarities of ferrite crystal and magnetic structure was characterized by Mossbauer and Raman spectroscopy supplemented by SEM and X-ray diffraction. Magnetic properties of synthesized particles were analysed using temperature and field dependence measurements of saturation magnetization. The parameters of heat generation ability at clinically available parameters of AC magnetic field related to phase stoichiometry, crystallite and magnetic domain sizes, exchange interactions within sublattices and surface were compared with widespread ferrite compounds of the same dimensionality.

The work has been carried out at the frame of the joint Russian-Mongolian RFBR Project *19-52-44003.*

Template synthesis of 1D magneto-optical nanostructures

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Advances in nanotechnology make it possible to design the ordered magnetic nanostructures (NSs) with the required morphology, structure, and magnetic properties for use in biomedicine for such tasks as biocatalysis, biodetection, bioseparation, targeted drug delivery and etc. For research and application nanoparticles (NPs), nanowires (NPs) and nanotubes (NTs) are of high interest. One of the most reliable methods for the controlled production of metallic one-dimensional NSs with specified dimensions, parameters, and properties is electrodeposition into the pores of templates.

We considered the template synthesis method for design one-dimensional multicomponent NSs: NTs and NPs by electrochemical deposition in the pores of ion-track membranes (TM). This synthesis technique provides a control of composition, their morphology, as well as the structure and properties of the resulting NSs. By varying the synthesis conditions (electrolyte composition, applied potential, deposition time, etc.) and template parameters (pore sizes, porosity) we could set the elemental composition, structure, optical and magnetic properties of one-dimensional (1D) NSs and their arrays. Metal-based NTs / NPs arrays can be synthesized from iron group metals (iron, nickel, cobalt) and their alloys, as well as plasmonic metals: copper, gold and silver.

The aim of the work is to develop magneto-optical arrays of 1D nanostructures using plasmonic metals and to propose ways for using them for a signal amplification in spectroscopy methods based on plasmonic resonance.

The choice of plasmon-active metal such Au, Ag or Cu for formation of arrays of NSs for the design of SERS-active substrates is limited by basic criteria: the affordable price, the degree of signal amplification, and the durability. The rapid oxidation of copper in air negatively affects the optical properties of nanostructures; therefore, it is more promising to obtain arrays of silver NT / NP. In the other hand, it is possible to produce well-known Ni NSs and design a functional coating of this magnetic NSs by noble metals (in particular, gold), which allows protecting the magnetic core from corrosion, reducing the toxicological effect, reduce the synthesis price and imparting new optical and magnetic properties.

TMs based on polyethylene terephthalate (PET) with a thickness of 12 μm and pore diameters of 100 to 400 nm were used as templates for fabricating of arrays of magneto-optical NSs. Two types of magneto-optical NSs were obtained. The first type is NSs - layered nanowires with alternating nickel and silver. The second type is gold-coatied nickel nanotubes. The structure and morphology of the obtained structures were studied by SEM and X-ray structural analysis. The use of combined NSs for SERS spectroscopy, including those with the application of an external magnetic field, is discussed.

Acknowledgments. This work was performed as part of a State Task for Moscow State Pedagogical University on the topic “Physics of Nanostructured Materials: Fundamental Research and Applications in Materials Science, Nanotechnology, and Photonics.”

Magnetic properties of S = 1 spin chain in $Sr_2Ni(SeO_3)_2Cl_2$: XY-antiferromagnet at Sakai-Takahashi phase diagram

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An experimental realization of the Haldane conjecture of a gapped spin liquid is of great interested among condensed matter scientists. The conjecture is implemented in the chains of Heisenberg integer spins bounded by identical intrachain exchange interactions J and could be realized in uniform quasi-one-dimensional integer spin compounds [1]. The Haldane phase has to compete with magnetic anisotropy and long-range ordered phases, depending on the ratio of interchain J' and intrachain J exchange interactions and uniaxial D and rhombic E single-ion anisotropy. The critical ratios J'/J and D/J for Haldane phase, easy axis long ordered AFM and easy plane long ordered XY-AFM were first discovered by Sakai and Takahashi [2]. Many compounds, both organic and inorganic, have been studied to verify this idea, some of them have been identified as belonging to the Haldane sector of the Sakai-Takahashi phase diagram.

In this work, the position on Sakai-Takahashi phase diagram was determined for the novel integer spin S = 1 chain compound, strontium nickel selenite chloride $Sr_2Ni(SeO_3)_2Cl_2$. The powder sample was obtained by gas transport method. XRD measurements showed that the crystal structure of the compound contains the NiO_4Cl_2-octahedra bridged by the SeO_3-pyramids into uniform spin chains. These chains are well separated by strontium cations and cavities of selenium's lone pair of electrons that could lead to 1D-dimensionality of magnetic subsystem. Physical properties were investigated in magnetization, heat capacity and thermal expansion measurements. Pulsed-magnetic-field magnetization measurements up to 45 T were provided by Dresden High Magnet Field Lab HLD EMFL. For magnetic structure calculations within the DFT it has been used the GGA+U approach with PBE potential within the VASP code.

Thus it was determined that strontium nickel selenite chloride, $Sr_2Ni(SeO_3)_2Cl_2$, is a spin-1 chain system which passes through a correlations regime at $T_{max} \sim 12$ K to long-range order at $T_N = 6$ K. The values of $J'/J = 0.083$ and $D/J = 0.357$ place this compound into a hitherto unoccupied XY-AFM sector of the Sakai-Takahashi phase diagram.

The authors acknowledge support by the Ministry of Education and Science of the Russian Federation within the framework of the governmental program of Megagrants P-220 and NUST "MISiS" Grant No. K2-2020-039. We also acknowledge the support of the HLD-HZDR member of the European Magnetic Field Laboratory (EMFL).

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Obtaining and studying the structural and magnetoelectric properties of nanocomposites of the PVDF/Metal

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Nowadays, composite multiferroics are of tremendous interest among scientists. This interest is partly due to the many technical applications of such structures [1] (for example, sensorics, spintronics etc.). One of the promising ferroelectric media for this kind of multiferroics is polyvinylidene fluoride (PVDF) [2]. However, in the thin-film state, the functional characteristics of PVDF strongly depend on the production method and on the technological parameters. One of the most effective methods for obtaining the maximum concentration of β-phase in thin-film PVDF is spin coating. Another important factor influencing the magnetoelectric properties is magnetostriction in a magnetic material. In addition, the efficiency of the magnetoelectric coupling can also be affected by the roughness of the magnetostrictive layer. Thus, this work is devoted to the study of the influence of these parameters on the magnetoelectric properties of film composites of the Metal / PVDF type.

The studied samples were M/PVDF sandwiches deposited on Corning glass substrates, where M = $Fe_{10}Ni_{90}$, $Fe_{50}Co_{50}$. Using IR spectroscopy and X-ray diffraction analysis, the optimal spin-coating parameters were determined at which the maximum concentration of β-phase (~ 60%) is reached. It was also established from the X-ray diffraction data that the PVDF films are in a deformed state (Figure 1a), which leads to an increased piezoelectric coefficient (~45 pm/V) compared to the bulk one, which is confirmed by the PFM data. Next, two-layer composites were prepared containing a metal layer (50-200 nm) and a PVDF layer obtained at optimal parameters (200 nm). In this case, such parameters as the type and thickness of the ferromagnetic layer, the roughness of its surface, and the thickness of the Ta interlayer between the functional layers were varied. An example of the implementation of the magnetoelectric effect in these structures is shown in figure 1b. The obtained value of the magnetoelectric coefficient was 24 mV/cm·Oe.

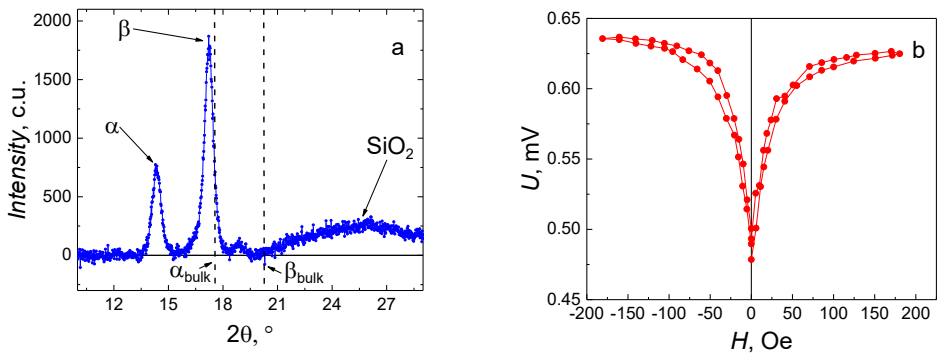

Figure 1. (a) XRD of thin PVDF polymer films obtained at optimal parameters; The letter symbols indicate the position of the diffraction lines of the corresponding phases in the film (α, β) and massive (α_{bulk}, β_{bulk}) states. (b) Magnetoelectric effect in the $Fe_{10}Ni_{90}$/PVDF composite.

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Synthesis and toxicological studies of biocompatible iron oxide nanoparticles for local hyperthermia and MRI

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The task we set in this work was to improve drugs for tumor hyperthermia and MRI. Nowadays suspension of magnetite nanoparticle coated with alkoxysilane was developed by «MagForce AG» [1] for local magnetic hyperthermia. Such particles also can be used as contras agent for MRI [2]. We synthesized biocompatible biodegradable iron oxide nanoparticles stabilized with oleic acid (Fe3O4-OA-NP), witch can become an alternative effective mean for hyperthermia and MRI. Here the result of the toxicological studies of the obtained nanoparticles is presented.

Magnetite particles were obtained by co-precipitation of iron (II, III) chlorides (at a molar ratio of 1:2) in an alkaline medium of ammonia followed by stabilization with oleic acid and sodium oleate [3]. Method was modified in part of stabilization of nanoparticles that let us to obtain stable high concentrated suspension.

The following characteristics of the obtained nanoparticles were determined: the sizes and morphology, ζ-potential, iron concentration, magnetization and specific absorption rate (SAR).

The acute toxicity of magnetic fluid was studied in white mice after intramuscular and intraperitoneal administration. For intramusculary Fe3O4-OA-NP was injected once into the thighs of both hind limbs, 0.5 ml per limb. For intraperitoneally substance was injected once in doses - 150, 300, 450, 600, 750, 900, 1200, 1500, 1800, 2100 mg / kg. The animals were observed for 30 days. The local irritating effect was studied in Wistar rats after intramuscular administration 0.5 ml of Fe3O4-OA-NP. The observation time for the rats was 7 days. After animal's euthanasia, the following were performed: histopathological analysis of internal organs and muscles, hematology and blood chemistry, calculation LD50.

Results. Average size of Fe3O4-OA-NP according to TEM data 8.7±3.1 nm, according to DLS - 25±8 nm, the ζ-potential was – 65±3 mV at pH = 7.7, the mass concentration of iron was 112 mg/ml, SAR of Fe3O4-OA-NP was 12 W/g Fe.

The results of acute toxicity study of the obtained Fe3O4-OA-NP make it possible to classify it as low-toxic compounds when administered intraperitoneally and practically non-toxic or relatively harmless when administered intramuscularly. The probit analysis showed values of LD50 for mice 652,3 mg/kg. In histology internal organs of mice Perls reaction shows Fe3O4-OA-NP is visualized inside cells and as free clusters. In the sinusoidal capillaries of the liver, magnetite diffusely located and in the cytoplasm of Kupffer cells. Perls' reaction indicated the presence of magnetite in the peritoneum, which covers the kidney and intestines and also on accumulation of magnetite nanoparticles in the cytoplasm of the omentum phagocytes. In the study of local irritating effect no macroscopic signs of inflammation were found at the injection site of Fe3O4-OA-NP. Muscle microscopy showed that magnetite nanoparticles were localized in endomysium, perimisium of muscle, and in the cytoplasm of tissue macrophages. Prussian blue was not observed inside the muscle fibers. These rats had hematological and biochemical blood parameters as in intact animals.

This work was supported by the Russian Foundation for Basic Research (grant No. 18-415-130007).

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Critical behaviour of the frustrated four-state Potts model on a triangular lattice

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Currently, there is a strong focus on the investigation of frustrated spin systems. This stems from an important role of frustrations in various magnetic systems. Frustrations as a result of competing interactions are considered to be the source of degeneracy and a disorder, which lead to the emergence of new and interesting physical phenomena [1].

In this study, using the Wang-Landau Monte Carlo algorithm, we investigate the influence of an exchange interaction competition on phase transitions, thermodynamic properties, and magnetic structures of the ground state for two-dimensional four-state Potts model on a triangular lattice with the first and second nearest neighbor interactions

The Hamiltonian can be represented as follows:

$$H = -J_1 \sum_{i,j} \cos\theta_{i,j} - J_2 \sum_{i,k} \cos\theta_{i,k}$$

where J_1 and J_2 are the parameters of the exchange ferro- ($J_1>0$) and antiferromagnetic ($J_2<0$) interactions for the first and the second nearest neighbors; respectively, $\theta_{i,j}$, $\theta_{i,k}$ are angles between interacting spins $S_i - S_j$ and $S_i - S_k$; $r=|J_2/J_1|$ is the magnitude of the second nearest neighbor interaction. Computations are carried out for systems with periodic boundary conditions and linear dimensions of $L\times L=N$, $L=12\div120$, were L is measured in unit cell size.

The density of states and the temperature dependences of entropy S are calculated. The ground state is shown can be either strongly degenerate, which indicates the presence of frustration in the system, or weakly degenerate in the dependence on the exchange interaction ratios between the first and second nearest neighbors.

The study on a structure of the ground state demonstrates that in this system there is a stripe, a triplet or a mixed stripe-triplet state is realized for phase 1, a highly degenerate disordered state or a weakly degenerate multilayer state for the frustrated phase, and an ordered ferromagnetic state for the ferromagnetic phase.

By determined temperatures of phase transitions the phase diagram of the system is plotted. The transition from the ferromagnetic and stripe-triplet phases to the paramagnetic is shown to be of a first-order phase transition. [2].

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Magnetostatic equilibrium in concentrated ferrofluids

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Magnetophoresis, that is, the motion of magnetic objects under the action of nonuniform magnetic field, is the physical basis for many applications of magnetic nanoparticles (MNPs) in biotechnology and medicine. Examples of such applications are magnetic cell separation and targeted drug delivery. It is known that the sensitivity of MNPs to the applied gradient field is among main factors determining their suitability for biomedical purposes [1]. In this contribution, we use methods of nonequilibrium statistical mechanics as well as Langevin dynamics simulations to study how the magnetophoretic movement of MNPs in a nonmagnetic viscous medium is affected by interactions between these MNPs (namely, dipole-dipole and Van der Waals interactions). We model a cylindrical microchannel filled with the colloidal suspension of MNPs in a nonmagnetic liquid (i.e., with the "ferrofluid"). A current-carrying linear conductor is placed along the microchannel axis. The system is thermostated. The nonuniform azimuthal field of the current causes the magnetophoretic drift of MNPs in the radial direction. This drift is hindered by the gradient Brownian diffusion. Over time, an equilibrium radial distribution of MNPs will be achieved in the system as the results of competition between magnetophoresis and diffusion. Here the equilibrium radial MNP distribution (as well as the relaxation time required by the system to achieve an equilibrium) is determined for different MNP concentrations and different particle magnetic moments. Simulation results are critically compared with the predictions of ferrofluid masstransfer theories available in the literature.

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Obtaining of the diluted magnetic semiconductor phase by thermal diffusion during pulsed laser deposition process

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Spintronics is one of the main directions of development of alternative electronics. For the implementation of electronic devices with the operation principle based on the use of carriers spin, ferromagnetic semiconductors with a Curie temperature close to room temperature are required. The most promising ones are the A^3B^5 diluted magnetic semiconductors highly doped with Mn or Fe. In particular, it was shown that the structures containing manganese, such as GaMnAs [1] and GaMnSb [2], are ferromagnetic up to a temperature of 240K. Spin light-emitting diodes [1] operating at low temperatures were created on the basis of such layers. It was further shown in [3] that replacing manganese with iron (in InFeSb and GaFeAs layers) makes it possible to obtain ferromagnetic properties at 300K.

In this work, a new method for the fabrication of diluted magnetic semiconductor is proposed: Fe films or Fe-Mn-C alloys are deposited onto a GaAs substrate by the pulsed laser deposition in vacuum, which is followed by an additional postgrowth annealing of the structure. The latter leads to the diffusion of Fe and Mn atoms into substrate with the formation of magnetic phases. In this way, a series of structures were obtained in which the deposition temperature, annealing temperature, and film thickness were varied.

The magnetic properties of obtained samples were investigated by measuring the magnetic field dependence of the Hall resistance. The latter is proportional to the component of the magnetization perpendicular to the film [3]. An additional magnetic investigation method was the measuring of the magnetic field dependence of the Nernst-Ettingshausen voltage. According to [4], studying the dependence of the thermomagnetic effect on the magnitude and direction of the magnetic field allows one to determine the form and character of spin-dependent scattering of free carriers.

The element distribution profile was obtained by the method of X-ray photoelectron spectroscopy, supplemented by the possibility of ion etching. The work demonstrates the diffusion of Fe and Mn into the bulk of a semiconductor, which is accompanied by the formation of chemical bonds Fe-C, Mn-As, Ga-Fe, Fe-As, corresponding to various magnetic compounds. This determines the presence of ferromagnetic properties at room temperature, which is confirmed by the hysteresis form of the dependences of the Hall resistance and the Nernst-Ettingshausen voltage on the magnetic field.

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Presence of mixed Zn/Co spinel ferrite nanoparticles inhibited of E. coli growth rate

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Nowadays, due to growing bacterial resistance to antibiotics, the search for antimicrobial agents is an important issue in the modern scientific world. Magnetic nanoparticles (MNPs) were considered as potential antimicrobial agents [1–2]. In our work, a set of magnetic nanoparticles of cobalt ferrite doped with zinc ($Zn_xCo_{1-x}Fe_2O_4$) was synthesized via the eco-friendly sol-gel auto-combustion method. Obtained particles displayed a room-temperature ferromagnetic behavior with tuned by chemical composition values of saturation magnetization and coercivity.

To examine effect of MNPs on bacterial cells, we used E. coli K-12 MG1655 bacterial cells. First, antimicrobial activity was tested with the disk diffusion method in order to qualitatively define the parameters of the experiment. As an alternative method quantitative analysis was performed by the optical density (OD600) measurement method on a UV/vis spectrophotometer detecting absorbance at 600 nm wavelength every half hour.

In the presence of $CoFe_2O_4$ and $ZnFe_2O_4$ MNPs, E. coli demonstrate a decreased OD600 of the bacterial medium compared with the control (non-treated) samples, resulting in the lag of bacterial growth inhibition in different timepoints. The values of OD600 at 330 min, the time selected as moments when bacterial strains reached sub-maximum population, demonstrate that pure $CoFe_2O_4$ and $ZnFe_2O_4$ MNPs have a more pronounced lag effect than mixed Zn-Co ferrite MNPs with the concentration of zinc $x = 0.25$. Cells growth of E. coli K-12 MG1655 was inhibited after MNPs ($x = 1$) from 240 to 330 min (p-value ≤ 0.001) and MNPs ($x = 0$) from 120 to 360 min (p-value ≤ 0.01).

Therefore, it can be concluded that in the case of different Zn concentrations, a slowdown in the increase in OD is observed in the period from 200 to 400 min. Zn-Co spinel ferrite MNPs induced the lag in E. coli growth, which was found in correlation with the magnetic and structural properties of spinel ferrites structure.

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Influence of internal stressess on the magnetic properties of amorphous ferromagnetic microwires in a glass shell

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Amorphous microwires with a positive magnetostriction coefficient have excellent properties of soft magnetic materials (coercive force no more than 4 kA/m) [1]. The magnetization reversal process, which ensures the magneto-bistable behavior of such microwires, allows to reach the domain wall high velocities [2]. The search for ways to control the magnetization reversal process in such microwires will use microwires as the main element in a number of devices [1].

In the manufacture of amorphous microwires with a glass shell the internal stresses arise in their metal core: (i) quenching and (ii) due to the difference in the coefficients of thermal expansion of metal and glass. For the experiment, the amorphous ferromagnetic microwires made of $Fe_{7.5}Si_{17.5}B_{15}$ alloy in a glass shell, fabricated by the Ulitovsky-Taylor method, with the ratio of the metal core diameter to the total diameter d/D = 12 μm / 27 μm = 0.44.

Experiment A. Hysteresis loops are constructed (by the induction method) and magnetostriction coefficient values is obtained (by the SAMR method) to assess the effect of stresses of type (ii) for each sample. The same magnetic characteristics are measured for the samples after the glass shell removal (mechanical), which leads to a change in the contribution of the stresses magnitude (type ii). *Result A.* After the glass shell for all the samples the value of the coercive force H_c, as well as the squareness coefficient (the ratio of the magnetic moment to the magnetic moment of saturation) decrease: the H_c value of the samples decreases on average from 417 A/m to 91 A/m. The magnetostriction coefficient λ_S for all the samples increase, it is the result of a decrease in the internal stress caused by the presence of the shell (type ii).

Experiment B. The experiment for estimation of the stresses magnitude by type (i) consists in carrying out a theoretical calculation from the experimental data on the measurement of hysteresis loops depending on the applied external stresses. *Result B.* According to the data for the anisotropy magnetic field value H_k from the hysteresis loops (H_c is equal to H_k), a graph of the H_k dependence on the stresses σ is plotted. The plotted dependence H_k (σ) was approximated by a second-order polynomial $H_k = a\sigma^2 + b\sigma + c$. From the value of the constant c, the free constant, in the obtained polynomial H_k (σ), it is possible to estimate the contribution of quenching stresses. The value of quenching stresses is approximately 172 MPa.

This work presents the results of studying the internal mechanical stresses effect on the magnetostatic and magnetostrictive properties of amorphous ferromagnetic microwires in a glass shell. Understanding the mechanisms of the properties formation depending on stresses of different nature will make it possible to manufacture microwires with specified properties. Thus, the problem of studying the joint and separate influence of different nature stresses on the magnetic properties of a microwire is actual.

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Magnetothermal properties of ZnMn ferrite nanoparticles

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The magnetic heat production by nanoparticles in alternating magnetic field (AMF) is a key factor in magnetic hyperthermia treatment, especially for proliferative tumors with low intrinsic blood vessels, such as pancreatic tumors: heating will increase membrane permeability and improve membrane transport after heating, leading to increased drug absorption in malignant cells [1]. The magnetic heating is characterized by Specific Absorption Rate (*SAR*), the power of heat production divided by mass. Efficiency of converting magnetic energy into thermal energy for nanoparticles is characterized by the so-called Intrinsic Loss Power (ILP). SAR and ILP are related to the size, size distribution of nanoparticles, and the frequency and amplitude of the applied AMF. In our work we have selected ZnMn ferrite nanoparticles with advanced magnetic heat performance. Nanoparticles have been fabricated by with chemical coprecipitation .

