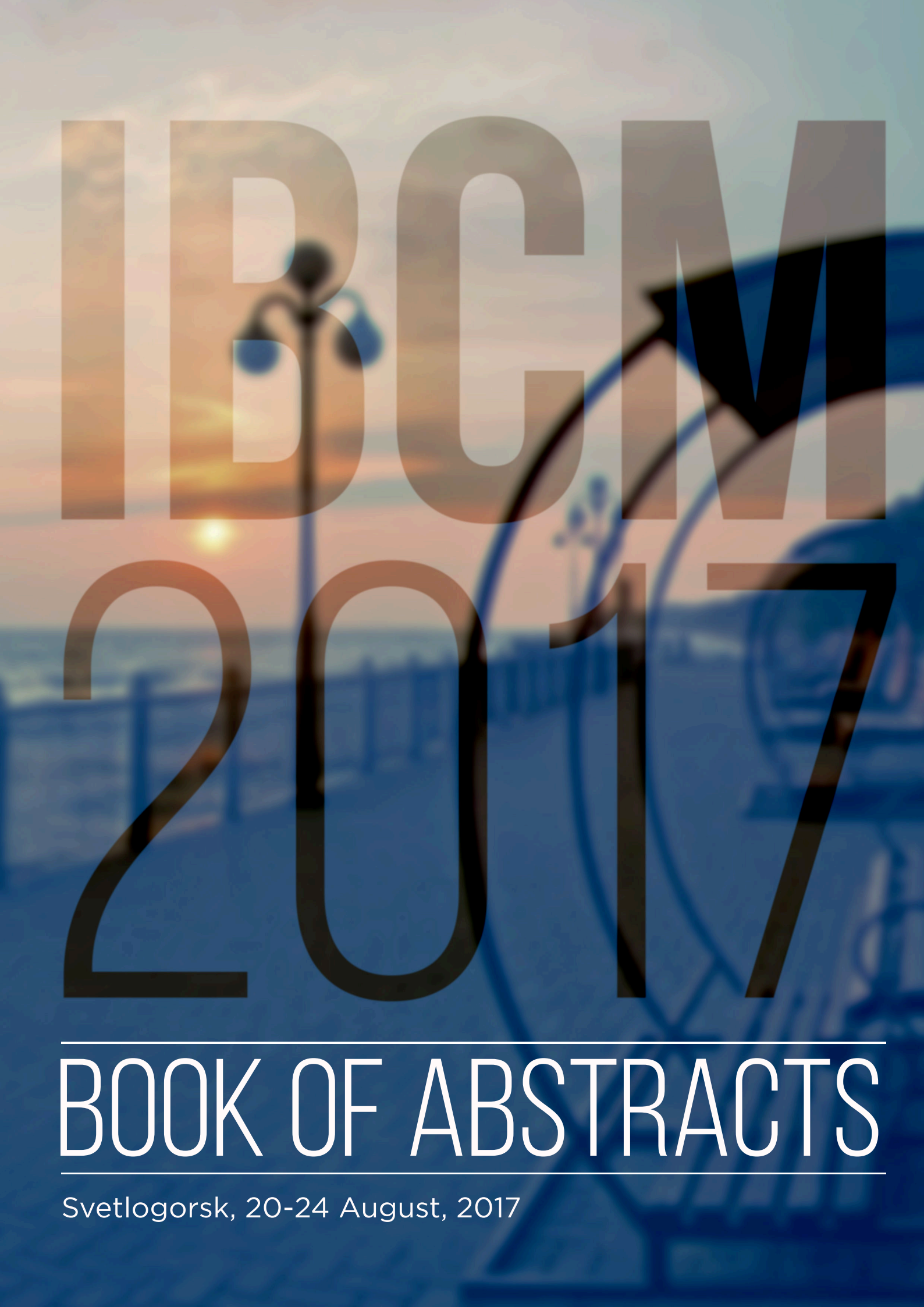

IBCM 2017

BOOK OF ABSTRACTS

Svetlogorsk, 20-24 August, 2017

INTERNATIONAL BALTIC CONFERENCE ON MAGNETISM: FOCUS ON FUNCTIONALIZED MAGNETIC STRUCTURES FOR ENERGY AND BIOTECHNOLOGY

IBCM 2017 is organized by

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Interdisciplinary Reference Centre: Functionalized Magnetic Materials for Energy and Biomedical Applications,

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- Theranostic + Nanoparticles
- Microfluidics
- Lab-on-a-Chip
- Simulation Methods
- Design of novel permanent magnets
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PLENARY LECTURES

SPINTRONIC MATERIALS FOR BIOTECHNOLOGY APPLICATIONS

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Many experiments in biotechnology use magnetic nanoparticles for tagging, actuating or separating. A key requirement of such particles is that they should have zero remanence (to avoid agglomeration when free in solution), should carry a high induced moment under moderate applied field and should have well-defined and strong anisotropy. We present a new approach to this problem based on ultrathin layers of perpendicularly magnetized material [1] recently developed for use in spintronic memory devices. We use the synthetic antiferromagnet Pt/CoFeB/Pt/Ru/Pt/CoFeB material system structured into sub-micron disks using nanosphere lithography. The particles are then released from the wafer into solution to form a colloidal suspension (see Fig. 1), which, because of the antiferromagnetic RKKY coupling across the Ru interlayer, present zero remanence. We show how the spin-flop transition usually associated with synthetic antiferromagnets is modified when the particles themselves are free to rotate [2]. We show how this can be used to control inter-particle interactions and show mechanical disruption to human glioma cells when the particles are used in a cancer therapy application [3].

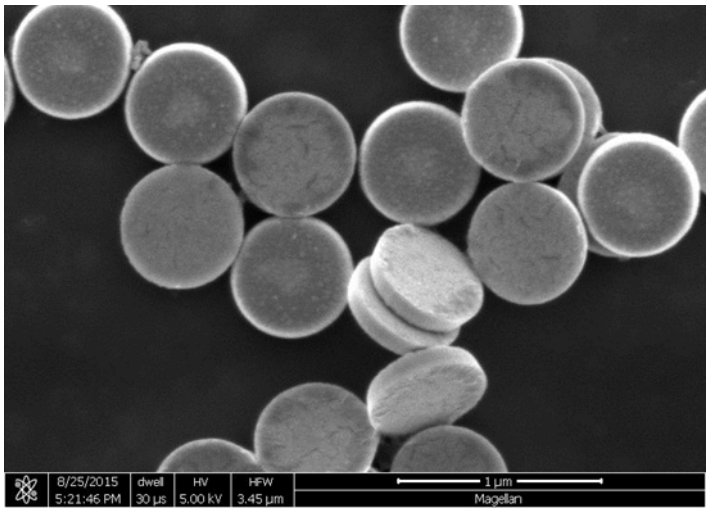

Fig. 1: Perpendicular synthetic antiferromagnets lifted off from a wafer into solution.

[1] T.Vemulkar, R.Mansell, D.C.M.C.Petit, R.P.Cowburn, M.S.Lesniak, *Appl. Phys. Lett.* **107**, 012403 (2015).
[2] T.Vemulkar, E.N.Welbourne, R.Mansell, D.C.M.C.Petit, R.P.Cowburn, *Appl. Phys. Lett* **110**, 042402 (2017).
[3] Muroski, Cowburn et al., *PLoS One* **11** (1), e0145129 (2016).

MICRO-FLUX SOURCES FOR MEMS AND BIO-MEDICAL APPLICATIONS

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Magnetic flux sources are used to manipulate biological entities (cells, embryos, DNA, proteins…). The magnetic field gradients produced by a flux source scales up as its size is decreased, resulting in increased force per unit volume. Hard magnetic flux sources are particularly interesting for compact and / or portable applications while the force produced by soft magnetic flux sources on a target object are easily varied. There is thus great potential for using both hard and soft micro-magnets as flux sources in biology and medicine.

In this talk I will briefly review our work on the development and micro-patterning of magnetic films, in particular Rare Earth - Transition Metal hard magnetic films [1,2], and the low-cost fabrication of micro-magnet arrays based on magnetic powders [3]. I will then describe recent advances made in the quantitative characterisation of stray fields and forces produced by micro-magnets using Magneto-Optic Imaging, Scanning Hall Probe Microscopy and Magnetic Force Microscopy [4-6]. I will give examples of bio-medical applications of the micro-magnets we have developed [7-14]. Finally, I will discuss potential uses of high intensity pulsed magnetic field sources in bio-medical applications [15].