The results of transmissive electron microscope (TEM) and fluid dynamics have demonstrated that the size of nanoparticles and its hydrodynamic diameters decreased with the increase of Zn content. The *ILP* dependence on AMF for the largest and the smallest nanoparticles at 150KHz are shown in the Fig. 1. The *ILP* of the smallest nanoparticles is constant, indicating the typical behavior of superparamagnetic nanoparticles. The significant increasing of *ILP* of the largest nanoparticle indicates the dependence of magnetic susceptibility of nanoparticle on magnetic field supposedly related to the inhomogneous micromagnetic structure of the nanoparticles.

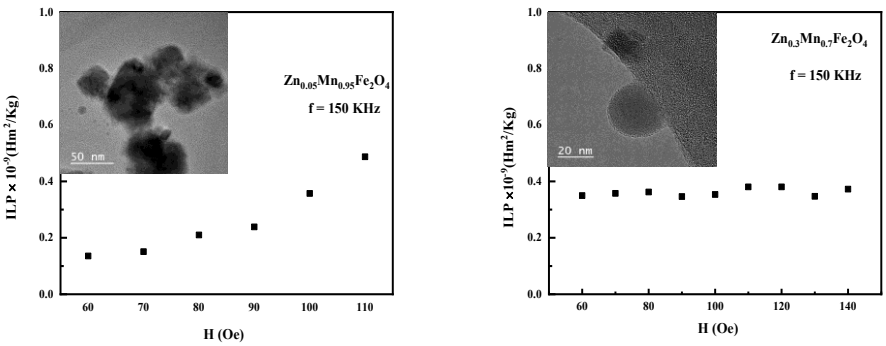

Fig.1 TEM images of ZnMn ferrite and the *ILP* values at 150KHz.

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Magnetoelectric materials based on lead zirconate titanate and cobalt ferrite

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Nowadays, great attention is paid to the search for materials that combine traditional properties (magnetic, piezoelectric, dielectric) in the required combination while also possessing fundamentally new (hybrid) ones [1]. Magnetoelectric materials are distinguished by a wide variety of properties and can serve as a basis for the development of functional devices necessary in the modern microwave and microelectronic technology (modulators of electromagnetic waves, magnetic memory elements, etc.).

However, most of the currently known single-phase magnetoelectric materials (multiferroics) exhibit a weak magnetoelectric effect, which makes such materials unsuitable for technical applications. It should be expected that a composite material consisting of ferrite and piezoelectric phases will have high magnetoelectric coefficients since the magnetoelectric coefficient is the result of piezomagnetic deformation and piezoelectric charge generation [2].

In contrast to single-phase magnetoelectric materials, the magnetoelectric effect in composite ones is the so-called "secondary" effect in the chain "magnetostriction - elastic deformation - piezoelectric effect". Thus, owing to the selection of components with high magnetostrictive and piezoelectric constants, it is possible to obtain the magnitude of the magnetoelectric effect necessary for practical use.

The present work is dedicated to obtaining composite magnetoelectric materials based on lead zirconate titanate and cobalt ferrite (PZT-CF). High-density ceramic samples are synthesized, the composition and microstructure of the obtained compounds are determined, and the magnetoelectric effect in the synthesized ferrite-piezoelectric composite materials is investigated.

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Hyperfine interactions in the noncentrosymmetric high-pressure phase B20-RhGe doped with Cd or Ta

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We present *ab initio* study of hyperfine quadrupole interaction in the high-pressure-synthesized phase of RhGe with a noncentrosymmetric B20-type cubic crystal structure. Using the Wien2k package, the electric field gradients (EFG) at a single impurity M (M = Cd, Ta) were evaluated in large supercells corresponding to dopant concentration x from ~6% to ~1%. We show that such impurities cause symmetry breaking, and upon doping, the initial cubic structure becomes actually triclinic. These doping-induced lattice distortions are very small (especially in case of Cd impurity), hence only slightly broadened B20-type reflections are visible in the corresponding x-ray powder diffractograms [1, 2]. Our calculations are essential for the metastable high-pressure phases, since the EFG as a local property is very sensitive even to extremely small changes in symmetry and atomic coordinates.

In the considered model compounds $Rh_{(1-x)}M_xGe$ and $RhGe_{(1-x)}M_x$, the evaluated EFGs at the Rh and Ge atoms are distributed with some scatter around average values close to the ones calculated for pure B20-RhGe in [1]. Figure 1 displays a schematic histogram showing the number of Rh/Ge atoms whose $|V_{zz}|$ values fall inside an interval of 0.5×10^{17} V/cm^2 ($|V_{zz}|$ is an absolute value of principal component of the EFG tensor). Calculated V_{zz} values at probe atoms M can fall both within and far beyond this distribution. Comparison of the calculated $V_{zz}(M)$ values with the

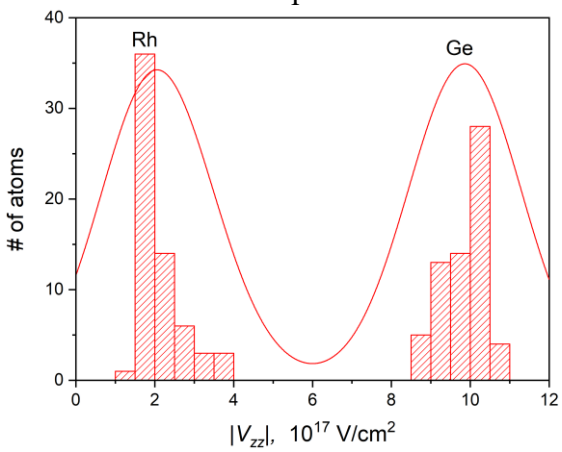

Figure 7. Distribution of Rh and Ge atoms by EFG values in doped RhGe.

experimental In^{111}/Cd^{111} and Hf^{181}/Ta^{181} TDPAC measurements [1, 2] indicates that the In/Cd probes substitute for Ge, whereas the Hf/Ta ones for Rh. Our calculations explain the observation of two quadrupole frequencies on Hf/Ta probes at relatively high concentrations x = 1–2% and only one frequency at x = 0.5% [2].

This work was supported by Russian Science Foundation under Grant No. 18-12-00438.

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FDTD simulation of electromagnetic wave propagation in magnetic randomly inhomogeneous media

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The model of a randomly inhomogeneous medium has been in great demand for many years both in fundamental science and in applied research and engineering applications. There are specific problems of statistical radiophysics and acoustics, in which this model plays an important role. Similar problems and its solution methods arise in plasma physics, solid state physics, magnetohydrodynamics and other areas. Furthemore, widespread use of optical and acoustic diagnostic methods in modern medicine is also based on the features of electromagnetic wave propagation in stochastic systems.

In this regard, there is important to development of numerical methods that make it possible to visually and simply represent the process of signal propagation in specific stochastic systems. Currently, there are many similar techniques, but the most widespread are grid methods. They are based on the procedure for discretizing space-time and the transition from differential equations for continuous functions to finite-difference equations for functions of discrete variables. The fundamental work in this direction was the Kane Yee paper [1], in which the method of finite differences in the time domain (FDTD) was first described. This work did not receive a wide response in the scientific community due to the high resource intensity of the developed method and the extraordinary expenditures of computer time required for its implementation, but recently the FDTD method is experiencing a "rebirth". There is an extensive literature on the use and development of the FDTD method in the field of electrodynamics of randomly inhomogeneous media [2-5]. Nevertheless, this area not only has not exhausted itself, but on the contrary – continues to remain very attractive, as it can potentially stimulate the study of many interesting effects.

In this work an algorithm for the numerical simulation of the propagation of electromagnetic waves in magnetic randomly inhomogeneous media by the FDTD method has been developed. That algorithm is suitable for analyzing the main time characteristics, as well as identifying the features of the propagation of various types of electromagnetic signals in layered randomly inhomogeneous magnetic media. The simulation of the signal propagation of the meander type in stationary randomly inhomogeneous media with a low level of phase contrast of two types – with a “diffuse” distribution of inhomogeneities and their “close packing” is carried out. Revealed influence concentration of inhomogeneities and the type of their distribution on the characteristics of the transmitted and reflected signals.

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Frequency bending properties of layered composite based on magnetoactive elastomer and PVDF substrate

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Smart or intelligent materials have been studied for more than several decades and are still of a great interest to the scientific community, both as an object for fundamental research and for practical application in robotics, biomedicine, etc. Among the widest variety of such materials, it is worth noting materials with several types of ordering (multiferroic) in which the magnetoelectric effect is observed.

Recently, a new type of layered composite multiferroics based on a magnetoactive elastomer and a piezopolymer substrate has been proposed [1], in which the magnetoelectric effect has been observed. It has been demonstrated that magnetic field exposure leads to bending deformation of the layered structure, which induce large electrical charges on the terminals of the piezoelectric substrate

In this work, the frequency bending properties of the magnetoelectric effect of layered structures under various external influences were investigated. The samples consisted of a commercial PVDF substrate and a film with a thickness of 3 mm and 0.34 mm, consisting of a magnetoactive elastomer with 65% of the mass fraction of carbonyl iron particles with a diameter of several micrometers, distributed in a silicone matrix.

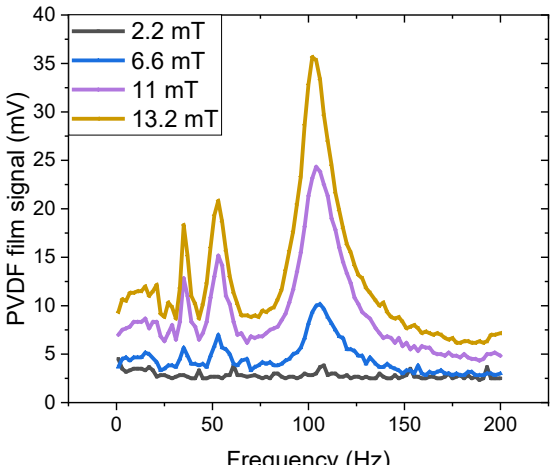

Figure 8. Frequency dependence of the PVDF film voltage at different amplitudes of an alternating magnetic field.

The measurements were carried out on the setup consisting of three Arduino microcontrollers providing alternating current supply to the electromagnet and reading the voltage induced from the PVDF film. An external permanent magnetic field was created by permanent magnets applied perpendicular to and in the plane of the sample.

The layered composite samples demonstrated the presence of several resonant peaks at multiple frequencies (Figure1), which values differed for thin and bulk samples. The applied external constant magnetic field led to an increase in the resonance's amplitude values, which is explained by the dependence of the bending force on the magnetic field gradient. Thus, this composite structure demonstrates the presence of a large magnetoelectric effect and this material is promising for the construction of functional electronics systems.

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Magnetic field switchable T-shape magnonic nonreciprocal power splitter

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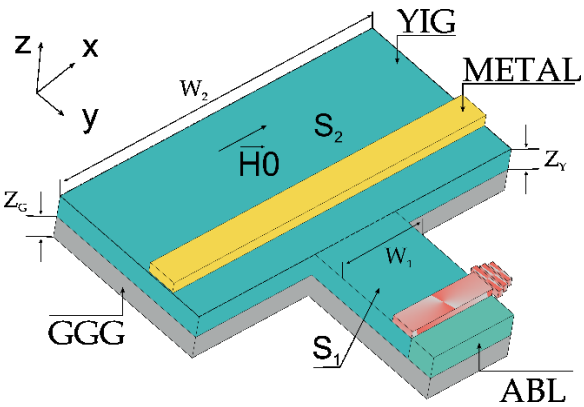

Fig1. Schematic representation of the studied T-shape magnonic waveguide.

Nowadays the interest design and implementation of various magnonic devices is of great interest [1]. A separate task is to study methods for controlling focused beams of a spin-wave signal required to create reconfigurable devices [2]. Numerical and experimental methods were used to study the influence of an inhomogeneous distribution of magnetization on spin-wave beams in a magnetic T-shaped film. Our study shows the possibility of controlling the direction of propagation of the spin-wave signal beams diffracting at the hole by changing the direction of the external magnetizing field.

The concept of the structure under study for creating focused beams of a spin-wave signal is shown in Fig. 1. Waveguide S_1 with a width of w_1 = 400 μm is connected to a magnetic film S_2 with a width of w_2 = 3000 μm. The thickness of the magnetic film was z_Y = 10 μm. In the transverse direction, a metallized layer with a width of w_2 = 10 μm is deposited onto the magnetic film. A spin wave excited by a microstrip antenna located at the edge of the waveguide S_1 propagates along the waveguide and, upon passing to the S_2 section, continuously propagates in the transverse direction of the y-axis due to the effect of diffraction. The beams formed in this way can be controlled by changing the direction of the external uniform magnetization field. The presented configuration of the device allows directing spin waves in different directions or blocking them, depending on the direction of the external uniform magnetic field and inhomogeneous distribution of magnetization. Thus, we show a new way to control focused beams of spin waves in unstructured magnetic films. The device can also be used as a power divider, which can be used in integrated circuits based on magnonics principles.

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Propagation of gap solitons in magnonic crystal – semiconductor structure

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Propagation of spin waves in ferromagnetic films can be accompanied by a number of nonlinear effects, such as the formation of solitons, modulation instability, and dynamic chaos [1, 2]. Using of periodic ferromagnetic films (magnonic crystals) can lead to the appearance of new nonlinear effects, such as nonlinear switching and formation of gap solitons [3]. At the same time, in the field of magnonics, much attention is paid to the study of the possibilities of electrical control of the spin waves properties. One of such methods is using of composite structures based on semiconductor and ferromagnetic films, in which the propagation of electron current in a semiconductor affects the dynamics of spin waves in a ferromagnetic film [4, 5].

We present the results of theoretical and experimental study of propagation of nonlinear spin wave pulses in heterostructure magnonic crystal - semiconductor (MC/SC) based on ferromagnetic film with periodic system of grooves. MC was loaded on semiconductor plate (SC). Possibility of the formation of gap solitons, as well as the possibility of electric and magnetic control of their properties is shown. One of the main properties of gap solitons is that their speed is less than speed of wave propagation in uniform ferromagnetic film. We found out that applying voltage to the SC layer electrical control allows to control the parameters of solitons, in particular, the number of pulses and their speed.

For experimental investigations we used Yttrium iron garnet (YIG) film with thickness 10 μm and saturation magnetization of 139 Gs. Periodic structure on YIG film was made as system of grooves with period of 200 μm. Silicon semiconductor wafer with thickness 500 μm was loaded on YIG film. For numerical simulation of propagation of spin wave pulses in the MC/SC structure, we used method of reconstructing wave equation from dispersion equation. We also taken into account nonlinearity of ferromagnetic medium. As a result, nonlinear coupled mode equation for amplitude of envelope was obtained.

The results obtained in this work allow us to consider periodic heterostructures based on MC and SC layers as promising candidates for the integration of magnon elements in a semiconductor architecture. Investigation of nonlinear effects of soliton formation is important in telecommunication applications for compressing pulses and increasing data bitrate.

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Novel diagnostic of steel wire rope with passive magnetic methods

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Steel wire ropes in every device like lifts, cableways, hoists used in roped transport devices are subjected to bending fatigue. According to the application area, steel wire ropes are often exposed to atmospheric influences. Very often, the impact of corrosion is inevitable [1]. The problem of determining the exact technical condition of the tested wire rope depends on many factors. The possibility of presenting the estimated mechanical stress while only relying on the Earth's weak natural magnetic field is proven in [2]. In this work, the authors would like to pay special attention to the influence of the position of the tested object concerning the magnetic field lines. The authors found no studies on the impact of magnetic location on the diagnostic result in technical diagnostics. This influence has been noticed in medical research [3]. The article examines a new fabric rope and then the same rope with an artificially introduced discontinuity (several wires were cut). The authors concluded magnetic passive technic's future on the non-destructive damage detection methods for steel wire ropes based on the research. It is significant to choose the appropriate distance from the tested object (the Earth's magnetic field's influence is substantial). In practical applications, the biggest challenge is the need to separate the Earth's magnetic field. A promising avenue for research is to combine various methods to characterize and detect damages from multiple dimensions.

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Electrodeposition of multilayered NiCu/Cu and CoCu/Cu nanowires, and investigation of their magnetic properties

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The method of electrodeposition allows the production of multilayered structures of different composition and provides control over the layer thickness [1, 2]. Multilayered structures consisting of thin ferromagnetic and magnetic layers exhibit the effect of giant magnetoresistance (GMR). The GMR effect in such structures is similar to that in multilayers but occurs in CPP (current perpendicular to plane) configuration [2]. GMR structures are perspective for usage in magnetic field sensors, magnetoresistive random-access memory (MRAM). The objective of this research is to synthesize multilayered nanowires and investigate their magnetoresistive properties.

The research is focused on multilayered NiCu/Cu and CoCu/Cu nanowires obtained by electrodeposition into pores of polymeric membrane (PET) made in JINT (Dubna, Russia). Properties of membranes are as following: diameter of pores 100 nm, density of pores 1.2 10^9 cm^{-2}, thickness 12 μm. Several NiCu/Cu samples were synthesized differing in thickness of ferromagnetic layers (it is expected to be between 7.5 nm and 30 nm) and in electrolyte contents (concentration of Cu ions was changed). For CoCu/Cu nanowires, the thickness of ferromagnetic and non-magnetic layers is expected to be 7.5 nm. The measurements of hysteresis loops were conducted using vibrating sample magnetometer. The external magnetic field was applied perpendicularly and parallel to the growth axis of nanowires. For magnetoresistance measurements the external magnetic field up to 2.6 kOe was applied perpendicularly to the growth axis of nanowires.

The magnetic parameters were extracted from the hysteresis loops which were of very similar shape for the magnetizing field in both directions (parallel and perpendicular to the wire axis). The coercive field increases in samples with thicker layers and in samples synthesized using electrolyte with smaller concentration of Cu ions. The MR ratio for all the samples varied between 0,6% to 1% and was affected by the number of nanowires connected to the conductive area. The MR ratio depended on the sample resistance, however, no dependance on electrolyte contents was observed. To increase the MR ratio, a fine control of the layer thickness is required.

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Spinel Nickel Ferrite nanosystems

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Spinel ferrites with the general formula MFe_2O_4 (M = Mn, Fe, Co, Ni) are considered among the most successful magnetic nanoparticles for technological applications such as density magnetic storage and bio-applications. Bio-applications such as the contrast enhancement as T_2-contrast agents in magnetic resonance imaging (MRI), drug delivery and hyperthermia, require magnetic nanoparticles with well-defined composition and morphology, narrow size distribution, surface properties and high saturation magnetization values.

Herein, we present the synthesis and characterization of truncated hydrophobic $NiFe_2O_4$ NPs of different sizes coated with oleylamine (OAm). Since hydrophilicity is essential for *in vitro* and *in vivo* applications, phase transfer becomes necessary. Three different phase transfer approaches were used to convert hydrophobic $NiFe_2O_4$ NPs to hydrophilic. Further, the NMR relaxivity was studied and evaluated. The three approaches are: a) addition of a positively charged coating layer by cetyltrimethyl ammonium bromide (CTAB), b) ligand exchange with 2,3-dimercaptosuccinic acid (DMSA) and c) polymer coating through a hydrophobically modified water-soluble polymer (HMWSP) - poly(sodium acrylate-co-dodecylacrylamide) (P(ANa-co-DAAm)) and a diblock amphiphilic copolymer poly(methacrylic acid)-b-hexadecane (PMAA-b-$C_{16}H_{34}$) [1-3]. The efficiency of a T_2-contrast agent is defined in terms of the transverse (r_2) relaxivity ($mM^{-1}s^{-1}$) and corresponds to the rate of proton relaxation.

For the T_2 measurements, a multi-spin-echo CPMG (Carr-Purcell-Meiboom-Gill) sequence was employed at various concentrations by NMR spectrometer (11.7 T). A linear concentration dependence of R_2 ($1/T_2$) was experimentally observed for $NiFe_2O_4$@CTAB, $NiFe_2O_4$@DMSA, $NiFe_2O_4$@P(ANa-co-DAAm) and $NiFe_2O_4$@PMAA-b-$C_{16}H_{34}$, permitting the determination of different r_2 values ($mM^{-1}s^{-1}$) because of the coating variation.

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Synthesis and characterization Citric acid-modified Iron oxide nanoparticles for biomedical application

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Iron Oxide Nanoparticles (IONPs) are of great interest to researchers in various fields of science and technology, including physicists, chemists, biologists and medics. The small sizes of magnetic nanoparticles, which distinguishes them from bulk materials, affects their physical-chemical properties and provides them with new properties that are beneficial for many applications. In addition, the biocompatibility and low toxicity of such nanosystems consisting of water disperssed IONPs (Fe_3O_4) modifiied and stabilized with bioactive molecules such as Citric Acid (CA) makes them very interesting for biomedical applications, especially as drug delivery systems in modern health care.

Reducing the undesirable toxic effects of chemotherapeutic drugs is the topical problem of today's medicine on healthy cells, and combined therapy with nanoparticles is expected to reduce the therapeutic dose of chemotherapy preparations and make the cure more specific. CA in this respect has a potential as this organic compound can be used as linker agent with anticancer drugs.

The most conventional method for obtaining Fe_3O_4 or γ-Fe_2O_3 is chemical co-precipitation. In our work we propose a simple and cost-effective method for obtaining colloidal suspensions composed of Fe_3O_4 nanoparticles coated with CA and dispersed in a liquid carrier (distilled water). Our particles were synthesized by chemical co-precipitation with ultrasonication (sonolysis) in a low vacuum environment [1,2]. Before coating with CA, the obtained IONPs were processed by electrohydraulic discharges in the high discharge current (HC) (several tens of Amperes) and low discharge current (LC) (several Amperes) modes in water medium using pulsed direct current (PDC). X-ray Powder Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR), Dynamic Light Scattering (DLS), Ultraviolet-Visible Spectroscopy (UV VIS), and Small Angle X-Ray Scattering (SAXS) were used to characterize the obtained samples.

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Deposition of $BaFe_{12}O_{19}$ thin films with perpendicular magnetic anisotropy on Al_2O_3 (102) substrate

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Interest in the production of thin $BaFe_{12}O_{19}$ films is due to the possibility of creating of a new planar microwave devices as well as magnetic data carriers with a high recording density. To implement such devices demand magnetically anisotropic films, which is determined by the crystallographic texture obtained as a result of epitaxial growth on single-crystal substrates. However, the films are amorphous after vacuum deposition at low substrate temperatures. During annealing, crystallization proceeds simultaneously throughout the entire volume of the film; therefore, the orientation of the substrate is not inherited completely. It was shown in [1] that hematite Fe_2O_3 crystallizes from the amorphous $BaFe_{12}O_{19}$ precursor at 300-500 °C. It is also known that hematite is characterized by a surface crystallization [2]. Thus, on the surface of an amorphous $BaFe_{12}O_{19}$ film, the formation of hematite (00l) grains with subsequent transformation into hexaferrite (00l) is possible [3]. On the basis of this effect, a technique of interval deposition with periodic interruption of deposition was proposed to form Fe_2O_3 (00l) grains on the surface, which act as a template for growth of $BaFe_{12}O_{19}$ (00l) during annealing.