[1] O. Akdogan, H. Sepehri-Amin, et al., *Adv. Electron. Mater.* **1**, 1500009 (2015).
[2] D. Le Roy, Gorky Shaw, R.Haettel, et al., *Mat. Today Comm.* **6**, 50 (2016).
[3] N. M. Dempsey, D. Le Roy et al., *Appl. Phys. Lett.* **104**, 262401 (2014).
[4] R. Grechishkin, M. Kustov, S. Ilyashenko, et al., *J. Appl. Phys.* **120**, 174502 (2016).
[5] Gorky Shaw, R. B. G Kramer, N. M. Dempsey et al., *Rev Sci Inst.* **87**, 113702 (2016).
[6] G. Ciuta, F. Dumas-Bouchiat, N. M. Dempsey et al., *IEEE Trans Mag* **52**, 6500408 (2016).
[7] O. Osman, L. F. Zanini, M.Frénéa-Robin, et al., *Biomed Microdevices* **14**, 947 (2012).
[8] V. Zablotskii, A. Dejneka, S. Kubinova, et al., *PLoS ONE* **8**, e70416 (2013).
[9] O. Osman, S. Toru, F. Dumas-Bouchiat, et al., *Biomicrofluidics* **7**, 054115 (2013).
[10] T. Brunet, A. Bouclet, P. Ahmadi, et al., *Nat. Comm.* **4**, 2821 (2013).
[11] J. Pivetal, S. Toru, M. Frenea-Robin, et al., *Chemical Sensors Actuators B* **195**, 581 (2014).
[12] J. Pivetal, D. Royet, G. Ciuta, et al., *J. Magn. Magn. Mat.* **380**, 72 (2015).
[13] D. Mitrossilis, J.-C. Röper, D. Le Roy et al., *Nat. Comm*. **8**, 13883 (2017).
[14] S. Delshadi, G.Blaire, P. Kauffmann, et al., *Bioanalysis* **9**, 517 (2017).
[15] D. Royet, Y. Hériveaux, J. Marchalot et al., *JMMM* **427**, 306 (2017).

MAGNETS AS ENABLERS FOR RENEWABLE ENERGY AND RESOURCE EFFICIENCY

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Magnetic materials are key components in energy related technologies, sensors and information technology. Magnets are inseparable from our everyday life. “Green” energy technologies such as wind turbines, electro-mobility and solid state cooling, heavily rely on high performance magnetic materials which have to be available in bulk quantities, at low-cost and with tailored magnetic hysteresis properties [1].

The realisation of these technologies is closely linked to the sustainable availability of the strategic metals for magnetism such as the group of rare earth elements (REE) namely Nd, Gd, Tb, Dy, transition metals such as Co, Ga, Ge, In, and the platinum group metals. Resource criticality is understood here as a concept to assess potentials and risks in using raw materials for certain technologies, and their functionality in emerging technologies. The concept of criticality of strategic metals is explained by looking at demand, sustainability and the reality of alternatives of rare earth elements [2].

There is an ever-growing demand for the benchmark high performance Nd-Fe-B magnets, most importantly for use in e-motor applications, for example, in all kinds of machinery, automatization and robotics in industry (Industry 4.0). The key question will be whether Nd-Fe-B needs to be and could be substituted substantially in some of the existing and upcoming competing technologies. The arrival of a more widespread use of e-mobility and wind energy and other smart magnet usages has yet to have its impact on this application field in terms of Nd demand. No substitute is at hand for the massive amounts of high-energy density magnet materials needed to run fast moving automated industrial machinery, and the demand is expected to rise for these kinds of applications. The same applies to e-motors in hybrid electric cars, where motor designers find highly limited construction space [2, 3]. There are different concepts for wind turbines, including those that require less or no permanent magnet materials. However, permanent magnet - so-called permanent magnet direct drive wind turbines - are far superior in terms of energy efficiency and maintenance cost and seem to be becoming the dominating type of machinery in Europe and worldwide [4].

Gas-vapour compression technology for refrigeration, heating, ventilation, and air-conditioning has remained unchallenged for more than 150 years. There is a huge demand for a smarter, more flexible and more efficient cooling technology. Magnetic refrigeration could be that alternative working without gas-based refrigerants. Energy spent for domestic cooling is expected to outreach that for heating worldwide over the course of the twenty-first century.

The talk will address these different global trends and will attempt to scale bridge these challenges by discussing the modelling, synthesis, characterization, and property evaluation of novel magnetic materials considering their micromagnetic length scales and phase transition characteristics [5,6].

[1] O. Gutfleisch, J.P. Liu, M. Willard et.al., *Advanced Materials* **23**, 821–842 (2011).
[2] R. Gauss, G. Homm, O. Gutfleisch, *J. of Industrial Ecology*, DOI: 10.1111/jiec.12488. (2016)
[3] O. Gutfleisch, M.D. Kuz´min, J. Gassmann, R. Gauss, *Annapolis*, *USA* (2014).
[4] R. Gauss and O. Gutfleisch, ed. P. Kausch und J. Matschullat, *Springer Spektrum Heidelberg, Springer-Verlag GmbH*, ISBN 978-3-662-48854-6, 99-118 (2016).
[5] K. Loewe, D. Benke, C. Kübel, T. Lienig, et.al., *Acta Materialia* **124**, 421-429 (2017).
[6] O. Gutfleisch, T. Gottschall, M. Fries, D. Benke, I. Radulov, K. P. Skokov, H. Wende, M. Gruner, M. Acet, P. Entel and M. Farle, *Phil. Trans. R. Soc. A* 374: 20150308 (2016). http://dx.doi.org/10.1098/rsta.2015.0308.

MAGNETOPHORETIC SHUTTLING SYSTEM FOR DIGITAL MANIPULATION OF LIVING CELLS TOWARDS CELLS-ON-CHIP

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The integration of a remotely controllable particles/cells manipulation in a lab on a chip systems promises to play a key role towards the advancement in gene sequencing, single cell analysis and cell separation technology. Particularly, most existing single cell platforms are unable to achieve large scale operation with flexibility on cells and digital manipulation, and thus there is urgent need of innovative techniques to accomplish the automation of single cells. Recently, the flexibility of magnetic shuttling technology using nano/micro scale magnets for the manipulation of particles has gained significant advances and has been used for a wide variety of single cells manipulation tasks. Here, we have developed a class of integrated magnetic track circuits designed by conventional lift-off technology for executing sequential and parallel, timed operations on an ensemble of single particles and cells. When the magnetic tracks are combined into arrays and driven by rotating magnetic field, the single cells/particles are precisely control for multiplexed analysis [1]. The concentric cells/particles transport to one point and then transported to apartments array for the single cell analysis were performed by the assembly of this magnetic track into a novel architecture, resembled with spider web network consisted of several radii and spirals. Furthermore, a planar Hall resistance sensor was integrated at the center of the web networks, and the manipulation and detection are achieved *via* superparamagnetic particles with dual functions as a biomolecule carrier for transportation and labels for monitoring [2]. This novel platform could possibly open a new biological assay system for both future diagnostic devices that overcomes diffusive bioanalytes transportation issues facing existing nano/micro-biosensors, and cells-on-chip which allows the heterogeneity analysis in individual cell levels.

[1] B. Lim, V. Reddy, X.H. Hu, K.W. Kim, M. Jadhav, R. Abedini-Nassab, Y.W. Noh, Y.T. Lim, B.B. Yellen, C.G. Kim, *Nature Communications* **5**, 1 (2014).
[2] B. Lim, S.R. Torati, K.W. Kim, X. Hu, V. Reddy, C. Kim, *NPG Asia Materials* (2017). doi:10.1038/am.2017.37

CHIRAL SPIN-ORBITRONICS

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Over the past few years there have been remarkable discoveries in spin-based phenomena that rely on *spin-orbit coupling* that could spur the development of advanced magnetic memory devices. These include the formation of *chiral* spin textures in the form of Néel domain walls and topological spin textures, skyrmions, that are stabilized by a Dzyaloshinskii-Moriya exchange interaction. The Dzyaloshinskii-Moriya exchange interaction is derived from broken symmetries and spin-orbit interactions at interfaces or within the bulk of materials. Another important consequence of spin-orbit effects are the unexpectedly high conversion efficiencies of charge current to *chiral* spin current from topological spin textures and in conventional metals, via the spin Hall effect [1,2]. Such spin currents lead to giant spin-orbit torques that can be used to switch the magnetization in three terminal magnetic tunnel junction memory elements or can be used to move domain walls in Racetrack Memory memory-storage devices. Indeed record-breaking current-induced domain wall speeds exceeding 1,000 m/sec have recently been reported in atomically engineered synthetic antiferromagnetic racetracks in which the domain walls are “invisible” with no net magnetization[3,4]. More complex non-collinear spin textures include the recent discovery of antiskyrmions[5] in a Heusler compound.