$BaFe_{12}O_{19}$ films were obtained by ion-beam deposition on Al_2O_3 (102) substrates. The intervals between deposition cycles were 5, 10, 15 and 20 minutes. The magnetic parameters were measured on a vibrating sample magnetometer (VM-07M) with a field applied parallel and perpendicular to the film plane. An NT-MDT NTEGRA Prima atomic force microscope was used to study the morphology of the surface grains.

First, it was found that the hysteresis loops differ for different directions of the field, which indicates the anisotropy. Second, the characteristics of the hysteresis loops were different for samples with different interval lengths. This fact is explained as follows: crystallization of hematite proceeds relatively slowly, and with a longer interval time more precursor is converted into Fe_2O_3 (00l) and then into $BaFe_{12}O_{19}$ (00l).

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Spectroscopic study and analysis of *d-d* transitions in Ni ions in nickel orthoborate (Cu, Ni)B_2O_4

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For more than a hundred years, active studies of copper metaborate CuB_2O_4 have been carried out, as a result of which new properties continue to be revealed that are of interest both in the framework of the study of this crystal and for the physics of magnetic compounds in general.

Thus, a giant optical magnetoelectric effect [1], significant dichroism with respect to the direction of propagation of light [2], and antiferromagnetic linear dichroism [3] were observed in this compound. The detection of linear antiferromagnetic dichroism [3] on the exciton lines of magnetic copper positions in isotropic ab-plane, in turn, allowed to register splitting of the well-known from the literature magnetic phase transition into a helicoidal structure at $T^* = 8$ K into two transitions at $T_1^* = 7.9$ K and $T_2^* = 8.5$ K. It should be noted that this splitting was not previously detected by other standard methods for studying magnetic structures [4, 5].

Studies of doped copper metaborates are also interesting. Thus, the partial substitution of nickel for copper (~ 3%) led to a significant increase in magnetization and the appearance of electric polarization under the action of a magnetic field [6]. It was also demonstrated the ability to control the magnetization of nickel-doped copper metaborate using an electric field [7]. Thus, (Cu, Ni)B_2O_4 is a multiferroic.

This work is devoted to the study of the absorption spectra of (Cu, Ni)B_2O_4 with various Ni concentrations (from 0.01 to 10%). In addition to the well-known exciton lines of copper, a large number of narrow lines are observed in the spectra in the region of 4000-6000 cm^{-1}. Most likely, these lines are associated with *d-d* transitions in Ni ions. The position, width and intensity of the lines have complex temperature and polarization dependences. The analysis of the obtained spectra is carried out, in particular, the spectra within the framework of the crystal field theory.

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Terbium substitution effects in $CeFe_2$: structure and magnetic properties

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Of particular interest among the rare-earth Laves phases is the compound $CeFe_2$. In $CeFe_2$, the valence of the cerium ion is 3.29 [1], and its partial substitution may cause changes in the valence and sharp fluctuations between the delocalized and localized electron states. Despite numerous studies of substituted $(Ce,R)Fe_2$ compounds [2-6], many unresolved questions remain.

In this article, the system of alloys $Ce_{1-x}Tb_xFe_2$ (x = 0, 0.1, 0.2, 0.3, 0.5, 0.7), obtained by arc melting. The diffraction spectra were recorded in CuKα-radiation at room temperature using an "Ultima IV" X-ray diffractometer (Rigaku, Japan). It is shown that the main phase of the studied compositions is the cubic structure of Laves ($MgCu_2$) C15 (Fd-3m). The Rietveld method determines the parameter of the main phase unit cell. In the system $(Ce,Tb)Fe_2$ with increasing Tb concentration, the cell parameter monotonically increases, and there is a positive deviation from Vegard's law, which is probably associated with a change in the Ce valence. The alloy surface features were studied by atomic force and magnetic force microscopy on the polished surface of the samples using a scanning probe microscope SMENA-A (Solver platform, NT-MDT, Russia) at room temperature. The presence of an inhomogeneous granular structure is revealed, and the parameters of the main structural elements are determined.

The magnetization of the samples was measured using an induction magnetometer (insert to the MagEq MMS 901 setup, AMT&C, (Troitsk, Moscow)) in magnetic fields up to 18 kOe in the temperature range of 80–350 K. The use of a high-temperature nozzle (350-1000 K) made it possible to determine the Curie temperatures of the listed compounds. The magnetocaloric effect was calculated both by the indirect method from the magnetization data and by the direct method (adiabatic temperature change) using the same installation. The magnetostriction was studied by the strain-gauge method in the temperature range of 80–350 K in magnetic fields up to 12 kOe. As a result of the conducted studies, the main magnetic, magnetothermal, and magnetoelastic characteristics of the $Ce_{1-x}Tb_xFe_2$ compound system were determined and the effect of partial substitution of Ce with terbium on the structure and magnetic properties of $CeFe_2$ was analyzed.

The work was performed under the government order of the Ministry of Education and Science of the Russian Federation (project # 075-00328-21-00).

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Biosensor based on Ag nanoparticles for microbial contamination detection

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One of the most actual problems of biology is the development of biosensors for ecotoxicology. The solution to this problem may be the development of biosensors based on a firefly bioluminescence system. Due to high sensitivity to adenosine triphosphate (ATP), this system is widely used for analysis of the presence or absence of microbial contamination in the different samples. In this work we report of the silver nanoparticles (AgNPs) influence on the extraction of ATP from bacteria cells and bioluminescence signal and the inhibition of luciferin-luciferase systems components by (AgNPs).

AgNPs were synthesized in solution using $AgNO_3$ reduction by $NaBH_4$ in the presence of benzalkonium chloride (BAC) as a stabilizing agent. Synthesized AgNPs have a spherical form with an average diameter of 5 nm (Fig. 1(a)).

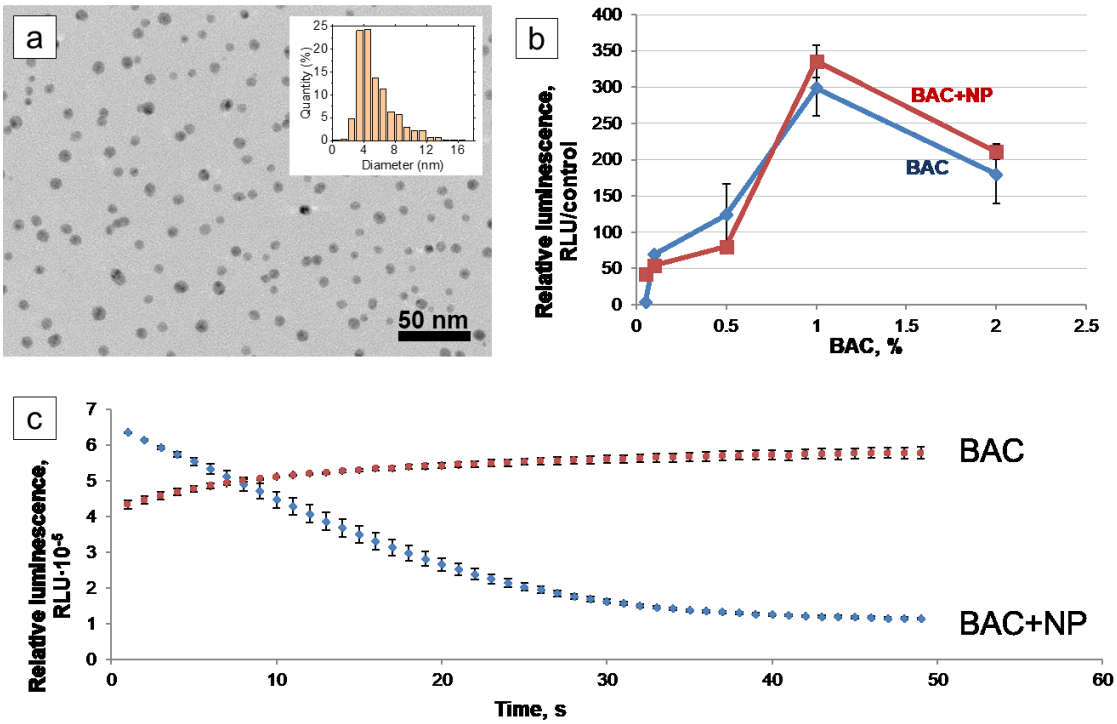

Fig. 1. (a) TEM image of synthesized AgNPs and statistical distribution over diameter; (b) extraction efficiency using various concentrations of BAC and BAC+AgNPs; (c) kinetics of the luminescence signal using BAC and BAC+AgNPs extraction solutions

The maximum signal of luminescence was investigated during extraction of ATP by BAC solution with and without AgNPs (Fig. 1(b)). It was shown that AgNPs effect on maximum signal and kinetics of the reaction comparing with BAC solution (Fig. 1(c)).

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The role of small-angle X-ray scattering and molecular simulations in 3D structure elucidation of a DNA aptamer - cancer cells magnetic separation agent

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Aptamers are oligonucleotide or peptide molecules that bind to a specific target molecule. Knowledge of the spatial three-dimensional structure of aptamer molecule is crucial for understanding the functions of specific aptamers and for determination of quantitative parameters of its specific binding.

Here we identified 3-D conformation in solution of the aptamer LC-18t which is a truncated version of our previously described aptamer to lung adenocarcinoma [1]. Small-angle X-ray scattering (SAXS) with molecular modeling method were applied to choose the most probable aptamer spatial conformation from several possible secondary structures [2]. Furthermore, we demonstrate that this truncated aptamer did not change its binding abilities and LC-18t was used for magnetic separation of circulating tumor cells from the human blood.

For atomistic modeling of aptamer structures, the following procedure is suggested: (1) use SAXS to determine the shape of the aptamer in experiment, (2) do the initial design of molecular secondary structure, (3) perform molecular modeling by using computational methods such as MD, and (4) compare atomic structure from simulations with the measured SAXS curve using special analytical programs. Although the proposed procedure to determine the structure is applied to an aptamer in this work, it is general and can be employed for any other type of molecules in solution.

By obtaining a reliable atomistic structure from simulations, one can rationalize the binding of an aptamer to a target, such as a protein. This can be very helpful in designing new, more efficient aptamers based on insight gained from molecular simulations.

The synchrotron SAXS data were collected at beamline P12 operated by EMBL Hamburg at the PETRA III storage ring (DESY, Hamburg, Germany).

The reported study was funded by RFBR, project number 19-32-90266.

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Cobalt zinc ferrite/gold-arginine nanocomposite as promising tool for leukemia treatment

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Magnetic nanoparticles showed a wide range of applications in biomedicine: MRI or hyperthermia agents, therapeutic vehicles, etc. Cobalt ferrite nanoparticles substituted with zinc ($Co_{0,5}Zn_{0,5}Fe_2O_4$) attracted attention due to their high chemical stability and custom magnetic properties [1]. Composite is formed of magnetic nanoparticles coated with dihydrocaffeic acid (DHCA) and gold nanoparticles with arginine for the achievement of hydrophilic and antibacterial effects which are essential for in vitro tests. In this work, we studied the influence of composite on proliferative activity and oxidation stress level of human leukemic Jurkat cells (Russian Cell Culture Collection, Institute of Cytology RAS).

The cytotoxicity of composite nanoparticles on Jurkat cells was measured using a WST-1 test and three concentrations (10, 50 and 100 µg/ml) were investigated after 2, 4, 6, 8, and 24 h exposure in cell suspension. During the last 2 h of exposure, 10 µl of WST-1 reagent was added. Absorbance was measured at 450 nm in a microplate reader. Fig.1 shows statistically the lowest proliferative activity cell culture after 24 h exposure to composite nanoparticles. The comparison of the viability of Jurkat cells after exposure with various concentrations shows the highest cytotoxicity on 100 µg/ml concentration.

The oxidative stress level was measured by flow cytometry analysis using DHE staining. The concentration 100 µg/ml was studied after 24 h exposure. Results shows that composite nanoparticles increasing the oxidative stress level of the cells by 27%. Thus, composite decrease cell culture's proliferative activity because of inducing oxidative stress in cells.

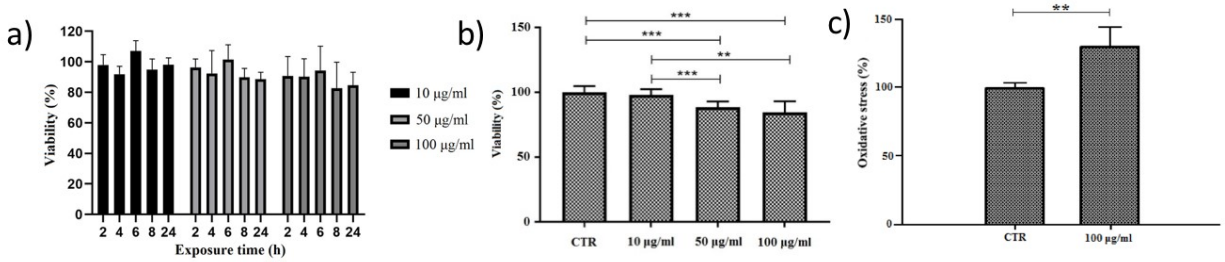

Fig. 1. a) Effect of exposure time and composite concentrations on viability of Jurkat cells. Viabilities were assessed by the WST-1 assay. The relative viability after exposures is presented as percentage compared to the control at the same time point, b) The relative viability of Jurkat cells after 24 h exposure to composite, c) Oxidative stress level after 24 h exposure to composite. Data is presented compared to the control at the same time point as percentage. Results shown are mean±SD from triplicate exposures, **: $P < 0,01$; ***: $P < 0,001$ (Student's T-test).

In summary, composite of cobalt ferrite nanoparticles substituted with zinc covered with dihydrocaffeic acid and gold nanoparticles with arginine at a concentration of 100 µg/ml are optimal for use in biomedicine as a drug for T- lymphoblastic leukemia.

This work was supported by the Russian Science Foundation No. 21-72-20158.

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Magnetic field mapping with magnetoplasmonic crystal-based sensor

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Magnetic field sensing requires high resolution, low power consumption, inexpensive production and miniature dimensions. Thus, the magnetic field sensors market offers optimal sensors suitable for a large number of specified tasks. One of the new approaches for magnetic field sensing is based on the use of magnetoplasmonic crystals (MPlCs) - plasmonic crystals made of noble and ferromagnetic materials[1,2]. Such structures enhance the transversal magneto-optical Kerr effect by the excitation of surface electromagnetic waves [1].

This work is devoted to magnetic field mapping with the use of a permalloy-based MPlC. Used MPlC is a subwavelength quasi-sinusoidal diffraction grating covered with 50 nm of Ag, 15 nm of $Ni_{80}Fe_{20}$ and 20 nm of Si_3N_4. Magnetic field dependence of the magneto-optical response is determined by the change of the $Ni_{80}Fe_{20}$ magnetization and shown in Fig1a. The MPlC was placed in a modulating AC magnetic field, corresponding to the center of the dependence's slope, and served as a sensing element, detecting changes of a magnetic field applied parallel to the AC field[1]. Method's resolution is determined by the optical spot size, focused on the MPlC's surface. Geometry of the experiment is shown in the inset of Fig1a.

As an example, the magnetic field map, generated with the central part of a round planar induction coil is shown in Fig1b. Coil's diameter is 15 mm and number of windings is 10. The map was plotted by moving the coil 1 cm behind the MPlC in the area of 24 mm^2 with a step of 0.5 mm. The spot size diameter was 150 um. DC current in the coil was equal to 400 mA. Results show that permalloy-based MPlC can operate as an effective probe for magnetic field mapping.

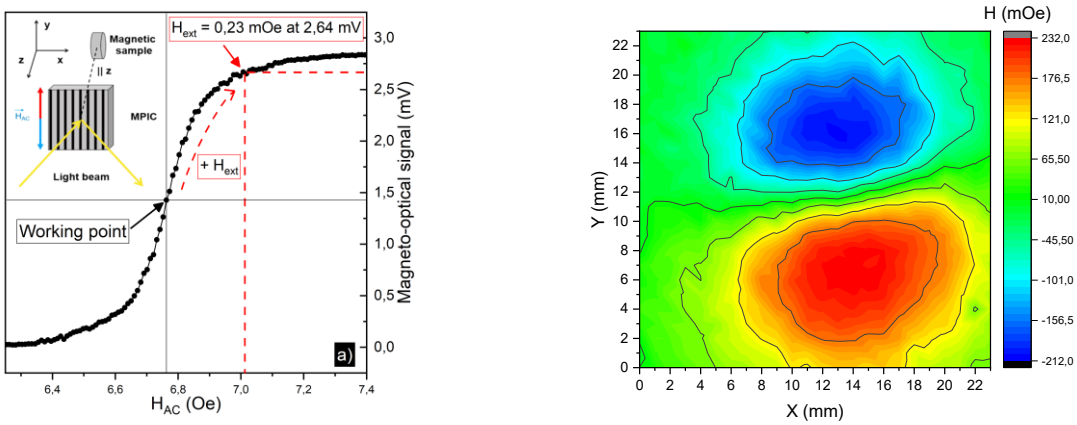

Figure 1. a) The magnetic field dependence of the magneto-optical response (black) and a signal proportional to external magnetic field H_{ext} (red). The geometry of the experiment is shown in the inset. b) Distribution of the magnetic field generated with a round planar induction coil.

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Magnetoactive metallopolymer nanomaterials containing cobalt, nickel and iron: synthesis, properties, application

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The aim of this work is to obtain and investigate new functional magnetic metallopolymer nanomaterials of a new generation with an increased level of consumer properties and qualities based on a number of precursors synthesized earlier by us – unsaturated dicarboxylates of cobalt (Co), nickel (Ni) and iron (Fe) – with the possibility of regulating the output physicochemical properties of nanomaterials at the stage of obtaining to improve their operational characteristics. A feature of these magnetic metallopolymer nanocomposites containing Co, Ni and Fe, which have intrinsic magnetic moment and magnetic susceptibility, is the solution of the actual problem of simultaneous synthesis and stabilization of nanoparticles (NPs) from aggregation even at the stage of self-regulating thermolysis by means of regular distribution of NPs in the polymer matrix and formation protective polymer shell of the core-shell structure while conserving their inherent physicochemical properties at nanoscale.

Magnetoactive metallopolymeric Co (II), Ni (II) and Fe nanocomposites, obtained by controlled thermolysis at a temperature 335±1ºC under an argon atmosphere of a number of previously synthesized and characterized by us unsaturated dicarboxylates of these metals (allylmalonates (Almal), acetylenedicarboxilates, glutaconates, itaconates (It), maleates, cis,cis-muconates, citraconates), are powders consisting of two structure elements, namely: in organic polymer matrix containing fragments $–CH_2–$, =CH– и =C= the spherical NPs of Co_3O_4/CoO/ α-Co, NiO/ß-Ni or γ-Fe_2O_3 in the polymer shell of the core-shell structure are embedded. It was established that the thermolysis of ItNi leads to the formation of carbon nanotubes. The enthalpy (ΔH^o_r) of formation reaction of Co, Ni and Fe carboxylates by the PM3 semi-empirical quantum-chemical method with using the HyperChem 8.0.8 (Hypercube Inc.) were calculated. The average NPs diameter (d_{adv}) of the obtained nanocomposites, namely 4-9 nm, was determined. A relationship between d_{adv} and ΔH^o_r of Co, Ni and Fe carboxylates was established. The microstructure and magnetic characteristics of the obtaine nanocomposites were determined: the highest coercive force is observed for nanocomposites based ItCo (1040 Oe), ItFe (119 Oe) and AlmalNi (131 Oe). The critical value of the NPs d_{adv} for Co associated with the transition from multi-domain to single-domain particles was found to be 3.8 nm.

The spectrum of potentional fields of application of the obtained nanomaterials is extensive – from gas and magnetic sensors, catalysts, high-density magnetic storage media to new forms of drugs and medical diagnostics. The investigations on the cultivation of cell cultures of soil-forming micromycetes and human tumor cells HepG2 and HeLa on media with content of the synthesized Co, Ni and Fe nanocomposites were carried out. The test intramuscular injections of magnetic Ni and Fe nanocomposites in mice line C57b in quantities of $2\cdot10^{-6}$g/g of weight didn`t reveal a toxic effects. This work was supported by the Russian Foundation for Basic Research (project 19-03-00237).

Tuning the Curie temperature in amorphous alloys by current annealing for biomedical applications

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Soft magnetic amorphous microwires are recently proposed as miniature temperature-sensitive elements for embedded sensor applications operating in the industrial temperature range of -20 – 100 °C [1]. In particular, such sensors are in high demand for controlling the inflammatory processes in various implants. The sensor operation is based on the dependence of magnetic properties on the proximity to the Curie temperature, T_c. In particular, a sharp change in high-frequency impedance near T_c can be used for developing MI-temperature sensors [2]. Other biomedical applications include hyperthermia methods with the use of ferromagnetic particles, for which controlling the T_c in the range of 40 – 60 °C would be of considerable interest. In the present paper, fine tuning of T_c in low-Curie temperature microwires of composition FeCoBSiNi was realized by current annealing.

Physical properties of amorphous alloys produced by rapid quenching are significantly changed by annealing at temperatures lower than the crystallization temperature owing to structural relaxation. Modifications in chemical and topological short range orderings during annealing is responsible for the T_c change. Kinetics of structural relaxation along with a randomizing effect dominating at higher annealing temperatures may result in a non-monotonic behavior of T_c with respect to the annealing time and temperatures. This gives an opportunity to determine the annealing conditions to set a desirable value of T_c and obtain an abrupt change in the magnetic behavior just below the T_c. Current annealing was proposed to control the Curie point of amorphous $Fe_5Co_{27.4}B_{12.26}Si_{12.26}Ni_{43.08}$ microwires having a T_c of 47 ºC in as-prepared state and the crystallization temperature of 472 oC. The samples under investigation had a total diameter of 36 μm and a metal core diameter of 31 μm.

The current annealing was done in air atmosphere for different times (10-60 minutes), the current magnitude was in the rage of 50 to 110 mA, which produced the heating effect of 150-450 ºC. The T_c was measured by VSM in the presence of a magnetic field of 8 kA/m. The value of T_c almost linearly increases with increasing the current magnitude from 50 to 95 mA reaching a value of 80.5 ºC. Further increase in the current magnitude produces a little change since the onset of crystallization is reached.

It is concluded that the step-current annealing is proposed as a simple and efficient technique to modify the Curie temperature of amorphous microwires.

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Excellent soft magnetic properties in Co-based alloys after heat treatment at temperatures near the crystallization onset

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Thermal treatments of amorphous alloys known to cause structural relaxation, which is followed by an evaluation of the magnetic anisotropy and saturation magnetostriction. In this work, we investigated the effect of annealing with a temperature close to the onset of the crystallization on the magnetic hysteresis properties of glass-coated amorphous microwires of Co-rich compositions with a nearly zero magnetostriction. The annealing process was performed on the wires by two methods: dc current annealing and conventional annealing in finance (at 475-490 ºC for 30 min). The current intensities were chosen such to ensure similar annealing conditions. The annealing temperatures were higher than the Curie temperature (~360 ºC) and slightly lower than the primary crystallization temperature (510 ºC). We have demonstrated a sharp change in the shape of the magnetic hysteresis after annealing which is caused by the change in the magnetostriction.

Typically, amorphous microwires of Co-rich compositions with negative magnetiostriction are regarded as excellent soft magnetic materials suitable for large and sensitive magnetoimpedance (MI) [1]. A well-defined circumferential anisotropy could be established in these wires by a proper choice of composition, geometry and annealing treatments, which increases the MI ratio up to hundred percent in characteristic fields of few Oersted [2]. The high sensitivity of impedance to low magnetic fields makes amorphous ferromagnetic microwires a promising material for the construction of different sensor systems.

In the present work, the transformation of the sign of magnetostriction in amorphous microwires of composition: $Co_{71}Fe_5B_{11}Si_{10}Cr_3$ (diameter: D/d=29/25 μm) and $Co_{66.6}Fe_{4.28}B_{11.51}Si1_{4.48}Ni_{1.44}Mo_{1.69}$ (diameter: D/d=35/25 μm) was established after annealing in a narrow temperature range near the crystallization onset. This restores soft magnetic properties and ensures high temperature stability of all magnetic parameters. The wires under the study were produced by quenching and drawing technique (also referred to as modified Taylor-Ulitovskiy method). The choice of composition is justified by specific magnetoelastic properties with near zero magnetostriction of the order 10^{-7}.

It is known that annealing without applied stress can produce short-range order relaxation and consequently releases some frozen-in stresses and improves soft magnetic properties. In the present paper, we propose current and conventional annealing at relatively high temperatures slightly lower than the primary crystallization temperature. This causes nano crystallization and sharp change in the saturation magnetostriction. Therefore, we proposed a method of controllable change in magnetic anisotropy by changing the sign of magnetostriction. In particular, this results in a change in the shape of magnetic hysteresis and enhances the sensitivity of MI at microwave frequencies.

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Indium-Silver and Thallium-Silver based double-Perovskites for photovoltaic & thermoelectric applications: a DFT study

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Energy consumption rate is increasing drastically with each passing day since last fifty years because of speedy industrial growth and population increase all over the world. The reliance on traditional fossil fuel power generation methods is causing a severe energy deficit. Therefore, to address this serious issue, the research in exploration of innovative materials for alternative cleaner and environment friendly power generation methods has attained much attention. Thermoelectric and photovoltaic materials have appeared as potential candidates in this scenario for producing power from wasted heat during conventional fossil fuel methods and from sun light available freely on earth respectively [1-2]. In this work, the structural, electronic, optical and thermoelectric properties of double-perovskites $X_2InAgCl_6$ (X = Cs, K, Rb) and Cs_2AgTlY_6 (Y = Br, Cl) have been studied using density functional theory. First principle DFT calculations were carried out describing Kohn-Sham states using plane wave pseudopotential approach as implemented in QUANTUM ESPRESSO [3]. Perdew, Burke and Ernzerhof (PBE) [4] and PBE-sol [5] within generalized gradient approximation (GGA) were used as exchange correlation functionals.

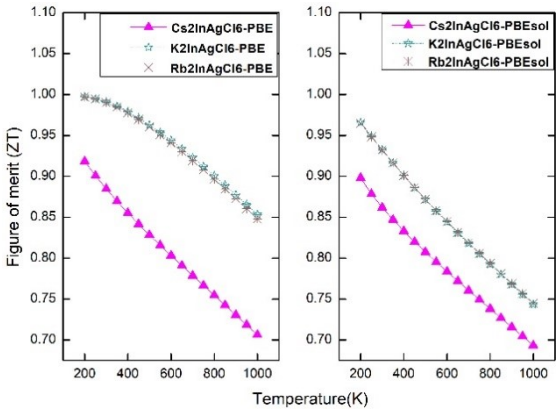

Figure 1: Figure of merit with respect to temperature using PBE and PBE-sol.

The calculated structural and electronic parameters of $X_2InAgCl_6$ fairly agree with reported findings. The direct band gaps, structural stability, thermal stability, significant absorption coefficients in visible range, large Seebeck coefficients and figure of merit (close to unity, see Figure 1) of these double-perovskites suggest that these compounds may play vital role in various optoelectronic and thermoelectric device applications. Further work is in progress for Cs_2AgTlY_6.

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Saddle point anomaly of Landau levels in graphenelike structures

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Studying the tight binding model in an applied rational magnetic field (H) we show that in graphene there are very unusual Landau levels situated in the immediate vicinity of the saddle point (M-point) energy E_M. Landau levels around E_M are broadened into minibands (even in relatively weak magnetic fields ~40-53 T) with the maximal width reaching 0.4-0.5 of the energy separation between two neighboring Landau levels though at all other energies the width of Landau levels is practically zero.

In terms of the semiclassical approach a broad Landau level or magnetic miniband at E_M is a manifestation of the so called self-intersecting orbit signifying an abrupt transition from the semiclassical trajectories enclosing the Γ-point to the trajectories enclosing the K point in the momentum space. Broad minibands in the immediate neighborhood of E_M represent a transition region where the first type of orbits is transformed to the second.

The structure of broad magnetic minibands is clearly fractal demonstrating fast oscillations of the band energy $E_m(k)$ with the magnetic wave vector k. Remarkably, the saddle point virtually does not affect the diamagnetic response of graphene, which is caused mostly by electron states in the vicinity of the Fermi energy E_F [1]. Experimentally, the effect of the broading of Landau levels can possibly be observed in twisted graphene where two saddle point singularities can be brought close to the Fermi energy.

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Magnetic nanoparticles for prevention and treatment against bacterial films

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Now there is a problem of the formation of antibiotic resistance associated, among other things, with bacterial films – heterogeneous communities of microorganisms surrounded by an extracellular matrix. In this form the bioavailability of antibiotics is reduced and prolonged, more doses of drugs are required, and during the time the drug penetrates into the biofilm, bacteria have time to develop enzymes and mechanisms that inactivate antibiotics. To overcome the low bioavailability of drugs, new methods of delivering of antibiotics to cells are being developed. Promising method of drug delivery is the use of metal oxides based nanoparticles, especially Fe3O4 and γ-Fe2O3 based nanoparticles. It has been proven that iron-based nanoparticles are low-toxic for eukaryotes, and at the same time they selectively penetrate into bacterial cells, destroying the cell membrane, causing oxidative stress and death of microorganisms. Another advantage of iron oxide nanoparticles is the ability to visualize and control their distribution in the body using a magnetic field.

To assess the antibacterial properties of magnetic nanoparticles in combination with drugs, spherical magnetite and ferrihydrite nanoparticles with size 2-5 nm were obtained by chemical coprecipitation. The structure of the nanoparticles was confirmed using Mössbauer spectroscopy.

Drug delivery systems have been designed by adsorption of arabinogalactan or chitosan on nanoparticles, loaded with the antibacterial wound-healing ointment *Laevomecolum,* or the combined antibiotic Amoksiklav®. The drugs were loaded either by adsorption or by chemical bonding: polysaccharides on nanoparticles were oxidized with EDC and then covalent binding with the antibiotic.The antibacterial activity of the obtained systems was assessed in gram (+) and gram (-) bacteria, and the antibacterial and regenerative properties were assessed on the model of burns on laboratory animals. It was shown that magnetic particles do not have a negative effect on the tissues near the burns and common condition of animals, and the use of nanoparticles in combination with *Laevomecolum* protects against wound infection and enhances tissue regeneration.

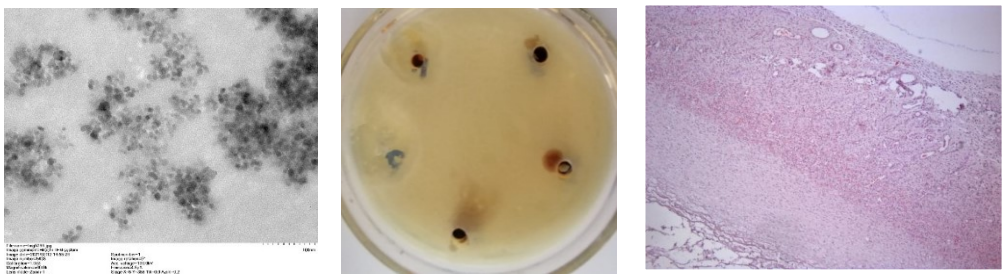

Fig.1. TEM of magnetic nanoparticles; *Bacillus sp.* treated with nanoparticles; dorsal skin area treated with nanoparticles loaded with drugs, stained with hematoxylin and eosin.

10-year stability of magnetite nanopowder prepared via an exploding wire method

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Inorganic nanoparticles (iNPs) derived from magnetic iron oxides have been currently investigated and tested for diagnostic and therapeutic applications in medicine. Nevertheless, only a limited number of iNPs were translated into clinical practice. More attention should be given to concerns regarding the long-term storage of magnetic iron oxide nanoparticles ex vivo because nanoscale magnetite (Fe_3O_4) oxidizes to maghemite (γ-Fe_2O_3) under environmental conditions. However, time duration of this process has not been well described.

We analyzed the structural, magnetic, and cytotoxic properties of magnetite nanoparticles (MNPs) designed via an exploding wire method and then stored them in a dark place under an ambient atmosphere (65±15% humidity, air pressure 760±20 mm of vacuum) at room temperature (22±4 °C) for 10 years. The nanopowder was obtained by V.S. Sedoi (Institute of High Current Electronics, Siberian Branch, Russian Academy of Sciences, Tomsk, Russia) in 2007. The X-ray diffraction (XRD), transmission electron microscopy (TEM) with the selected-area electron diffraction (SAED) pattern, and magnetic studies (magnetic remanence, saturation magnetization) were performed. In vitro cytotoxicity of MNPs was tested with 24-h culture of human blood mononuclear leukocytes (hBMLs) using 0.4% trypan blue solution. Ten maximum tolerated doses (10 MTDs) of MNPs in 0.9% NaCl solution were used. One MTD of iron in water was equal to 0.3 mg/L.

According to transmission electron microscopy (TEM), MNPs had a spheroid or polyhedral shape with rounded edges. The SAED pattern of the sample demonstrates for 10 years its crystalline nature: the bright rings formed by spots related to (111), (220), (311), (400), (422), (511) and (440) axis patterns of face-centered cubic structure of Fe_3O_4. One weak-intensity ring marked as 110_α was related to small concentration of α-Fe. A lognormal size distribution of MNPs with a mean value of 39.9 nm (2007 year) or 31.7 nm (2017 year). XRD measurements demonstrated that the predominant phase was magnetite (96−97 wt.%, approximately); additionally, a small amount of metallic iron in an α-modification (2−3 wt.%) was observed. The saturation magnetization (M_S) for the aged MNP powder was unexpectedly higher than that for the as-prepared MNP powder. The reduced remanence magnetization (M_R/M_S) was equal for both samples. We believe that future studies are needed with the use of additional, more specific equipment which may shed more light on this explanation for the increased M_S value. The cytotoxic influence of MNPs was not detected in vitro by a cell counter for any year of the long-term study.

In summary, the 10-year usability of the structural, magnetic, and cytotoxic properties of electroexplosive nanopowder is a very useful feature for its biomedical development as an inorganic carrier for the diagnostics and a treatment of cancer and a wide variety of other illnesses.

Spin-wave transport in lateral waveguides with vertical coupled ring resonator

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In recent years, there has been great interest in using the advantages of spin waves for data transmission and computations, and this interest is mainly due to the energy efficiency of this technology [1]. Magnon network elements have recently been proposed based on structures that are magnon couplers and several experiments have been performed with coupler-based reconfigurable magnonic circuits that can act as interconnection and frequency spatial division demultiplexing magnonic devices. Optical microcavities in optics backward or forward drop (for resonators) depending of the mode in resonator or number of resonators. [2] Channel drop filters in photonic crystals. Since the even state exhibits an odd symmetric property with respect to the mirror plane parallel to the waveguides, the transfer occurs along the backward direction of the drop waveguide,

The principle of the proposed structure is schematically pictured in Fig. 1a. The coupler based on a conventional DC, which parallel-couples a narrow YIG waveguide S1 to adjacent waveguide. The internal magnonic ring structure was formed from L-type junction of four magnonic waveguides Zi of equal width si = 500 μm (i = 1..4) in order to maintain the spin-wave phase matching. Magnonic ring was placed above two parallel magnonic stripes S1 and S2 of width w1 = 500 μm and w2 = 500 μm, respectively.

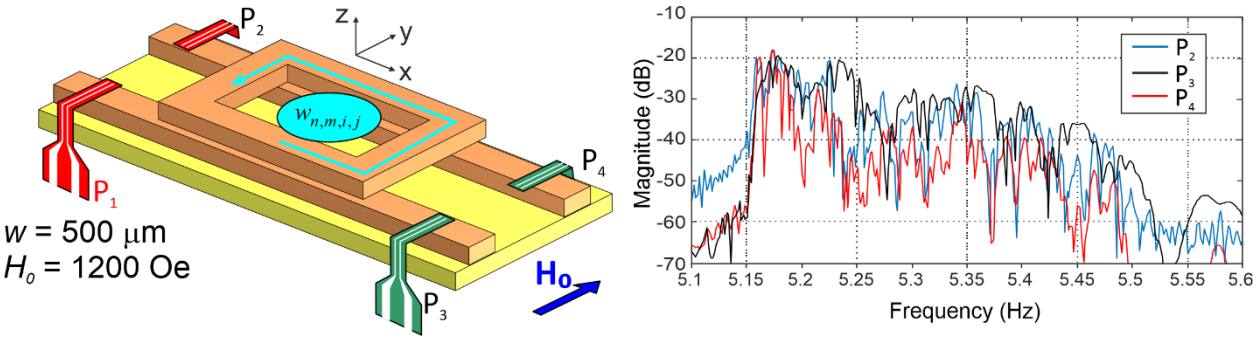

Fig1.(a) Schematic view of investigated structure; (b)Transmission spectrum of MSSW in the structure under study

We report that in this structure can be obtained special regimes of SW coupling. Thanks to usage of ring resonator SW can propagates forward and backward without changing direction of internal magnetic field.

Work is supported by the Russian Science Foundation (No. 20-79-10191).

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Magnetic properties of $CoFe_2O_4/NiFe_2O_4$ and $CoFe_2O_4/NiO$ core/shell nanoparticles: the case of ultrathin shells

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Bi-magnetic core/shell nanoparticles (NPs) demonstrate enhanced magnetic properties concerning single-phase systems [1]. In the frame of this work, the study of two NPs systems with core/shell structures is presented: the first system is a core of magnetically hard cobalt ferrite ($CoFe_2O_4$) covered by a magnetically soft nickel ferrite ($NiFe_2O_4$), while the second system is the $CoFe_2O_4$ covered with an antiferromagnetic NiO. The single-phase $CoFe_2O_4$ NPs (seeds) were synthesized with a high-temperature decomposition method [2]. At the second step of the reaction, the $CoFe_2O_4$ NPs were covered with the second magnetic phase via a seed-mediated growth. The structure and morphology of synthesized core/shell NPs were revealed by x-ray diffractometry and (scanning) transmission electron microscopy (STEM). All core/shell samples possessed a higher diameter than the seeds, which confirms the building-up of ~1 nm shell. According to the magnetic characterisation of samples performed with SQUID magnetometer, the seed NPs exhibit a high saturation magnetisation (~80 $A \times m^2/kg$) which was slightly decreased when the shell was formed. At low temperatures, the soft $NiFe_2O_4$ ultrathin shell increased the effective magnetic anisotropy of the core/shell system due to an enhanced spin canting effect [3]. The formation of the antiferromagnetic shell of NiO also led to an increase in anisotropy. Investigation of the magnetic size of particles via magnetic viscosity at 5 K and fitting of M-H curves at 300 K with Langevin function indicates that magnetic volume of NPs increased when they were covered with $NiFe_2O_4$ but not changed if the shell was NiO.

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Synthesis of Ferritic Ceramics $BaFe_{(11,9-x)}Mn_{0,1}Ti_xO_{19}$ by Solid-Phase Reaction

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Ferrite ceramics with the composition $BaFe_{(11.9-x)}Mn_{0.1}Ti_xO_{19}$, where x = 0.1, 0.5, and 1 with the magnetoplumbite structure, have been obtained for the first time by sold state reaction. The physicochemical parameters of the synthesis have been worked out. Studies have shown that the optimum temperature for the solid-phase reaction is 1400°C. Isothermal holding time is 5 hours.

Figure 1 shows the X-ray diffraction curves of the samples under study. Vertical lines indicate literature data [1]. The coincidence of the positions and intensities of the reflections given in the literature and in the experimental spectra indicates that the obtained samples's structure coincides with the barium hexaferrites structure. Samples are monophasic. It was found that the parameters of the unit cell have a non-monotonic character of change with an increase in the iron substitution's degree. Probably, this may be due to the irregular distribution of substitutional elements over iron positions at low concentrations.

Figure 2 shows DSC curves recorded at a heating rate of 10°C. It can be seen from the figure that a thermal effect arises on all samples, the temperature and intensity of which monotonically decreases with an increase in the degree of substitution with titanium. An increase in the concentration of substituting manganese and titanium atoms leads to a decrease in the Curie temperature. This is due to a decrease in the forces of exchange interaction when iron is substitution by titanium and manganese.

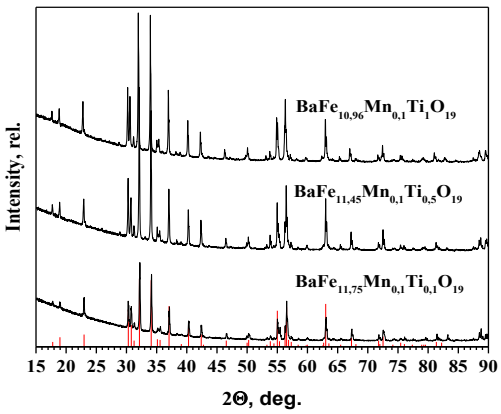

Fig. 1. Powder X-ray diffraction patterns for synthesized samples

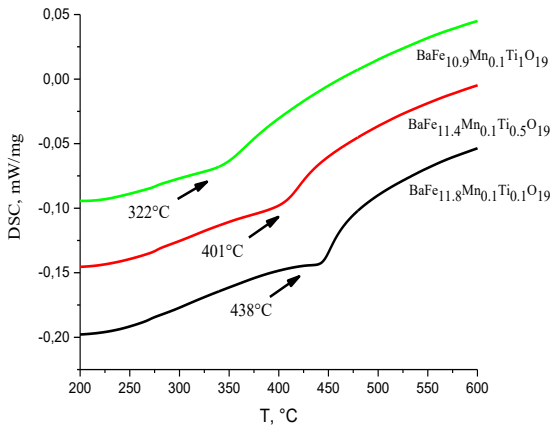

Fig. 2. DSC curves of the samples and Curie temperature

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Properties and segregation tendency of Fe-Rh-Z (Z=Pt, Pd) alloys

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Fe-Rh-based alloys have attracted a lot of attention because of their possible application in magnetic cooling, thermally assisted magnetic recording and spintronic devices [1-3]. Fe-Rh alloys exhibit a metamagnetic phase transition (AFM-FM). The metamagnetic phase transition in Fe-Rh succeeds also the large change in magnetization, which is responsible for a giant magnetocaloric effect upon variation of a magnetic field. It well known, that the magnetic order in FeRh compounds depends strongly on the concentration. Properties and segregation in a series of Fe-Rh-Z (Z=Pt, Pd) alloys is studied by first-principles calculations.

The properties of Fe-Rh-Z alloys are investigated by using the density functional theory calculations as implemented in the VASP package. The ab initio calculations have been carried out by using the 16-atom supercell approach with different initial spin configurations. The energy calculations were performed for the supercell. Calculations were carried out for ferromagnetic and three kinds of antiferromagnetic states.

The equilibrium lattice parameters a = 3.012 Å for $FeRh_{1-x}Pd_x$ (x = 0.5) up to 3.05 Å for $FeRh_{1-x}Pd_x$ (x = 1). It can be concluded that the addition of Pd atoms leads to an increase in the lattice equilibrium parameter due to the larger atomic radius of Pd compared to the lower Rh value.

Let us first consider an analysis of the stability for Fe-Rh-Z (Z=Pt, Pd) compounds under study. One minimal criterion of the crystal structure stability is the formation energy E_{form}, which can be calculated as the difference between the alloy's ground-state energy and the energies of the individual elements in their respective ground states. We find that the formation energies of all alloys are negative, meaning that they are stable in a cubic structure against decomposition into their elemental constituents.

This work was supported by RSF-Russian Science Foundation No. 17–72–20022.

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The voltage response of a structure comprising a magnetoactive-elastomer cylinder and a piezoelectric material to magnetic field step excitations

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In traditional (layered) magnetoelectric (ME) heterostructures, it is the mechanical strain that mediates the ME coupling between the magnetic and the electric phases. We utilize the same idea and investigate in detail the voltage response in an unconventional structure shown in Fig. 1. Such a design is proposed for the first time. The structure contains a magnetoactive elastomer (MAE) cylinder. This MAE is a composite material consisting of micrometer-scale iron particles embedded into a soft polymer matrix. If a MAE cylinder is placed into a magnetic field parallel to its axis, it elongates [1] and exercises pressure on a piezoelectric (PE) bimorph ring, leading to its deformation. As a result, an electric voltage arises between the electrodes of the PE material. This phenomenon can be considered as a manifestation of the direct ME effect in the MAE-PE structure.

The bimorph ring has a thickness t of 400 µm and the outer and inner diameters of 40 mm and 10 mm, respectively. A MAE cylinder has a height of 6.2 mm and a diameter of 15 mm. The particle concentration p is 80 mass%. The shear modulus of the MAE material in the absence of a magnetic field G_0' is about 40 kPa. A plastic cone is attached to one base of the MAE cylinder and the entire arrangement is fixed in a specifically designed measurement cell. The cone is pointing towards the PE bimorph, rigidly fixed at its rim to the measurement cell. The measurement cell is positioned between the poles of an electromagnet. The magnetic field having the maximum value up to $H = 420$ kA/m is switched on and off, creating step excitations of the structure. The induced voltage is recorded by a digital oscilloscope. The transient behavior and the magnetic-field dependencies of the voltage are obtained.

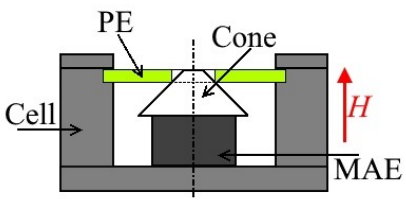

Figure 9. Schematic diagram of the cross-section of the investigated structure.

The amplitudes of induced voltages increase nonlinearly with the applied magnetic field and correlate with the deformation of the MAE cylinder. The maximum voltage value U of ≈ 4.2 V exceeds the voltage value obtained under similar conditions in [2]. Dependence of output voltage on sample parameters and different excitation conditions (e.g., pulse trains) is investigated.