[1] Zhang, W. et al., *Sci. Adv.* **2**, e1600759 (2016).
[2] Demasius, K.-U. et al., *Nat. Commun.* **7**, 10644 (2016).
[3] Yang, S.-H., Ryu, K.-S. & Parkin, S. S. P.,. *Nat. Nano.* **10**, 221-226 (2015).
[4] C. Garg, S.-H. Yang, T. Phung, A. Pushp, S.S.P.Parkin, *Sci. Adv.* **3**, e1602804 (2017).
[5] A.K. Nayak, et al., *Nature* (2017).

Invited talks

MAGNETIC SHAPE MEMORY FREE-STANDING NANODISKS: ACTUATION MECHANISMS AND POSSIBLE APPLICATIONS

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Magnetic shape memory materials display multifunctional properties (e.g. magnetomechanical, magnetocaloric, magnetoreisistive…) arising from the presence of a martensitic transformation and magnetic states [1]. Low-dimensional materials, mainly thin films, have recently attracted much interest for their great potential in novel applications (e.g. microactuators, energy harvesters, solid-state microrefrigerators) [2]. We have shown that in epitaxial thin films the magnetic and structural properties can be optimized at the different length-scales by an appropriate choice of substrates/underlayers, thickness and growth parameters, including temperature and stress applied during growth [3, 4].

In the present talk we will focus on patterned structures and free-standing nanodisks.

Patterned thin films were obtained by polystyrene-nanosphere lithography of epitaxial NiMnGa-based thin films grown by sputtering r.f. on MgO substrates with a Cr underlayer. Free-standing nanodisks (d=160, 650 nm) were subsequently obtained by removing the Cr underlayer by a selective chemical etching. A multiscale structural and magnetic study was performed by means of electron microscopy (HREM, STEM-HAADF, electron diffraction, Lorentz microscopy), X-ray diffraction, AFM/MFM, and SQUID magnetometry.

Patterned thin films maintain the same macroscopic martensitic and magnetic properties of continuous thin films (e.g. martensitic transformation temperature, crystalline structures, magnetization loops). On the other hand, their microstructural and magnetic configurations are influenced by lateral confinement and release from substrate.

Remarkably, the combined application of temperature and field to free-standing nanodisks gives rise to substantial microstructural changes, enabling different actuation modes. Areal variation of the order of some percent, and tunable in intensity and sign by the application of T and magnetic fields have been obtained

These features, arising from the combination of ferromagnetic and martensitic properties, pave the way to the realization of ferromagnetic shape memory nanoactuators. Possible new–concept biomedical applications will also be discussed.

[1].M. Acet, et al., *Handbook of Magnetic* Materials **19**, Elsevier, Amsterdam (2001).
[2] A. Backen et al., *Adv. Eng. Mat.* **14**, 696 (2012).
[3] P. Ranzieri et al., *Acta Mater.* **61,** 263 (2013).
[4] P. Ranzieri et al., *Adv. Mater*. **32,** 4760 (2015).

FROM PARTICLES TO ORIENTED ASSEMBLIES: EFFECTS ON MAGNETISM AND APPLICABILITY

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Magnetic nanoparticles provide a unique versatile platform for modern technologies since they can be remotely and non-invasively employed as imaging probes, carrier vectors and smart actuators. To start with, we need magnetic nanoparticles with several well-defined and reproducible structural, physical, and chemical features, while specific-application nanoparticle design imposes several additional constraints. [1, 2] Since an external magnetic field is the usual drive of magnetism-based application schemes, we should have to maximize field effect by tuning particle collective magnetic features. Nanoparticles will eventually appear with suppressed magnetic features, depending on surrounding conditions/features/interactions, thus their configuration in 2D or even 3D oriented assemblies is widely proposed as a powerful way to control their macroscopic magnetic response on demand. Such assemblies have a direct impact on hysteresis losses, effective anisotropy and susceptibility. Mobility of the magnetic nanoparticles within the colloidal dispersion is a crucial factor that affects the assembly formation success rate, since diverse effects, such as magnetic, electrostatic, viscous, gravitational and molecular interactions are involved. Thus, magnetic nanoparticles may arrange randomly (Figs.1a-1b) or in order (Figs.1c-1e), accounting the complex three-dimensional magnetic coupling among them in conjunction with external field interactions (Fig.1f). [3-6] Magnetism both at the nanoscale level (single particles and assemblies) but also macroscopic collective magnetic features are found dramatically different for the different formations and alterations of applicability schemes arise.