The work is supported by a joint project of the RFBR (grant no. 18-502-12037) and the Deutsche Forschungsgemeinschaft (grant no. 389008375).

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Microstructure and electrical transport properties of nanoscale $[(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}/In_2O_3/C]_{46}$ multilayers

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Introduction

The explosive growth of spintronics technology has led to the study of multilayers (MLs) based on the ferromagnetic CoFeB alloy due to their remarkable tunnel magnetoresistance (TMR) and anomalous Hall effect [1]. In this paper, we investigate the microstructure and electrical transport properties of nanoscale $[(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}/In_2O_3/C]_{46}$ multilayers, where 46 is the number of repetitions of the three-layer structure.

Experimental methods

The MLs were obtained here by ion-beam sputtering of three targets in argon plasma with an operating pressure of about $5\cdot10^{-4}$ Torr. The first target was a plate of $Co_{40}Fe_{40}B_{20}$ amorphous alloy with SiO_2 quartz inserts placed above it. The second target was a In_2O_3 ceramic plate, and the third one was a graphite plate. The deposition was carried out on an unheated glass substrate. A *V*-shaped screen was placed between the target and the substrate to create a thickness gradient of nanocomposite layers and interlayers. The samples were studied by XRD on the DRON-4-07 diffractometer using CoK_α radiation. A ARL X'TRA diffractometer with a CuK_α radiation, Bragg-Brentano geometry, and three resolution-defining slits were employed for scanning the XRR profiles. The fitting of the experimental XRR data were performed into GenX to extract layer thickness, multilayer periodicity, and layer densities in the MLs [2]. The Ecopia HMS-3000 Hall Measurement System was used to study the specific electrical resistance and TMR of MLs at room temperature with a field strength of 0.51 T in the CIP geometry.

Results and discussion

The XRD data characterize the X-ray amorphous state of ferromagnetic clusters CoFeB, the dielectric component SiO_2 of metal-containing nanocomposite layers, and the In_2O_3 and carbon interlayers. The fitting of the XRR curves showed high values of the roughness of the MLs layers. However, the density of the nanocomposite layer $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ is in good agreement with the theoretical density of the composite of this composition (4.2 g/cm^3). The density of In_2O_3 interlayers is significantly lower than the density of bulk indium oxide (7.3 g/cm^3). The error in determining the density of In_2O_3 is due to the greatest ability, in comparison with other nanolayers, to form islands and their oriented growth. The density of carbon interlayers is in good agreement with the literature data for graphite (~2.1 g/cm^3). The measurement of the transport properties demonstrated that the specific electrical resistance of the MLs decreases with increasing thickness of the non-magnetic In_2O_3/C interlayers. Moreover, in the ML with the smallest In_2O_3/C interlayer thickness, the resistance is close to the value for the $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ layer. All samples showed the absence of TMR in CIP geometry.

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Magnetocaloric effect and magnetostriction of $GdH_{0.15}$ single crystal in the vicinity of the magnetic phase transitions

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The study of the properties of rare earth metals is of great practical importance, since by themselves, their alloys and compounds are widely used in all areas of modern technology. Gadolinium occupies a special place. This functional magnetic material with a Curie temperature close to room temperature (T_C = 293 K) is used in magnetic refrigerators. In a magnetically ordered state, the magnetic moment Gd is directed along the c axis; however, with decreasing temperature, a magnetic phase transition is observed (T_{SR} ~ 250 K), at which its deflection occurs. The aim of this work is to study the influence of hydrogenation on the magnetocaloric effect (MCE) and magnetostriction (MS) in the vicinity of the "order-order" and "order-disorder" magnetic transitions in a Gd single crystal.

The Gd single crystals were grown by a modified Czochralski method. The confirmation of the single-crystal state of the obtained sample, as well as its orientation along the main crystallographic directions, was carried out using the Laue method. The metals were hydrogenated using a Sievert-type setup without destroying the monocrystalline structure. The amount of hydrogen in the sample was 0.15 at.H/f.u. The magnetocaloric effect was measured by the direct method (adiabatic temperature change) using by MagEq MMS 901 setup, AMT&C, (Troitsk, Moscow) and also was calculated from the data on magnetization. The magnetostriction was studied by the strain-gauge method. All measurements were carried out in temperature range of 80-350 K in magnetic fields up to 12 -18 kOe.

The set of λ(H) isotherms was obtained for Gd and $GdH_{0.15}$ as a result of measuring the magnetostriction along the c and b axes of the single crystal with the external magnetic applied along the c axis and in the perpendicular direction. The magnetostrictive constants l_{ij}^a were calculated (E. Callen and H. Callen's method) based on the experimental data obtained.

For the hydrogen-charged Gd we found that MCE becomes anisotropic in the vicinity of the "order-desorder" phase transition while the parent Gd shows an isotropic MCE. The temperature dependences of the magnetostrictive constants are obtained. It was found that the introduction of even a small amount of hydrogen atoms into the gadolinium crystal lattice can have a significant effect both on the magnitude and sign of the MS constants.

Optically driven ferromagnetic resonance in easy-plane iron ferrite garnet films

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Epitaxial ferrimagnetic films of yttrium-iron garnet demonstrate a wide range of applications due to the high quality factor for radiofrequency, acoustic and other oscillations. The crystal lattice stability under various cation substitutions gives a possibility to adjust the physical properties of the material. For example, the cation substitutions provide a possibility to synthesize the (111) films with in-plane magnetization direction and these films find an application as sensitive materials for magnetic fields sensors.

Ferromagnetic resonance (FMR) spectra recorder in easy-plane ferrite-garnet films are reported in [1]. Due to the frequency range up to 1 GHz and low, up to 4 mT, in-plane magnetic fields the contribution of the second order cubic magnetic anisotropy into FMR frequency has been demonstrated. Through the frequency swiping to record FMR spectrum, the narrow lines caused by resonance modes of transverse elastic oscillations have been detected against the relatively wide FMR line.

The goal of present report is the photoinduced modification of FMR spectra detected in epitaxial ferrite-garnet film. We have used the same $BiY_2Fe_{4.4}Sc_{0.6}O_{12}$ sample as in the work [1]. The sample has been irradiated with laser light of wavelength 680 nm and power up to 50 mW during FMR spectrum recording. The laser beam directed normally to the film plane so that the light spot size is about sample size. The effect is best observed when external magnetic field directed along hard direction in film plane. The laser power increase leads to the increase the FRM frequency at the room temperature. The similar phenomenon that is FRM frequency increase induces sample heating. However, the thermally induced increase of FRM frequency takes place below about 350 K. The further heating on the contrary decrease the FRM frequency. The important peculiarity is the maximal increment of FRM frequency produced by sample heating is about triple less the photoinduced FRM frequency increment. The FRM frequency shift increases with light intensity and this shift doesn't depends on light polarization direction in (111) film plane.

We suppose that the observed phenomenon is probably caused by photo-induced modification of magnetic anisotropy. The magnetic field increase and corresponding increase of FRM frequency result the experimentally observed diminishment of photoinduced FMR frequency shift. These can be consider as an additional argue for anisotropy modification mechanism because magnetic field increase results in relative decrease of magnetic anisotropy contribution into FRM frequency.

The photoinduced FRM frequency shift in cation substituted epitaxial ferrite-garnet films is the phenomenon observable in low filed FMR experiments.

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Immobilization of cellulase enzyme onto iron oxide nanoparticles to improve thermal and pH stability

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Lignocellulosic enzymes have been used in the pretreatment and hydrolysis of the biomass, are getting special attention to produce the sustainable green biofuel. However, free enzymes not only difficult to separate from reaction media but also highly temperature and pH sensitive, so a controlled environment is required to maintain. A proper immobilization support material needs to adopt to improve their stability and reusability. In this research, cellulase immobilized magnetic nanoparticles were prepared to improve thermal and pH stability and reusability of enzyme.

The magnetic iron oxide nanoparticles (IONPs) were prepared by the chemical co-precipitation method and modified with 3-aminopropyl triethoxysilane (APTES) for amino functionalization. Glutaraldehyde was used as a cross-linker between enzyme and functionalized nanoparticles. The amino groups and aldehyde groups can form stable covalent immobilization that can improve the stability of immobilized magnetic nanoparticles.

The transmission electron microscopy (TEM) demonstrates spare shape nearly monodisperse nanoparticles with a size of 20±5 nm. After cellulase immobilization, a vibrating sample magnetometer (VSM) measured strong 62.8 emu/g magnetizations. Fourier-transform infrared spectroscopy (FTIR) confirmed the immobilization of cellulase onto nanoparticles The prepared nanomaterials demonstrate very high, 97% immobilization efficiency confirmed by the Lowry protein assay. The highest activity of immobilized cellulase was achieved at 40°C and pH 5. The immobilized nanoparticles exhibit 64% and 47% relative activity at higher pH and temperature, respectively. Immobilized cellulase relative activity was achieved 83% after five cycle of reusability study. Overall, the pH and thermal stability were improved, and higher reusability of enzyme immobilized nanomaterials was achieved.

Binder jet 3d printing templates for smart composites with pattern structures

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At the moment, methods of making smart materials and composites for creating biological scaffolds are being actively developed [1]. These methods are based on the use of volumetric polymer templates, which serve as a framework for creating the structure of the future composite. In the work [2], a model was proposed for increasing the magnetoelectric effect in nanocomposites based on polymers for use in biomedical applications. However, only a two-dimensional composite has been investigated, so this work proposes expanding the space of a polymer composite by modifying the manufacture of smart composites by additively printing patterns of different structures using binder jet 3d printing.

Thanks to this technology, it is possible to create accurate volumetric polymer models with high resolution. The frame is presented in the form of a substrate and a pattern of a structure designed in a CAD program. After printing, the layout can be used as a frame for the future scaffold of the required structure. In this work, templates with three patterns of structures were designed and three copies of each master model were made, which were subsequently used to create and study scaffolds for cell differentiation in vitro and investigated the development of cells in these scaffolads.

This work was supported by the Russian Science Foundation No. 21-72-30032.

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Simulation of sequential magnetization and demagnetization of magnetosensitive vesicles

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Magnetosensitive vesicles are closed submicron-sized amphiphilic membranes which are self-assembled with magnetic nanoparticles (MNPs). The prospects of such systems relate to the design of biocompatible remotely guided theranostic containers and nanosurgery tools since the inner site of the vesicle can be filled by bioactive content and double layer of the membrane is structured by the MNPs [1]. The crucial point on understanding of effective scenarios of applications is associated with methods of overcoming cellular membrane and initiation of drug release which are based on coupled magnetic, structural and mechanical response on applied magnetic field. In this sense it seems challenging a problem to use vesicles of modified morphologies (other than spherical) to produce non-uniform intramembrane MNPs rearrangement and shape changes. This contribution presents results of computer simulation of response of the vesicular magnetopolymer assemblies on applied increasing and then decreasing homogeneous magnetic field.

A model of magnetosensitive vesicle is based on coarse-grained “bead-spring” representation and implemented using ESPResSo software which is oriented on soft matter calculations [2]. The vesicle consists of two closed particulated shells which are assembled from the polymeric beads bonded by a set of interparticle potentials. The outer and inner shells constructed of this way in fact mimic the double-layered structure of the amphiphilic membrane: the beads inside of every shell are connected by linear elastic springs and angle harmonic potential to designate the stretching and bending properties. The beads of different shells are also connected by the system of springs to keep thickness of the membrane approximately the same. The intramembrane space is loaded by equal-sized MNPs which are assumed to be soft spheres coupling with each other via magnetic dipolar interaction. Soft repulsion also describes the interaction between the MNPs and polymeric beads, thus magnetic layer turns out to be locked inside the membrane (leaving of the MNPs through the polymeric wall is difficult). Based on spherical templates the developed computation tool allows to transform vesicle into non-spherical shape namely elongated spheroids and disc-like particles. All the beads are placed in a thermal bath according to Langevin thermostat [3]. The system is subjected to an external magnetic field strength of which initially increases up to defined value and then decreases to zero during step-by-step computational experiment. The obtained after simulation results includes analysis of MNPs aggregates rearrangements during the cycle of magnetization-demagnetization as well as vesicle shape and volume changes associated with this magnetostructural response.

The study was supported by a grant from the Russian Science Foundation (project No. 20-71-00045).

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Comparative analysis of PCM obtained by vacuum infusion and contact molding

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In order to assess the prospects of composite products manufactured by the method of vacuum infusion (VaRTM) [1], in comparison with composites obtained by the method of contact molding (CM), we carried out thermogravimetric studies, studies of the microstructure of the binder on a scanning electron microscope of samples made by the above methods, and a study of the VaRTM sample using a high-energy X-ray computational tomograph (VT-600XA).

Thermogravimetric study (Fig. 1) indicates a significant difference in the matrix / filler in the samples. In the VaRTM sample, the proportion of the matrix was 28.9%. This is due to the fact that contact molding does not provide sufficient molding pressure, which leads to an increase in the proportion of the binder in the composite material to 34.8%. In turn, this leads to a difference in the density of the obtained samples. Thus, the density of the CM sample is 20% less than that of the VaRTM sample.

Investigation of the microstructure of the binder on a scanning electron microscope (Fig. 2) indicates the presence in the CM samples of a significant number of pores with a diameter from 200 μm to 400 μm and reaching 1 mm in length. The packing density of fibers in composites differs significantly. In the VaRTM sample, the areas between the fibers filled with the matrix are from 10 to 40 μm, while when using the contact molding method, the packing density is much lower. Areas filled with matrix material reach 200 μm.

Tomographic scanning (Fig.3) showed that the spread in the values of the relative density (RMS) of the VaRTM sample is 9.1-9.7%. The density characteristics along the height of the sample are stable. Some leaks are observed, comparable to the thickness of the monolayer (0.01-0.03 mm).

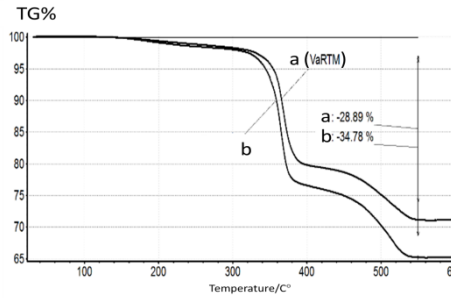

Figure 1 - Thermogravigram of composites obtained by methods *a (VaRTM) and b-contact molding*

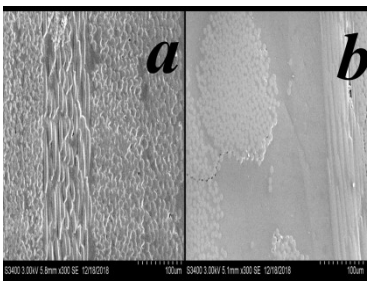

Figure 2 - Structures of composites obtained by methods:
a - VaRTM (x300), b - contact molding (x300)

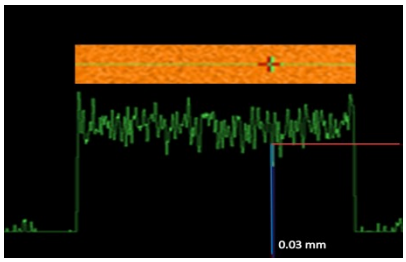

Figure 3. - Histogram of material looseness distribution along the selected section of the composite

The denser packing of the reinforcing material in the VaRTM composite contributes to an increase in its strength and a more even distribution of the load. The results obtained indicate that the production of composites by the method of vacuum infusion (VaRTM) is promising.

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Magnetic properties of the sintered hard magnet $Nd_2Fe_{14}B$ with amorphous and crystalline structures

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Neodymium magnets have found wide application in various industries due to the best magnetic characteristics and technological capabilities of making magnets of almost any size and shape. These magnets used to manufacture powerful microelectromotors, compact and high-quality microphones and speakers, powerful lifting mechanisms, and other equipment.

This work aims to study the magnetic properties of samples from hard magnetic alloys Nd2Fe14B obtained by spark plasma sintering [1]. Two series of cylindrical-type specimens with amorphous and crystalline structures with different sintering temperatures were obtained: diameter 10.3 mm, height 3-4 mm.

The results of the magnetic measuring are shown in Fig. 1. The different behavior of the magnetic characteristics from the sintering temperature is observed for samples with amorphous and crystalline structures.

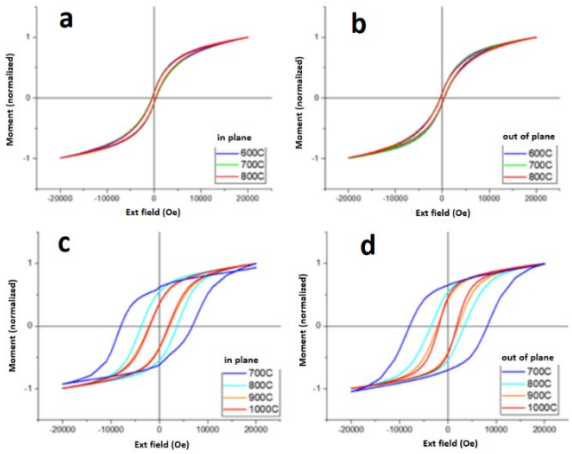

Figure 1. Dependence of the magnetic hysteresis loops from the ceramic sintering temperature. (a) amorphous alloy, the field is directed parallel to the axis of the ceramic plane, (b) amorphous alloy, the field is directed perpendicular to the axis of the ceramic plane, (c) crystalline powder, the field is directed parallel to the axis of the ceramic plane, (d) crystalline powder, the field is directed perpendicular to the axis of the ceramic plane.

Electron microscopic and magnetic studies have established that samples obtained from crystalline powder have better magnetic properties for permanent magnets at a sintering temperature of 700 C. The magnetic properties of crystalline powder samples show a clear dependence on the sintering temperature. At the high temperature of sintering, the reduction of coercive force and remanent magnetization is observed. Probably this reduction is a consequence of melting and sintering of grain boundaries and, thus, a decreasing of stresses and dislocation density.

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An estimation of magnetic properties of existing and prospective atomic chains in the framework of the Heisenberg Model

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The investigations of the magnetic properties of atomic chains are of general interest due to its possible applications in spintronics [1], creation of the next generation mass storage devices [2], quantum communications [3], and other fields [4] of research. For application of the atomic chains as bits of information, their reversal time of magnetization needs to be sufficiently long. The possibility of engineering of such memory elements appeared after the discovery of the giant magnetic anisotropy energy (MAE) of Co atoms on the Pt(997) surface. Ferromagnetic Co chains can grow on the step edges of Pt(997) surface at low concentrations of Co atoms. Another interesting opportunity is use of finite-sized antiferromagnetic chains as bits of information. The possibility of creating and remagnetization of such chains using STM was demonstrated for Fe atomic chains on Cu_2N/Cu(001) surface.

A lot of theoretical investigations have been devoted to ferromagnetic and antiferromagnetic finite-sized chains. For example, the kinetic Monte Carlo (kMC) method [5] allows calculating the critical temperature, the reversal time of magnetization, and the coercive field of ferromagnetic chains. Recently, the simple analytical method [6] for the investigation of the magnetic properties of the finite-length atomic and biatomic chains has been developed in the framework of the Heisenberg model with uniaxial magnetic anisotropy. The method allows estimating the reversal time of magnetization of ferromagnetic and antiferromagnetic atomic and biatomic chains in the cases of the spontaneous remagnetization, the remagnetization under the interaction with a STM tip, and the remagnetization under the external magnetic field.

In the present investigation we use the analytical method [6] for estimation of magnetic properties of a wide range of ferromagnetic and antiferromagnetic atomic and biatomic chains. First of all we discuss the atomic and biatomic chains which have been created experimentally. The prospective atomic chains which can be created in future are also under discussion. As a result, we make some conclusions about the possible applications of atomic and biatomic chains.

The research is carried out using the equipment of the shared research facilities of HPC computing resources at Lomonosov Moscow State University [7, 8]. The investigation is supported by the Russian Science Foundation (Project No. 21-72-20034).

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Investigation of accelerated motion of domain wall in a bistable ferromagnetic microwire

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Currently much attention is paid to the unique properties of ferromagnetic bistable microwires in a glass shell, manufactured by the Ulitovsky-Taylor method [1]. Due to their size, microwires are an extremely promising material for the development and creation of magnetic memory elements [2]. The speed of magnetic devices based on microwires directly depends on the rate of remagnetization of these microwires, therefore, one of the main goals of the study of microwires is to find ways to speed up this process.

The process of remagnetization of a bistable microwire is carried out by the motion of the domain wall [3,4]. The micron geometrical dimensions and the amorphous state of the metal core of the microwire do not allow studying the features of the micromagnetic structure and its change in an external magnetic field. Accordingly, most modern research in this direction is focused on studying the dynamics of motion of domain walls in the process of microwire remagnetization. The Sixtus-Tonks method is a classical method for measuring the velocity of motion of a domain wall depending on the magnitude of the external magnetic field [5].

The method for determining the type of motion of a domain wall in the process of remagnetization of bistable ferromagnetic microwires was based on sequential measurements the field dependence of the velocity of motion the domain wall in different pieces of the wire. To detect acceleration, a series of receiving coils (from three to five) were used instead of the two receiving coils that are used in the classical method.

In the investigation, three types motion were observed: accelerated, uniform and decelerated motion of the domain wall in microwires with metallic core compositions $Fe_{77,5}Si_{7,5}B_{15}$, $Fe_{77}Si_{10}B_{10}C_3$, $Fe_{47,42}Ni_{26,6}B_{12,99}Si_{11}C_{1,99}$ with different diameters. It was found that the type of motion of the domain wall is not determined by the composition or diameters of metallic core or the microwire, but by the distribution of the fields of nucleation of the domain wall (the distribution of local defects of various nature along the length of the microwire).

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Angular dependences of magnetization and coercivity in nanoheterogeneous magnetic materials SmCoCuFeZr

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Understanding of coercivity mechanisms in hard magnetic materials is a pressing challenge [1, 2]. Micro- and nanoheterogeneous SmCoCuFeZr alloys consist of two basic structural components to SmM_5 and Sm_2M_{17} type (M = Co, Fe, Cu) [3]. After special thermal processings in components of alloys it is formed ordered nanostructure, providing high coercivity and temperature stability of magnetic properties. Investigations of angular dependences magnetization and coercivity of these alloys were carried out.

For realization of a high coercivity state alloys were exposed homogenizing at 1170–1190ºC during 3–6 hours and isothermal annealing at 800ºC during 2–24 hours. The further cooling was carried out by two ways: hardening up to room temperature or slow cooling up to 400ºC. Such variation of heat treatment has allowed realizing a wide spectrum of coercivity values of the investigated alloys.

The revealed features of the magnetization reversal of SmCoCuFeZr alloys are discussed in the model of a mixed mechanism of magnetic hysteresis: irreversible rotation of the magnetization vector in the central regions of the cells and pinning of the domain wall to the boundary phase of the cells.

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Comparison of the microstructure and magnetic properties of films and composite powders based on 3-d metal

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In recent years the area of curvilinear magnetism has attracted much attention motivated by promising potential applications in the area of magnetoelectronics, spintronics, magnonics. The curved geometry of novel materials can cause a range of fascinating geometry-induced effects on the magnetic properties of materials [1]. Here we present the results of comparison studies samples with planar and sphere geometry: Co(P), CoNi(P), Ni(P) single-layer films, Co(P)/CoNi(P), Co(P)/Ni(P) multilayer films (2D grain packing), ultradispersed Co(P), Ni(P), CoNi(P) powders, and composite Ni(P)/Co(P) layered powders (3D grain packing).

The samples were synthesized by the chemical deposition method, which allows controlling phosphorus content in samples. All films have an fcc nanocrystalline structure with a P content of 7%. The crystallites of the single layer for the multilayer films have a thickness comparable to the layer thickness (1-10 nm), with a diameter in the plane of the layers several times more. The synthesized particles have a spherical shape with a diameter of up to 1 μm. In composite Ni(P)/Co(P) core-shell powder, Co(P) particles form a continuous layer with a two-dimensional spatial packing of grains with thickness ~ 0.2 μm. It is found that the Co(P) shell structure is determined by Ni(P) core composition. The magnetic characteristics of the samples under study show the features of two-dimensional magnetism. Ferromagnetic resonance (FMR) spectra of powders demonstrate one broad absorption peak with a resonance field characteristic of spherical particles. For multilayer Co(P)/CoNi(P) films with a parallel orientation of the FMR spectrum, the spectrum consists of two narrow absorption lines corresponding to the Co(P) and CoNi(P) layers. Spin-wave resonance spectra were observed for the films in the perpendicular orientation. The films are low-coercive as a plane of easy magnetization. The line width ΔH of the FMR spectra and the coercive force H_c of multilayer films are practically independent of the layer thickness. The values of ΔH and H_c for powders are several times higher than those for films. For one-component powders with a phosphorus concentration of 7%, the ΔH and Hc values are also weakly dependent on the particle size. The qualitative behavior of local anisotropy field H_a concentration dependence for powders isn't coinciding with the analogy dependences ΔH and H_c. This indicates the presence of several competing contributions to the magnetic anisotropy of the samples. The main contribution to ΔH and H_c for powders and films is made by the shape anisotropy of individual crystallites. In this case, the dipole-dipole interaction between structural parts makes a significant contribution to the magnetic properties of the films. The change in H_a of powders is due to a change in the relative thickness of the surface layers of particles and the contribution of magnetocrystalline anisotropy.

The research was funded by RFBR, Krasnoyarsk Territory and Krasnoyarsk Regional Fund of Science, project number 20-43-240003.

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Correlation of chemical composition and magnetic properties in the (Ni-Zn-Co)Fe_2O_4 system

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Samples of nickel-zinc-cobalt ferrite with the general formula $Zn_{0.3}Ni_{0.7-x}Co_xFe_2O_4$ (x=0-0.7) were prepared. Solid-phase synthesis was chosen as a method of obtaining the material. The sintering process was carried out at a temperature of 1150 °C for 5 hours. As a result of the study on a SEM Jeol JSM 7001F equipped with an Oxford INCA X-max 80 the actual sample formulas were calculated. The data about phase composition and lattice parameters were investigate on powder X-ray diffractometer Rigaku Ultima IV. X-ray phase analysis showed that all prepared samples are monophasic and have a spinel structure. Due to the fact that Zn and Co atoms have different ionic radii, when Zn atoms (r (Ni^{2+}) = 0.49 Å) are replaced by Co atoms (r (Co^{2+}) = 0.58 Å), the crystal lattices - the growth of unit cell parameters.

The Curie temperature was determined on a Netzsch STA 449 F1 Jupiter differential scanning calorimeter (DSC) in platinum crucibles in an argon atmosphere. Fig. 1 shows DSC curves of samples. Figure shows that in the temperature range 200 - 600 °C, all samples have an endothermic process. The inflection point of the DSC curve corresponds to the temperature of the ferromagnet/paramagnet phase transition. The measurements of magnetic properties were carried out using a vibrating sample magnetometer Lakeshore 7400 series in the magnetic field range of ±16 kOe at room temperature (see fig. 2). As a result, the following conclusions were obtained: substitution by ions of cobalt cations leads to a decrease in the Curie temperature. Substitution of cobalt cations for nickel cations leads to an increase in saturation magnetization, remanent magnetization, and coercivity.

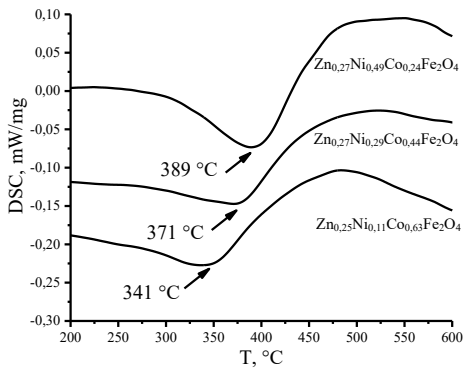

Fig. 1. DSC curves of the samples

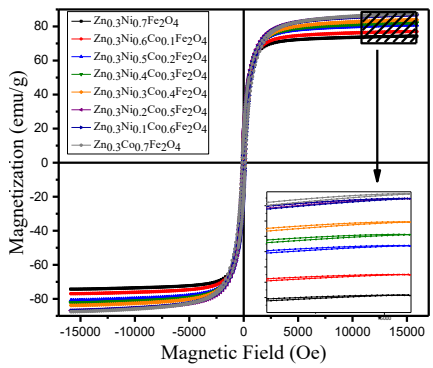

Fig. 2. Field dependences of the specific magnetization of ferrites at T =300K

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ESR studies of the magnetic properties $Mn_{0.325}Hg_{0.675}Te$

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Compounds of solid solutions of mercury and manganese tellurides attract increased attention of modern researchers. Objects belong to the class of topological insulators and to the Weyl semimetals [1], show a large positive g-factor [2]. In single crystals of *p*-$Hg_{0.74}Mn_{0.26}Te$ the authors indicated the existence of magnetic polaron complexes [3, 4].

The aim of this work was to study the magnetic and transport properties of the $Mn_xHg_{1-x}Te$ (x=0.325) monocrystals by magnetic resonance method. It were obtained electron concentration n=+1.1×10^{16} cm^{-3} (500 Oe), +1.2×10^{16} cm^{-3} (15000 Oe); resistivity ρ = 2.05 Ω·cm, mobility μ = 2.8 × 10^2 $cm^2 \cdot V^{-1} \cdot s^{-1}$ for the sample at 77K. The electron spin resonance (ESR) spectra has been recorded using E12 spectrometer (Varian) in X-band at 9.4 GHz. Measurements have been performed at the temperature 4.2 K and at the magnetic fields varying from 0 to 10^4 Oe. Angular dependencies of ESR spectra are presented in Fig. 1 for single crystals $Mn_xHg_{1-x}Te$ (x=0.325).

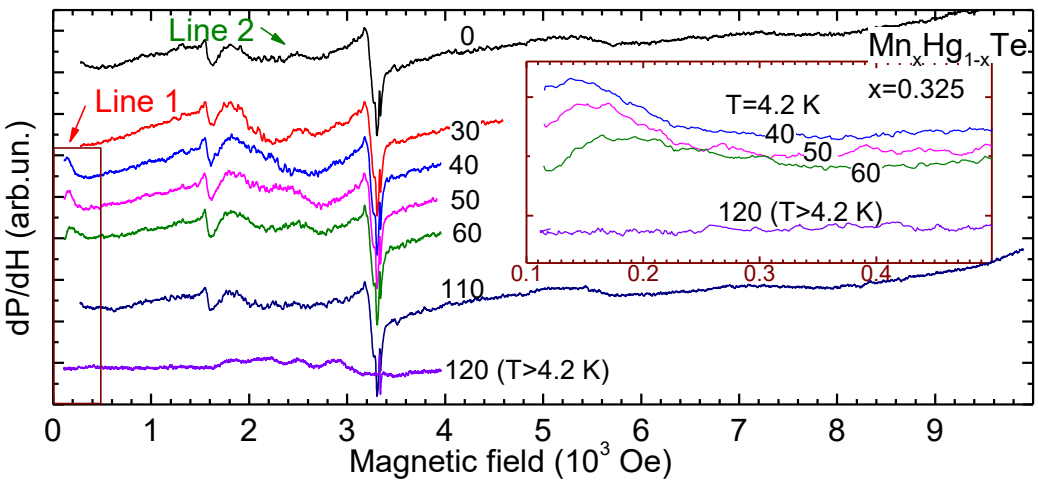

Fig. 1. Angular dependencies of ESR spectra in $Mn_xHg_{1-x}Te$ (x=0.325) at 4.2K.

The angular dependence of ESR line was presented in Fig.1. As shown in Fig.1, there is one line probably due to magnetic polaron with effective g≈35. The ESR line with g≈2 connected with spins Mn^{2+} ions with strong antiferromagnetic the interaction between spins. In magnetic fields above 5×10^3 Oe, broad lines (oscillations) are observed.

At temperatures above 4.2 K the lines did not observed.

The nature of the exchange interactions between the spins of the charge carriers and the spins of the manganese ions is discussed.

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Magneto-optical biosensor based on Au_3Fe_{1-x} hybrid nanocrystals for lung cancer detection

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Nowdays, biosensors based on magneto-optical and plasmonic effects are used to detect oncological biomarkers. The combination of ferromagnetic and noble metals makes it possible to obtain nanostructures of intermetallic compounds that simultaneously exhibit plasmon resonances and magneto-optical activity. The strong magneto-optical effect of a ferromagnetic metal leads to a sharper spectral line shape, which leads to an improvement in the detection limit. Instead of controlling the reflection coefficient magneto-optical biosensors (MOSPR biosensors) measure the transversal magneto-optical Kerr effect (TMOKE) upon the excitation of the SPR mode [1]. The position of the resonance feature strongly depends on the refractive index of the dielectric medium, which makes it possible to use it for the optical detection of various analytes. Small changes in the refractive index will cause large changes in the magneto-optical response, which will significantly improve the sensitivity of the MOSPR biosensor.

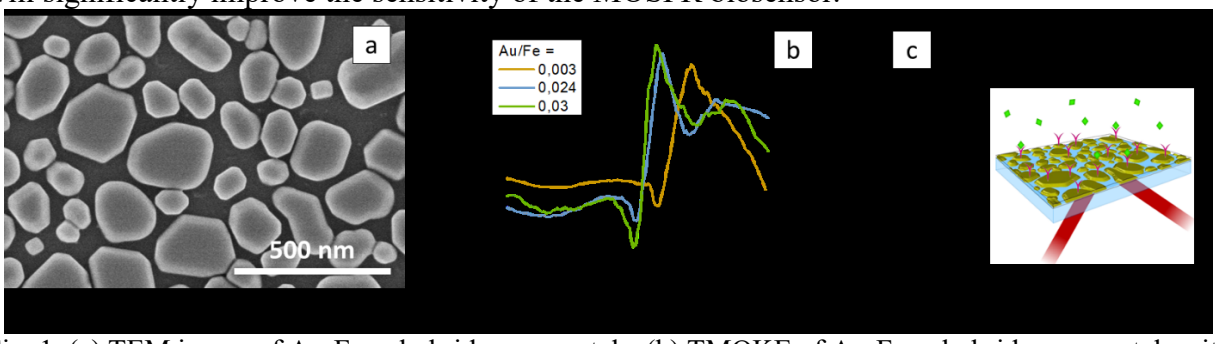

Fig. 1. (a) TEM image of Au_3Fe_{1-x} hybrid nanocrystals; (b) TMOKE of Au_3Fe_{1-x} hybrid nanocrystals with different Au/Fe ratio; (c) MOSPR-sensogram of adenocarcinoma proteins detection

To create a sensitive medium for a magneto-optical biosensor MBE synthesized Au_3Fe_{1-x} hybrid nanocrystals (Fig. 1(a)) demonstrating a strong magneto-optical effect were used (Fig. 1(b)) [2]. Thiol-modified aptamers were used to detect proteins of adenocarcinoma. Detection was carried out using geometry with the dependence of the magneto-optical parameter (TMOKE) on the photon energy of incidence of emission (Fig.1 (c)). Thus, ensembles of intermetallic compounds Au_3Fe_{1-x} modified with lung cancer aptamers acting as ligands were used as a sensitive element for a MOSPR biosensor to detect proteins of adenocarcinoma of lung cancer.

Acknowledgements

The work is carried out with the assistance of Krasnoyarsk Regional Center of Research Equipment of Federal Research Center «Krasnoyarsk Science Center SB RAS» and supported by the Russian Foundation for Basic Research to the research project No. 20-32-90134.

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Surface modification of Magnetite nanoparticles for their applications

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Magnetic nanoparticles (NPs) are widely studied and are considered a very promising material for modern technologies such as nanomedicine, magnetic separation, catalysis, etc.

Various synthesis methods lead to a wide variety of properties of the obtained NPs. Therefore, the study of particles obtained by a certain method, the determination of their properties and the search for applications remains an urgent task and requires research in each specific case.

The morphology, magnetic, optical and magneto-optical properties of the obtained hybrid nanoparticles have been studied. The adsorption properties of nanoparticles for the removal of cationic and anionic dyes from aqueous solutions have been investigated.

The work is a generalization of studies of magnetic Fe3O4 nanoparticles synthesized by the method of thermal decomposition with surface modification with various materials (PEG, SiO2, C and oligonukleotides), depending on the ligands used, the most preferable option for the practical use of nanoparticles is considered.

The crystal structure of the NPs were characterized by X-ray diffraction measurements using a Bruker D8 Advance diffractometer (Cu Kα radiation, 40 kV, 25 mA, $\lambda = 1.5418$ Å).

The morphology, microstructure and local elemental composition of the NPs were investigated using transmission electron microscopy (TEM). TEM experiments were performed with a JEM-2100 (JEOL Ltd.) microscope operating at the accelerating voltage of 200 kV. The microscope was equipped with an Oxford Instruments energy dispersive spectrometer (EDS) used to determine the elemental composition of the samples. JEOL JEM-1230 microscope operated at an accelerating voltage of 80 kV was used also in the Precision Instruments Center of NPUST.

The FTIR spectra of synthesized NPs were measured with a FT/IR-6700 spectrometer (Jasco).

Magnetic properties were measured by a vibrating sample magnetometer (Lakeshore 7400 series VSM).

The absorption spectra were recorded with UV/Vis circular dichroism spectrometer SKD-2MUF (OEP ISAN). The dye concentrations were determined by measuring the absorbance at the maximum adsorption of dye. The quartz cells with optical path length of 5 mm were used.

The excitation and fluorescence spectra were measured on a Fluorolog 3–22 spectrofluorometer (Horiba Jobin Yvon).

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Partial measurements were carried out at the Krasnoyarsk Regional Center of Research Equipment of Federal Research Center "Krasnoyarsk Science Center SB RAS"

Impact of Al^{3+} ions on magnetic and microwave properties of BaM:Ti hexaferrites

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Single phase bisubstituted hexagonal barium ferrite with the general formula $BaFe_{11.5-x}Ti_{0.5}Al_xO_{19}$ (where x varies in the range of 0.1-3) was obtained by solid-phase synthesis for the first time. Iron oxides Fe_2O_3, aluminum Al_2O_3, titanium TiO_2, and barium carbonate $BaCO_3$ were chosen as the initial components for preparing the charge. Sintering was carried out at a temperature of 1400°C for 5 hours.

The synthesized samples formulas were calculated according to the data of energy-dispersive spectroscopy using an Oxford INCA X-max 80 EDX analyzer installed on an SEM Jeol JSM 7001F electron microscope.

The phase composition of the samples was studied on a Rigaku Ultima IV powder X-ray diffractometer. X-ray phase analysis showed that all prepared samples were single phase and have the structure of barium hexaferrite. Iron substitution with Al^{3+} ions reduces the unit cell parameters value in the crystal lattice. This change is due to the fact that Fe and Al atoms have different ionic radii ($r(Fe^{3+}) = 0.645$ Å and $r(Al^{3+}) = 0.535$ Å) [1].The magnetic properties of the obtained samples were measured using a Versa Lab Quantum Design magnetometer. Figures 1 and 2 show the curie temperature, saturation magnetization, and coercivity dependences on the aluminum substitution degree. The aluminum substitution degree increasing leads to a monotonic decrease in the curie temperature (Fig. 1) and saturation magnetization (Fig. 2). In this case, the value of the coercivity increases (Fig. 2).

The reported study was funded by RFBR (project number 20-38-70057). Additionally D.A.V. thanks system of President's grants for young doctors of science (MD-5612.2021.4) for putting facilities at the author's disposal.

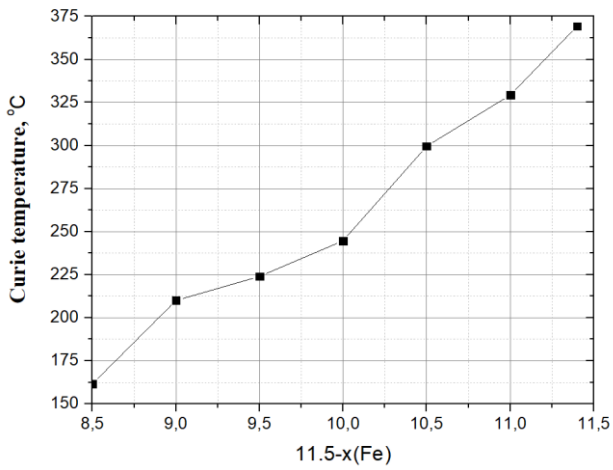

Fig. 1. The dependence of the Curie temperature on samples composition (where x - Al^{3+} substitution level)

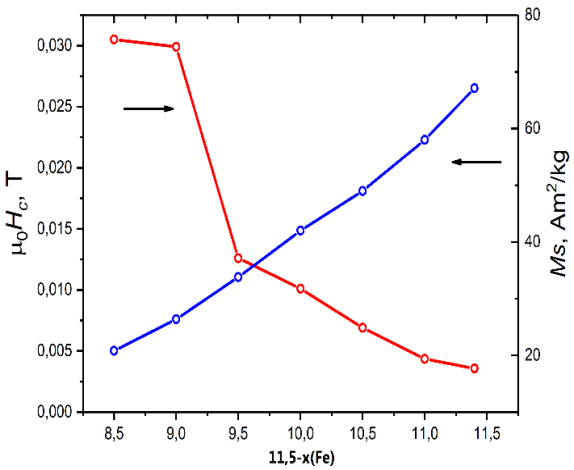

Fig. 2. The dependence of Hc и Ms on samples composition (where x - Al^{3+} substitution level)

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Investigation of the properties of Titanium substituted Barium Hexaferrite

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The aim of the presented work is to study the properties of the obtained by solid synthesis reaction titanium substituted barium hexaferrite.

Due to specific crystal structure with several cation positions different in coordination, the $BaFe_{12}O_{19}$ type ferrites are characterized by great capacity for the accommodation of different metals at high doping levels that provides a possibility for wide tuning of physical properties by cation substitution. Hexagonal ferrites from the $BaFe_{12}O_{19}$ family are highly attractive for the application in microwave technology due to high chemical and thermal stability and strong magnetic anisotropy [1]. Most studies have only focused on substitution by several elements rather than substitution by only one element [2]. In this work, titanium is used as the substitute material. $BaFe_xTi_xO_{19}$ (x=0.5, 1, 2). Synthesis method is solid state reaction. Analysis: XRD, VNA.

Analysis of these results reveals that:

- All diffraction peaks are attributed to the $BaFe_{12}O_{19}$ phase [3] that verifies the formation of the solid solution $BaFe_{12-x}Ti_xO_{19}$ at least up to x = 2 (Fig. 1)
- Increase of Ti content induces the dielectric permittivity increase up to 6.2 at x = 0.5-1 and up to 10.5 at x = 2 (Fig. 2)

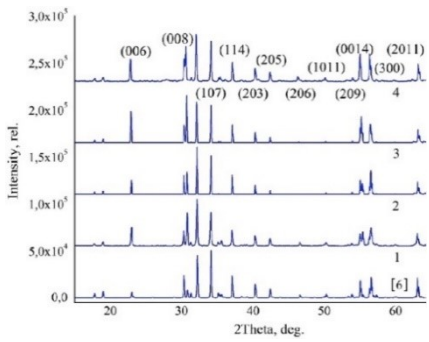

Fig. 1. Powder X-ray diffraction patterns for synthesized samples x=0 (1), x=0.5 (2), x=1 (3), x=2 (4)

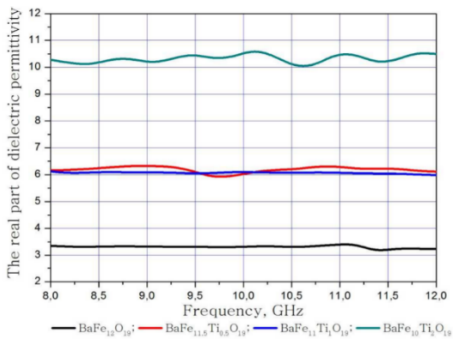

Fig. 2. Dependence of real part of dielectric permittivity on frequency

The results of the produced work on the production of substituted M-type hexaferrite and analyses of published data on the preparation, composition, and structure of modified hexaferrites allows to consider that: Ti-doping of $BaFe_{12}O_{19}$ strongly increases the dielectric loss tangent and, respectively, the $BaFe_{12-x}Ti_xO_{19}$ solid solutions can be used for creation of efficient absorption layers in the microwave range.

The reported study was funded by RFBR (project number 20-38-70057). Additionally, the project was supported President's grants for young doctors of science (MD-5612.2021.4).

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Magnetoactive elastomer as a multifunctional material

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Investigations of magnetoactive elastomers carried out over years have unveiled the fact that these materials possess multiple properties based on a strong relationship of their parameters with external magnetic field. The existence of this dependence is at the root of the multiplicity of names to characterize the composites, namely magnetorheological elastomers, magnetic gels, magnetoelastics, magnetocontrollable elastomers, etc. Whereas some of the properties got a description during the Plyos Conference [1], the number of newly discovered ones continues to grow. At present, the following phenomena exhibited by magnetoactive elastomers attract the most interest.

Magnetorheological effect. It is the most extensively studied property of the material. Essentially, it features the capability to vary the viscoelastic parameters under the influence of magnetic fields. In a field of 600 mT, the relative viscoelasticity of a sample being at small strains increases by 2-3, or even higher, orders of magnitude. At the same time, the absolute elasticity changes by an increment of about 10 MPa. This property may be used in designing controllable damping units.

Another property of high importance is magnetodeformation. This phenomenon was intensively studied by M.Zrínyi starting from 1996. Influenced by a magnetic field, a sample of magnetic elastomer stretched by 100-300% and bent. This feature may find use in robotics in designing soft-gripping devices, microactuators, and magnetic worms, which are capable of moving under the influence of magnetic fields. Meanwhile, in homogeneous fields, the material may exhibit magnetostrictions with magnitudes of up to 10%; such a giant effect can take place under moderate pressures around 10-20 kPa, however.

The shape memory effect is one more interesting feature, exhibiting which an elastic sample placed in a magnetic field retains the shape after the deforming force is off. Becoming plastic, the material somewhat resembles clay.

Magnetoresistance and the magnetodielectric effect, manifesting themselves when a sample influenced by a magnetic field varies its conductivity by 2 or more and its dielectric loss tangent by 1 order of magnitude, has been studied quite extensively. Under the simultaneous action of magnetic field and hydrostatic load, the material exhibits magnetopiezoresistance, an effect manifesting itself via a superadditive increase of the electric conductivity. In multiple states the material conducts electric current according to the tunneling mechanism with parameters also controllable by means of field strength. Depending on the intensity of the influence, magnetic elastomer may be either a non-conductor, semiconductor, or conductor, for practically the entire set of its properties is determined by the structuring of magnetic particles inside the polymer. Whereas in the case of a magnetically soft filling material, its structuring is reversible, introduction of magnetically hard particles results in forming structures irreversibly. At the same time, variation of external field results in complex structural rearrangements accompanied by the formation of ring-like structures inside the polymer matrix.

The research is supported by the RFBR, grant #19-53-12039, and the DFG, grant # Bo 3343/3-1

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Modeling and simulation of the magnetic domains evolution in Heusler alloys

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Heusler alloys belong to the class of functional (smart) materials. They can change their shape and size under the action of an external magnetic field and restore them as a result of reverse phase transition, which can also be controlled by the magnetic field, yet of much higher magnitude. In the martensitic state, these alloys form a lot of magnetic domains with differently directed magnetization vectors. Energetically, these domains are in the state favorable for correlating with each other, so that the total magnetization of the material in the absence of external magnetic field is close to zero. When applying such a field, the walls of magnetic domains begin to move, the magnetization vectors rotate, and the reorientation of martensitic variants takes place.

We model the behavior of such a material in an external magnetic field using a microstructural approach based on the general theory of micromagnetism, which goes back to the work of Brown [1]. At a temperature much lower than the Curie temperature of the material under consideration, the magnetization is described in terms of the time and space dependent vector field of spontaneous magnetization **M**, which has a constant length. We analyze the possibilities of using two approaches to describing the behavior of such material in an external magnetic field. The first one is based on minimization of total magnetic energy with account of limitations imposed on the spontaneous magnetization vector and scalar magnetic potential. The free energy density consists of four micromagnetic energy contributions, namely the Zeeman (or external) energy, the demagnetization energy, the exchange energy and the magneto-crystalline anisotropy energy. Another approach is based on describing dynamic of the process using the Landau — Lifshitz — Hilbert equation.

We have considered the problems of magnetization of single martensite variant using the first approach and twinned martensite using the second approach. The solutions to these boundary value problems were obtained numerically by the finite element method using the FeniCS package. The evolution of the magnetic structure was investigated (the motion and interaction of 180-degree magnetic domain walls when an external magnetic field was applied in different directions). The mean value of the projection of the magnetization onto the axis along which an external magnetic field was applied is considered as macroscopic parameters. The magnetization curves were obtained in the external magnetic field directed at different angles to the anisotropy axis.

This work was fulfilled under financial support of the Russian Foundation for Basic Research through Grant 20-01-00031.

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Enzyme-free electrochemical immunoassay and microfluidic immunochip based on magnetite nanoparticles for determination of clinically significant analytes

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High-tech healthcare and personalized medicine are today the priorities of the development in the Russian Federation. Traditional laboratory methods of medical diagnostics are replacing by portable sensory devices for the determination of a wide range of clinically significant analytes. The unique combination of ultraselectivity of the immunoreceptor and high sensitivity, accuracy, expressiveness of electrochemical methods allows to successfully apply electrochemical immunosensors to the analysis of a wide range of objects with a complex sample matrix and ultra-small operating volumes.

The increase in the sensitivity and accuracy of immunoassay is achieved through the use of labels. Enzyme labels often used for this purpose are expensive and unstable. Original enzyme-free methods, sensors and chips for immunodiagnostics of pathogenic microorganisms and viruses based on Fe_3O_4 nanoparticles/nanocomposites is actively developing at the Department of Analytical Chemistry, Institute of Chemical Technology UrFU. Magnetite nanoparticles synthesized with co-precipitation method are used as a labels and agents for magnetic separation and concentrating. The analytical signal was the reduction current of Fe (III) ions obtained after dissolution of immunocomplexes containing nanoparticles [1], the oxidation-reduction current of electrochemically active organic coatings based on polypyrrole, quinoline modified polyvinylbenzyl chloride, SiO_2 modified with ferrocene [2], or the oxidation current of previously reduced nanoparticles in an aprotic medium [3,4].

The morphology, surface properties of magnetite nanoparticles, the formation of organic coatings and the electrochemical reactions in water and aprotic solutions have been studied in details. The developed methods and sensors in sensitivity and accuracy of detection surpass the capabilities of the traditionally used enzyme immunoassay methods. The development and practical application of label-free/non-reagent sensors and microfluidic chips contributes to the reduction of time, material and labor costs, as well as the miniaturization and automation of measurements. The construction of microfluidic immunochip for bacteria detection using magnetic nanoparticles as tracers and labels was also proposed.

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Hard/soft magnetic bilayer and trilayers. Monte Carlo study

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In 1991, it was proposed to produce permanent magnets with alternating hard and soft magnetic layers which resulted in the maximum energy product $(BH)_{max}$ [1] increase, as well as to the discovery of a very interesting phenomenon: the reversibility of the magnetization reversal curve (exchange-coupled behavior) [2]. This phenomenon is called a spin spring by analogy with the mechanical properties of solid bodies under elastic deformation. All this has led to the fact that the technological significance of these materials has acquired a new level: the production of permanent magnets with record values $(BH)_{max}$, the use as fast acting attenuators, magnetic sensors, advanced media storage with a high recording density, etc.

In the most of hard/soft magnetic heterostructures there is strong in-plane anisotropy and magnetic moments lie in plane of bilayers [2]. Therefore, field properties of magnetic hard/soft heterostructures can be estimated using a simple model integrating the standard XY-model [3-6]. The total energy of the system is represented as :

$$E = -\frac{1}{2}\sum_{i,j} J\left(S_i^x S_j^x + S_i^y S_j^y\right) - \sum_i K\left(S_i^x\right)^2 - g\mu_B \sum_i \left(H^x S_i^x + H^y S_i^y\right), \qquad (1)$$

where the first sum allows for the exchange interaction of each magnetic atom with nearest neighbors inside layers; the second sum is a contribution of the anisotropy into a system energy; the third sum is a contribution of an external magnetic field into a system energy, $g \approx 2$ is the Lande factor, μ_B is the Bohr magneton, $H^{x,y}$ are projections the external magnetic field **H**, $S_i^{x,y}$ are spin projections $\mathbf{S}_i$ localized on site i.

The temperature dependences of magnetization M, their longitudinal and transverse components, as well as the magnetizations of each j-th magnetic monolayer M_j.

We also investigated the processes of magnetization reversal of the hard/soft bilayer and trilayers model under the action of an external magnetic field: the influence thickness of the hard magnetic layers on the magnetization reversal of the magnetic trilayers. The irreversibility field H_{irr} for both magnetic trilayers increased by 30 %, and the exchange-bias field H_{ex} increased by almost 150 % relative to the values for the magnetic bilayer model. Behavior of the magnetic bilayer under the external magnetic field was shown to agree with theoretical predictions well enough.

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Investigation of FeRh alloy by wide-field Kerr microscopy

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The wide-field Kerr microscopy has emerged to become a well-established, most versatile and flexible laboratory technique for the investigation of magnetic domains. The method is based on the magneto-optical Kerr effect [1] i.e., small alterations of the polarization plane of linearly polarized light upon reflection from a non-transparent magnetic specimen, which are then detected and used for magnetic domain image formation. A typical wide-field Kerr microscope is based on an optical polarization reflection microscope that applies the Köhler illumination technique for homogeneously illuminated samples [2].

FeRh alloys (with the Rh content from 47 to 53%) serve as the most convenient model objects for studying the nature of magnetic phase transitions (PT) in materials showing giant magnetocaloric effect (MCE) [3,4]. Metamagnetic (PT) from the antiferromagnetic (AFM) to the ferromagnetic (FM) state is observed in FeRh alloys. This discovery led to the suggestion of using Fe–Rh as a magnetic refrigerant.

The microstructure of $Fe_{48}Rh_{52}$ is consisted of α' (B2) and γ (A1) phases (paramagnetic, fcc, γ phase was redistributed in the magnetic, bcc, α' phase by diffusion) [5]. Images of the magnetic domain structure were obtained by using a Kerr microscope. The paramagnetic γ phase surrounded by cylindrical magnetic domains of α' phase is clearly showed in the images.

Analysis of the obtained image intensity as a function of the temperature was allowed to see the phase transition from the FM to the AFM state $T_1 \approx 317$ K and of the inverse AFM–FM transformation $T_2 \approx 307$K in a magnetic field of 100 mT.

This work was supported by funding under the joint program of the Ministry of Science and Higher Education of the Russian Federation and the German Academic Exchange Service DAAD “Mikhail Lomonosov/Immanuel Kant” (project passport № 2295-21)

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Application of the Rutherford Backscattering Method in powder nanotechnology

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Rutherford Backscattering Spectrometry (RBS) is an ion scattering technique used for compositional thin film that are less than 1μm thick analysis. During an RBS analysis, high-energy He2+ ions with energies in the region from several hundred kiloelectron-volts to 2 - 3 MeV are directed onto the sample and the energy distribution and yield of the backscattered He2+ ions at a given angle is measured. Since the backscattering cross section for each element is known it is possible to obtain a quantitative compositional depth profile from the RBS spectrum obtained. The application of methods based on Rutherford Backscattering Spectrometry is extremely interesting for adsorption energy devices, in particular, these methods can be used with maximum efficiency for various chemoelectronic converters.

For this reason, the preparation of planar-distributed chemoelectronic converters and the study of the elemental composition of adsorbates using the Rutherford Backscattering Spectrometry technique was the purpose for the investigation.

The tasks of this study included: development and optimization of the technology for producing planar chemoelectronic converters a functional layer in the form of rounded drops containing monodisperse nanosized (7.5 μm) particles of a solid solution of the ZrO2 system - 3 mol% Y2O3 (YSZ) in the PVA polymer matrix, study of the theoretical characteristics of the obtained chemoelectronic converters [1], study of the elemental composition of the obtained chemoelectronic converters using Rutherford Backscattering Spectrometry.

The atomic and chemical composition of these layers has been studied using nuclear and atomic methods. The thickness of the oxide layers was found to be approximately the same for all implanted samples. These values were determined on the basis of Rutherford Backscattering Spectrometry and nuclear reactions (RBS/NR).

The study was performed in the scope of the H2020/MSCA/RISE/SSHARE number 871284 and the RO-JINR Projects within the framework of themes FLNP JINR: 04-4-1105-2011/2022 and 03-4-1128-2017/2022.

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Influence of substitution with aluminum on the structure and properties of nanosized particles of hexagonal strontium ferrite obtained by the method of wet chemistry

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Among magnetic materials, a special place is occupied by hexagonal ferrites of the M type, which have been known for more than 50 years and have a significant set of magnetic properties. Ferrite-based nanomaterials can find application in the creation of promising devices, storage media, high-frequency devices, as well as for applications in the field of medicine. Wet chemistry is a simple and cost-effective technology for producing such materials.

These ferrites can also be used as absorbers of electromagnetic energy in the frequency range of natural ferromagnetic resonance. The anisotropy field and microstructure of the material determine the operating frequency of devices in the microwave range. To change the value of the anisotropy field, substitution of iron ions by ions of other metals is used [1].

There are few works devoted to strontium hexaferrites substituted with aluminum, especially in the nanosized state [2, 3].

Experimental samples of $SrFe_{12-x}Al_xO_{19}$ (x = 0; 0.5; 1; 1.5; 2.0; 2.5) were obtained by the method of chemical coprecipitation. The synthesized samples were identified by XRD and Mössbauer spectroscopy. The magnetic parameters were investigated using a vibromagnetometer. It is shown that with an increase in the fraction of substitution with aluminum, the value of the coercive force increases significantly. By the method of dielectric spectroscopy in the frequency range 25 Hz - 1 MHz, the spectra of the dielectric constant, the loss tangent and the AC conductivity were obtained in the temperature range of 20 - 100 degrees. The results were discussed.

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Deformation of a magnetic liquid drop in a uniform non-stationary magnetic field at high Reynolds numbers

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Non-stationary magnetic field causes deformational oscillations of a magnetic liquid drop. Investigation of this phenomenon for low Reynolds numbers is presented in [1] and [2]. The goal of this work is to investigate theoretically small deformational oscillations of a magnetic liquid drop in an applied non-stationary uniform magnetic field at high Reynolds numbers. A drop of a magnetic liquid suspended in another magnetic liquid immiscible with the former is considered. The Reynolds numbers are so high that the viscosities of the liquids can be neglected and the liquids can be regarded as ideal. The variation of the magnetic field is so slow that the quasi-stationary approximation for the magnetic field may be used.

The system of equations for the velocity, pressure, and magnetic field intensity consists of the continuity and Euler equations for an incompressible fluid, the Maxwell's equations in the ferrohydrodynamic approximation [3], and the constitutive relation for the magnetic field. The flow of the liquids is regarded as potential. The boundary conditions on the interface between the liquids include the impenetrability condition, the condition for the jump of the normal component of the total stress vector, the continuity conditions for the tangential component of the intensity of the magnetic field and for the normal component of the magnetic induction. The boundary conditions at infinity include the conditions for the velocity, pressure, and magnetic field intensity. Besides, the conditions of boundedness for the velocity, pressure, and magnetic field intensity should be fulfilled.

The representation of the magnetic field intensity and of the velocity of the flow in the form of the multipole expansion [4] written in terms of irreducible tensors are used in solving the problem. Within this approach, the magnetic field intensity and velocity are sought for in the form of series with vector and tensor coefficients for which some relations are obtained that allow one to determine these coefficients. With the use of these relations, the coefficients are sought for in the form of asymptotic expansions over the parameter $(\mu_i - \mu_e)aH_{am}^2/(4\pi\sigma_s)$, the smallness of which provides the smallness of the deformations of the drop. Here, a is the radius of the undeformed spherical drop, μ_i and μ_e are the magnetic permeabilities of the magnetic liquids inside and outside the drop, H_{am} is the maximal absolute value of the intensity of the applied magnetic field, and σ_s is the surface tension of the interface between the liquids.

With accuracy up to the terms of the first order, in an oscillating applied magnetic field with the intensity $\boldsymbol{H}_a=H_{am}\cos(\omega t)\boldsymbol{k}$, the drop is a prolate spheroid, elongated along $\boldsymbol{k}$, performing deformational oscillations with the angular frequency 2ω, and, in a rotating applied magnetic field with the intensity $\boldsymbol{H}_a=H_{am}[\cos(\omega t)\boldsymbol{i}+\sin(\omega t)\boldsymbol{j}]$, it takes the shape of a tri-axial ellipsoid rotating around its minor axis, directed along $\boldsymbol{k}=\boldsymbol{i}\times\boldsymbol{j}$, with the angular speed ω. Here, t is the time, ω is the angular frequency, and $\boldsymbol{i}$, $\boldsymbol{j}$, and $\boldsymbol{k}$ form a triple of orthonormal vectors.

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Aminated magnetic nanoparticles for epithelial cell separation

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Bladder cancer has the highest recurrence rate. But the vast majority of the cancer cases, over 70%, are found at non-invasive stage being confined to the mucosa or submucosa but not reaching muscle layer. So the tumor cells can desquamate into the bladder cavity and be observed in patient urine. Magnetic nanoparticles are considered as the perspective instruments for cells separation and may be very useful for bladder cancer cells capturing from urine for diagnostics and studies.

The aim of the study was to synthesize and investigate magnetic nanoparticles (MNPs) for epithelial cell separation for subsequent non-invasive bladder cancer investigations.

Magnetic nanoparticles were synthesized by co-precipitation method using $FeCl_3$и $FeCl_2 \cdot 4H_2O$ at the molar ratio 2:1 dissolved in 100 mL distilled water. NH_4OH (25%) solution was injected to reach pH 10-11, andthe mixture was stirred for 30 min at room temperature. ThenthesolidFe_3O_4 was collected with magnet and washed several times with distilled water until pH became neutral. The MNPs were coated with tetraethyl orthosilicate (TEOS) and 3-aminopropyl triethoxysilane (APTES) to obtain a magnetic core shell of sufficient thickness and containing amino groups on the surface.

The MNP sobtained were studied by transmission electronic microscopy, IR spectroscopy, magnetometry methods (Fig.1.). Studies were carried out on theequipment of the Krasnoyarsk Regional Center of Research Equipment of Federal Research Center «Krasnoyarsk Science Center» SB RAS.

A

B

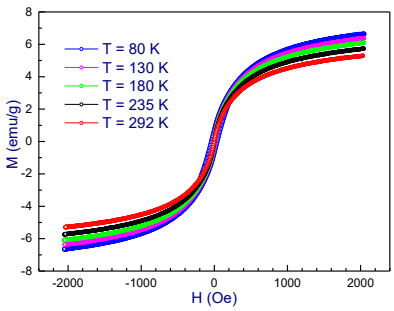

Fig. 1. IR spectrum (A) and hysteresis loops (B) of amino silane coated MNPs.

This work was supported by Russian Foundation for Basic Research, Government of Krasnoyarsk Territory, Krasnoyarsk Region Science and Technology Support Fund to the research projects No. 20-42-242902 and by the Council of the President of the Russian Federation for State Support of Young Scientists and Leading Scientific Schools (project no. MK-1263.2020.3). We are grateful to the Center of collective use of FRC KSC SB RAS for the provided equipment. Participation in the conference was supported by the «Krasnoyarsk Regional Fund for the Support of Scientific and Scientific and Technical Activities». Competition of projects for organizing the participation of students, graduate students and young scientists in conferences, scientific events and internships (II stage of 2021). Application code: 2021051707717.

Granulometry of nanocomposite films using Atomic Force Microscopy images

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A wide range of composite materials representing two- or three-dimensional structures is being studied [1-3]. The range of elementary units composing these structures is also rich: quantum dots, nanowires, rings, more complex particles with a core-shell structure, films, etc. Particles may be interacting or non-interacting. Note that the modeling of composite structures usually considers regular structures of homogeneous elements.

Obviously, combining particles of different types in a two-dimensional matrix, or, for example, in a gel, may allow to significantly expand the range of obtained magnetic characteristics, and in some cases to obtain qualitatively new properties (for example, to obtain a heterogeneous medium with several resonance frequencies when using ellipsoidal-shaped magnetic particles and rings).

Machine learning and generative design methods, developed using the methods of modern IT science, make it possible to solve such problems in a reasonable computational time.

Filtering and clustering algorithms, a type of machine learning task, can improve the accuracy of image analysis. Machine learning algorithms can also help with the accumulation of material for analysis. In mathematical statistics, "bootstrap" techniques are used to create pseudo-samples to test empirical distributions. If we use convolutional neural networks to analyze images of films with specified parameters in order to identify patterns, and then generative neural networks to produce new images that take into account these laws, it becomes possible to accumulate a base for research without spraying real films, which will greatly simplify the research process.

The study was supported by the Russian Science Foundation (project No. 21-72-20048).

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FORC and TFORC analysis of electrodeposited Ni-Fe-Ga ferromagnetic shape memory nanowires

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Ferromagnetic shape memory alloys are materials that undergo a structural transformation after applying an external magnetic field [1]. Several ferromagnetic shape memory alloys can be found within the large group of Heusler alloys [2]. Moreover, some of them exhibit a multifunctional behavior, which depends on their chemical composition. Ni-Fe-Ga Heusler alloy shows a multicaloric and ferromagnetic shape memory behavior [3]–[5]. Such material might be used during preparation of simultaneous sensor and actuator devices.

In this work, electrodeposited Ni-Fe-Ga nanowires were characterized as an array, using a temperature dependent First Order Reversal Curve (FORC) and Temperature First Order Reversal Curve (TFORC [6]) analyses. The FORC analysis reveals that the nanowires array behaves as a multi-domain material. The FORC distribution has a diverging shape with a minimal coercive field distribution [7], implying that the nanowires exhibit a homogeneous chemical composition. Structural characterization of the Ni-Fe-Ga nanowires reveals that the nanowires do not exhibit the stoichiometric X_2YZ Heusler chemical composition, but the composition does not change within the nanowires array. The nanowires consist of Ni-Fe rich regions with a diffused Heusler cubic phase. A deeper analysis of the FORC results shows a presence of several phases, which interchange between the temperatures of 300 K and 395 K. Cooling - TFORC distribution has a narrow T_u interval, which also supports the homogeneous nanowires composition. Analysis of the cooling - TFORC measurements shows several maxima within the pre-defined structural transformation region. The maxima may correspond to the structural transformation of the phases that are present in the nanowires´ structure.

The current results of the FORC analysis show that the Ni-Fe-Ga nanowires exhibit a structural transformation within the transformation temperature region. The structural transformation is also visible during the TFORC measurement, showing a matching behavior.

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Room temperature circularly polarized electroluminescence in heterostructures based on a diluted magnetic semiconductor

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Currently, the field of science associated with the development and study of spin light-emitting diodes (SLEDs) capable of circularly polarized emission has received significant development. Diluted magnetic semiconductors (DMS) are promising materials for ferromagnetic injectors in such SLEDs. To date, the most studied material among dilute magnetic semiconductors is (Ga,Mn)As, which retains ferromagnetic properties only up to 200 K [1], therefore the problem of increasing the Curie temperature for DMS is one of the most urgent in spintronic technology.

This paper reports on the creation and study of a spin LED, in which a GaAs:Fe ferromagnetic layer was embedded as an injector of spin-polarized carriers into a heterostructure with an $In_{0.2}Ga_{0.8}As$/GaAs quantum well. The circularly polarized light emission at room temperature in the GaAs:Fe/MgO/GaAs structure was obtained.

The magnetic field dependence of the circular polarization degree of electroluminescence (EL) - $P_{EL}(B)$ - was measured in the temperature range of 10-300 K in a closed-cycle He cryostat. At the temperatures of 10, 50, and 75 K, the $P_{EL}(B)$ dependence contains a hysteresis loop. The magnitude of the coercive field at a temperature of 10 K is 56 mT, at 50 K - 38 mT, and at 75 K - 5 mT. This type of magnetic field dependence of the circular polarization degree is probably associated with the magnetic properties of GaAs:Fe and is caused by the injection of spin-polarized electrons from the ferromagnetic GaAs:Fe layer. When the temperature rises above 75 K, the hysteresis loop disappears completely whereas polarization is retained. The maximum degree of circular polarization associated with saturation of magnetization is ~ 0.4%; this value weakly depends on the measurement temperature in the range (10 - 300 K). In addition, saturation of the polarization was observed over the entire temperature range at the same magnetic field values ~ ± 200 mT. For the control structure without a GaAs:Fe ferromagnetic injector (the Al contact was deposited directly on the GaAs spacer layer), the P_{EL} value is a linear function of the magnetic field, and the value of the circular polarization degree does not exceed 0.04%. Unlike the polarization degree the EL intensity decreases monotonically with increasing temperature. Based on the obtained results, we assume that the Curie temperature for a GaAs:Fe ferromagnetic injector exceeds 300 K, which is in good agreement with the results obtained earlier in [2] for GaAs:Fe with similar parameters.

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Estimation of parameters of domain wall by EMF signal generated while its movement in glass-coated cylindrical amorphous ferromagnetic microwires

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Glass-coated cylindrical amorphous ferromagnetic microwires are in a focus of many investigations as they can be used for constructing various physical or bio sensors, coding, memory and logic devices. The key property of such microwires that enables those applications is very fast re-magnetization process realized through domain wall (DW) propagation under applied longitudinal magnetic field. At present, due to their amorphous state and relatively large size it is not possible restore the DW structure using experimental methods. The full-fledged theory to describe microwires has not been yet constructed either. Therefore, indirect methods that allow to estimate DW structure is considered as a significant option to "look inside" the wire.

In this work we develop a method of estimation of width and slope of DW based on theoretical model proposed in [1]. Thus, we suppose that the DW does not change its structure while propagating. We derive the formula that allows one to compute the EMF signal generated while the DW is propagating. We select the most appropriate parameters to coincide with the detected signal. We also consider if the DW is planar or inclined based on the signal.

The derived formula consists of two parts. We consider which part plays a prominent role for various wires. We also present a simplified version of the formula derived with a few additional assumptions and conclude in which cases it can be used instead of the general one.

We develop a software application that allows one to obtain the parameters of the DW automatically. It supports input data in various formats, batch processing with multi threading. A user may select an algorithm (a general formula or the simplified one), supposed magnetization distribution inside DW (planar, inclined and even other). An application may also check all supported distributions and algorithm in parallel in order to find the best one for the given data. All settings can be modified either by using .ini files or by means of GUI. The application may compute parameters for several wires and several input data simultaneously. A user may select the desired output format (including graphical one) and has many options to tweak it.

According to [1], knowing the width, velocity and slope of the DW, we may also estimate stresses and magnetic anisotropy inside the wire. This task is also fulfilled by the presented software application.

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Diode heterostructures with a ferromagnetic (Ga,Mn)As layer

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The results of an experimental study of a new design of diode heterostructures with ferromagnetic (Ga,Mn)As layers are presented. Structures were grown using a combination of MOCVD epitaxy and pulsed laser deposition (PLD) and contained *p*-(Ga,Mn)As/*n*-InGaAs heterojunctions. The ~ 1.8 μm thick *n*-$In_xGa_{1-x}As$ (x ~ 0.1) buffer layer doped with Si atoms (n ~8×10^{16} cm^{-3}) was grown on n^+-GaAs(001) substrates using MOCVD at a temperature of 650°C. Then, at 330°C, a p-type (Ga,Mn)As layer (at nominal Mn content of 0.13) with a thickness from 5 nm to 100 nm and a GaAs cap layer (9 nm) was formed using PLD. An ohmic Au contact was deposited on the (Ga,Mn)As layer by electron beam evaporation, and 600 μm diameter mesa structures were made by photolithography and chemical etching. Base contact to n^+-GaAs substrate was formed by electric-spark firing of the Sn foil. Magnetic field dependences of diode resistance were studied in a closed-cycle helium cryostat at temperatures from 10 to 300 K. A magnetic field was applied perpendicular to the structure surface. Studies by transmission electron microscopy (TEM) showed the absence of any defects at the (Ga,Mn)As/InGaAs interface and found high crystalline perfection of the low-temperature (Ga,Mn)As (fig.1). The observed (Ga,Mn)As layer thickness of ~ 5 nm is in good agreement with technological parameters. The GaAs cap layer contains stacking faults arising from its relaxation due to the difference in the lattice parameters of (Ga,Mn)As and GaAs. In addition, inclusions of the second phase (MnAs and/or MnGa) with a crystal lattice different from GaAs (marked by circles) are visible. The negative magnetoresistance (*MR*) at temperatures below 70-80 K ((Ga,Mn)As Curie temperature) was revealed within magnetotransport measurements (fig.2). The effect is associated with a decrease in carrier scattering due to ferromagnetic ordering and with a decrease in the potential barrier at the (Ga,Mn)As/*n*-InGaAs interface. *MR* demonstrates a non-monotonic dependence on forward bias voltage with a maximum in the voltage range close to the height of the *p–n* junction potential barrier.

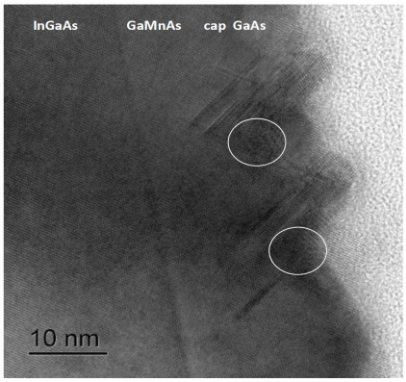

Figure 1. High resolution TEM image of the cross section of a diode structure with a 5 nm thick GaMnAs layer.

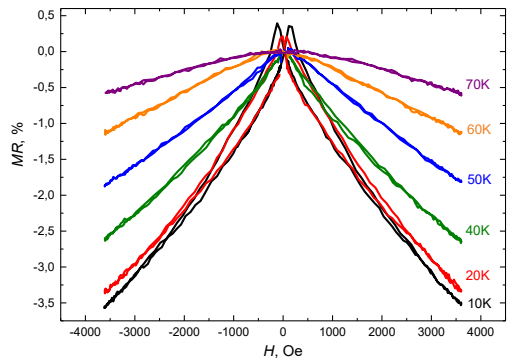

Figure 2. The magnetoresistance dependence on the magnetic field for diode structure with a 30 nm thick GaMnAs layer (forward bias voltage 1 V).

This study was supported by Russian Science Foundation (grant 19-19-00545).

Synthesis of high-entropy ceramics with a perovskite structure

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Perovskites are a general name for compounds, the chemical formula of which can be generally represented as ABO_3. Various elements can act as cations A and B. The most prospective materials with a perovskite structure have unique physical properties.

The present study is devoted to studying the possibility of synthesizing compounds with the general formula $[Cr,Mn,Fe,Co,Ni]BO_3$, where one or more rare earth elements from the following list act as the B cation: Sm, Eu, Gd. Such multicomponent systems have a high mixing configurational entropy of components, and taking into account the elemental composition, we can expect them to display interesting magnetic and electrical properties.

The compounds were synthesized by solid-phase sintering. Chromium oxides Cr_2O_3, manganese Mn_2O_3, iron Fe_2O_3, cobalt CoO, and nickel NiO were taken as the sources for the position A substitution. Samarium oxides Sm_2O_3, europium Eu_2O_3, and gadolinium Gd_2O_3 were taken or the position B substitution. The starting components were measured in stoichiometric ratios, mixed and ground in an agate mortar. The resulting oxide mixture was pressed. The tablets obtained as a result of pressing were placed in a high-temperature oven on a platinum substrate and sintered at a temperature of 1400 ° C for 5 hours. The samples obtained as a result of synthesis (Table 1) were certified by powder X-ray diffraction, electron microscopy, and energy-dispersive spectroscopy. According to powder X-ray diffraction data, the synthesized samples are monophasic. Table 1 shows the calculated lattice parameters. Energy dispersive X-ray spectroscopy data showed good agreement between the initially planned and experimentally obtained elemental composition.

Table 1. Parameters of the crystal structure of the obtained compounds

№	Brutto formula	Crystal system	Lattice parameters, Å		
			a	*b*	*c*
1	$[Cr,Mn,Fe,Co,Ni][Sm,Eu]O_3$	Orthorombic	5.4515(9)	5.4645(6)	7.7075(14)
2	$[Cr,Mn,Fe,Co,Ni][Sm,Gd]O_3$	Orthorombic	5.3253(3)	5.5188(3)	7.5957(4)
3	$[Cr,Mn,Fe,Co,Ni][Eu,Gd]O_3$	Orthorombic	5.3086(2)	5.5241(2)	7.5791(3)
4	$[Cr,Mn,Fe,Co,Ni][Sm,Eu,Gd]O_3$	Tetragonal	3.8662(3)	3.8662(3)	7.7342(8)

As a result of this work the new high-entropy ceramic magnet samples with a perovskite structure were synthesized for the first time. The crystal structure has been studied. The next stage of the work will be the study of the magnetic and electrophysical properties of the resulting compositions.

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Double layer magneto-active films for magnetophotonics and optomagnonics

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Today the scientific community is actively developing the idea of design magneto-optic and optomagnonic structures that combine the optical effects of transmission / localization of optical waves and the dynamics of magnetization at femto- and picosecond times [1, 2]. Various rare-earth garnets and iron garnets, the crystal structure of which makes it possible to achieve a wide variation in the properties of magnetic system, are quite proven materials for such applications. Particular attention should be paid to compositions with the addition of bismuth and cerium, which significantly increase the magneto-optic response and make it possible to detect the dynamics of magnetization by means of direct magneto-optic effects. Unfortunately, modern experimental possibilities make it difficult to use garnets of different composition in combination with other components (for example, nanoscale one-dimensional and two-dimensional lattices of other magnetic or nonmagnetic materials) in real synthesis of magneto-active structures, which makes many calculated models unpromising and unrealizable in practice. Crystallization process is one of the most important factors which determine films' quality. In the work we present a detailed comparison of influence of synthesis regimes on crystal quality and other properties of double layer bismuth-substituted iron garnet (Bi:IG) films on substrates with and without garnet structure. Bi:IG films were fabricated by reactive ion beam sputtering method (RIBS) on gadolinium gallium garnet or fused quartz. The garnet phase was formed by crystallization annealing. It was found that smoother and more homogeneous samples on non-garnet substrates can be obtained using slow and prolonged annealing, while high-quality films on garnet substrates are formed with shorter heating and annealing. Figure 1 shows the morphological parameters of a sample with irregular crystal structure.

TVM, ANSh, VNB acknowledge support by the Russian Ministry of Education and Science (Megagrant project N 075-15-2019-1934) for the synthesis of samples.

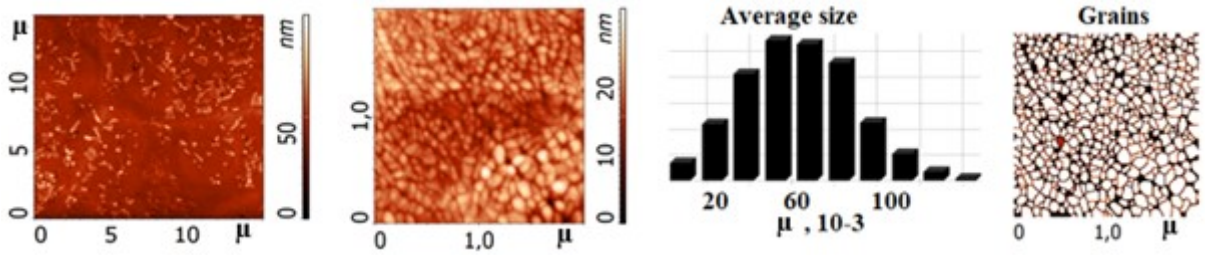

Figure 1. Topography and grain analysis of double layer Bi:IG on fused quartz substrate.

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Cobalt(II) carboxylate complexes with redox-active ligands as a platform for the synthesis of bistable systems

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Redox-active ligands can reversibly accept electrons that leads to change their electronic structure from neutral to radical-anion (one electron), dianion (two electrons), etc. Such type of electron dynamics causes switchable physical properties, particularly magnetic bistability [1].

Recently we have shown that the replacement of two pyridine (Py) molecules in the compound $[CoI_2(Py)_2]$ with one molecule of redox-active diimine ligand led to significant improvement of operating parameters of corresponding Single Ion Magnets [2]. At the same time, metal carboxylate complexes are also promising objects for design of new magnetic materials [3].

The aim of this work was to synthesize compounds containing both carboxylic anions and redox-active ligands (1,4-diaza-1,3-butadienes, *o*-iminoquinones). We believe that a combination of two factors - the electronic lability of redox-active ligands and a variety of structural forms of carboxylates - can lead to the creation of new materials with controllable physical properties. The conditions for the synthesis of compounds, their structure (see Figure 1), and some properties will be discussed during the session.

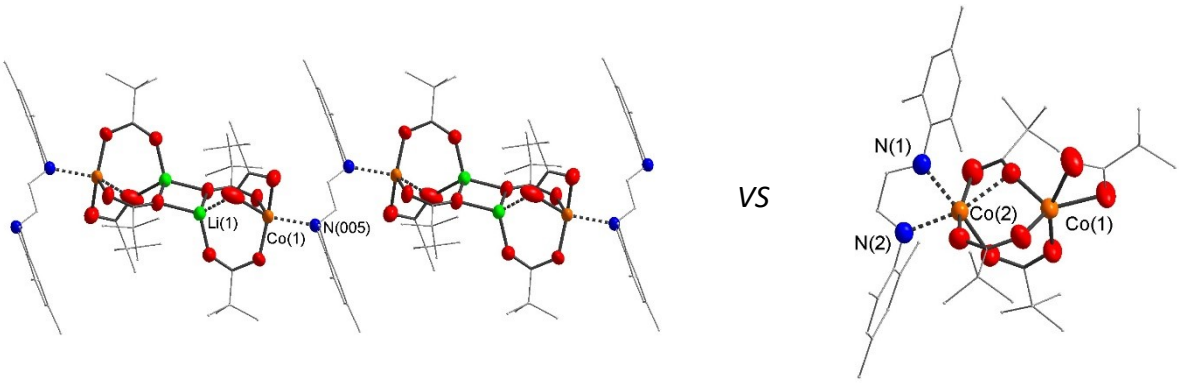

Figure 1. Molecular structures of some Co(II) carboxylate complexes which will be discussed during the session

Acknowledgement. This study was supported by the Russian Science Foundation (grant 19-13-00436).

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Magnetic coatings of transition metals synthesized using arabinogalactan

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Electroless deposition is the simplest and most economical method for synthesizing metal coatings. These coatings have high hardness and corrosion resistance [1,2]. Electroless deposition is an autocatalytic process; the reduction of metal ions in solution is carried out by the oxidation of the reducing agent. In this work, the polysaccharide arabinogalactan was used as a reducing agent to obtain ferromagnetic metal coatings of transition metals.

Ferromagnetic coatings were prepared from aqueous solutions of cobalt, nickel, and iron sulfate. Arabinogalactan isolated from larch was used as a reducing agent. Sodium citrate and EDTA were used as a complexing agent and stabilizer. The deposition was carried out at a temperature of 80 °C. The coatings were studied by electron microscopy, Mössbauer spectroscopy, and magnetometry. The studies were carried out on the equipment of the Krasnoyarsk Regional Center for Collective Use of the Federal Research Center of the KSC SB RAS.

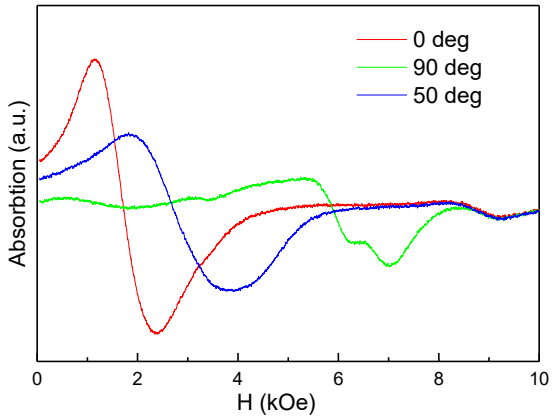

Fig.1. Ferromagnetic resonance spectra

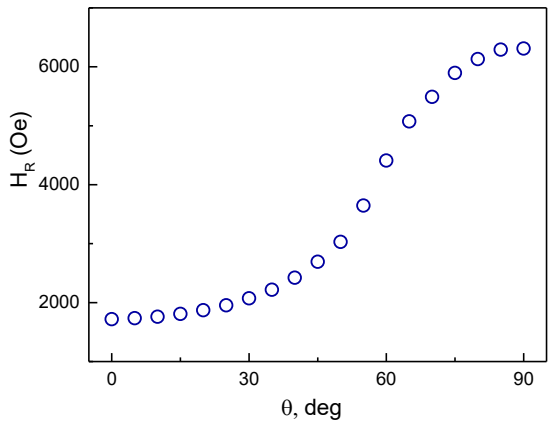

Fig.2. Angular dependence of resonance field

To reveal the morphological features of the prepared alloys, and to study their magnetic properties, the method of ferromagnetic resonance was used. Figure 2 shows the dependence of the FMR resonance field on the angle between the direction of the applied magnetic field and the Ni coating plane (the angle varies from 0° - the field is applied in the coating plane to 90° - the field is applied along the normal to the plane). The angular dependence is characteristic of a planar magnetic coating. The resonance field for the parallel orientation was 1700 Oe, and for the perpendicular orientation was 6300 Oe.

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Phase transitions and magnetic properties of $Fe_{100-x}Al_x$ ($15 \leq x \leq 25$) alloys

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Fe-Al-based functional materials are a perspective for industrial application due to the unique combination of properties such as high strength, corrosion stability, low density, and low cost [1,2]. The right framework for such materials development is the knowledge of the binary Fe-Al phase diagram. The present work is devoted to theoretical studies of the structural and magnetic phase transitions, as well as magnetic properties of binary $Fe_{100-x}Al_x$ ($15 \leq x \leq 25$ at. %) alloys with different crystal structures.

To study the ground state and magnetic properties of $Fe_{100-x}Al_x$ ($15 \leq x \leq 25$ at. %), the Korringa-Kohn-Rostoker method was used as implemented in SPR-KKR [3] computational package. The geometry optimization was performed for crystal structures observed experimentally in Fe-Al alloys. These structures are ordered $D0_3$, partially disordered B2, and fully disordered A2. The disorder in $D0_3$, B2, and A2 phases was produced with the coherent potential approximation. Computations were performed in general gradient approximation in the form of Perdew–Burke–Ernzerhof [4]. According to the Birch-Murnaghan equation of state, the equilibrium lattice parameters a_0 and the total energies E_0 were evaluated for all considered phases. The energy difference relative to the energetically favorable structure allows us to obtain temperatures of the structural phase transitions. Curie temperatures are estimated within the Heisenberg model in the mean-field approximation. Estimated structural and magnetic phase transition temperatures allow us to construct the complex phase diagram for $Fe_{100-x}Al_x$ ($15 \leq x \leq 25$ at. %) depicted in Figure 1.

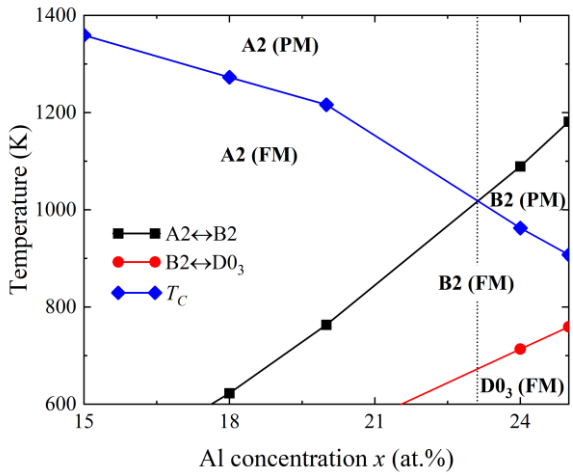

Figure 1. Theoretical concentration phase diagram of $Fe_{100-x}Al_x$ ($15 \leq x \leq 25$ at. %) alloys.

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M-type hexaferrites $BaFe_{12-x-y}Ti_xAl_yO_{19}$ and $SrFe_{12-x-y}Ti_xAl_yO_{19}$ single crystals growth

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This work is devoted to the development of a technology for bulk barium and strontium hexaferrites single crystals growth. In intial matrix some of the iron atoms are substituted by titanium and aluminum atoms. It was found that the ferrites magnetic properties can be significantly changed by partial or complete substitution of iron cations with dopants. Thus, by changing the iron substitution degree, we get the opportunity to adjust the magnetic properties of the material for a specific task.

Single crystals were grown by the method of spontaneous crystallization from solution. Sodium oxide (Na_2O) was used as a solvent. The choice of sodium oxide as a solvent is due to the fact that sodium is not incorporated into the crystal structure of barium and strontium hexaferrites. The initial components for the charge preparation were iron oxides Fe_2O_3, aluminum Al_2O_3, titanium TiO_2 and carbonates of barium $BaCO_3$, strontium $SrCO_3$, sodium Na_2CO_3. All components used were of no lower than analytical grade. The concentration of the solvent was 26.6 mole percent.

The starting components mixture was heated to a temperature of 1300 ° C and kept at this temperature for 24 hours to homogenize the solution. The furnace was cooled at a rate of 4.5 ° C/hour to a temperature of 1000 ° C. The separation of the crystals from the solvent was carried out by boiling in nitric acid. The elemental composition of the obtained crystals was determined by the EDS method. The single phase form was checked with powder XRD. The appearance of the crystals is shown in Figure 1.

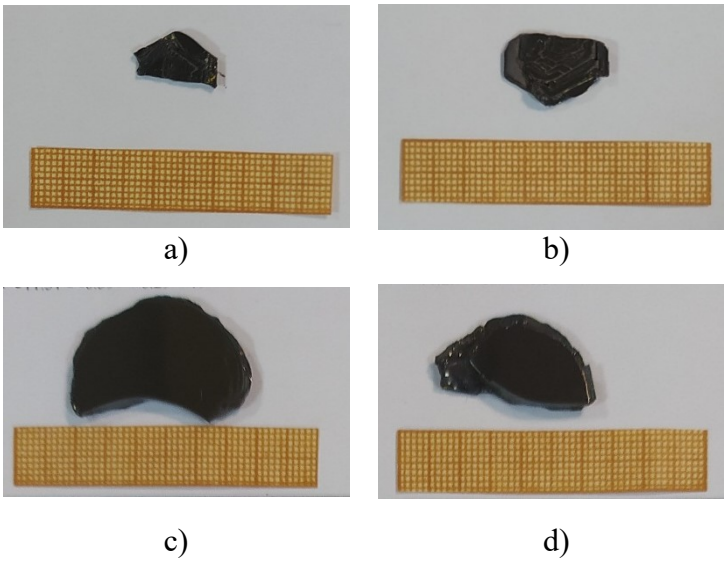

Fig. 1. Samples of the obtained single crystals:
a) $BaFe_{11.09}Ti_{0.51}Al_{0.4}O_{19}$,
b) $BaFe_{11.19}Ti_{0.471}Al_{0.35}O_{19}$
c) $SrFe_{11.31}Ti_{0.391}Al_{0.29}O_{19}$,
d) $SrFe_{11.29}Ti_{0.41}Al_{0.31}O_{19}$.

As a result of the work done, bisubstituted single crystals of barium and strontium hexaferrites with a magentoblumbite structure were obtained for the first time in the world.

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