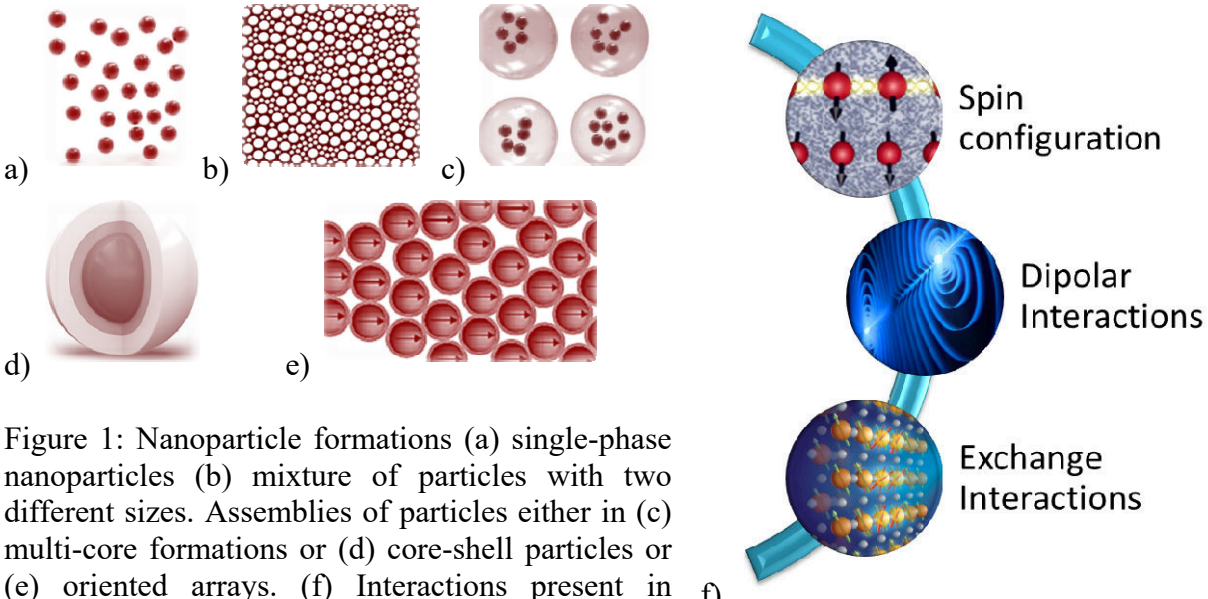

Figure 1: Nanoparticle formations (a) single-phase nanoparticles (b) mixture of particles with two different sizes. Assemblies of particles either in (c) multi-core formations or (d) core-shell particles or (e) oriented arrays. (f) Interactions present in magnetic nanoscale formations.

[1] M. Angelakeris, Biochimica et Biophysica Acta-General Subjects, 2016, in press, DOI: 10.1016/j.bbagen.2017.02.022.
[2] K. Simeonidis et al., *RSC Adv.* **6**, 53107 (2016).
[3] S. Liébana Viñas et al., *J. Mag. Magn. Mater.* **415**, 20–23 (2016).
[4] D. Sakellari et al., *Mat. Sci. Eng. C* **58**, 187–193 (2016).
[5] E. Myrovali et al., *Scientific Reports* **6**, 37934 (2016).
[6] K. Simeonidis et al., *Scientific Reports* **6**, 38382 (2016).

EFFICIENT COOLING WITH Fe_2P BASED MATERIALS

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Domestic refrigeration and air-conditioning contributes to about 30% of the electricity bill of an US household. The majority of cooling devices nowadays utilizes the vapor refrigeration cycle which works as follows; first the gas is compressed in a compressor, the heat produced in the compression stage is released to the environment and the gas condenses to form a liquid. In a throttling stage the pressure of the liquid is lowered and the fluid cools down. Evaporation from the cold fluid takes up the heat from the substance that needs to be cooled and the gas is fed back to the compressor.

This refrigeration cycle can be made energy-efficient when certain gases are utilized. However, these gases are extremely strong greenhouse gases. Currently refrigerant gases are the fastest growing source of greenhouse gas emissions, and according to the Kigali deal shall be phased out in the near future [1].

With the advent of giant magnetocaloric effects (MCE) that occur in conjunction with magneto-elastic or magneto-structural phase transition of first order (FOT), magnetocaloric refrigeration near room temperature became feasible. In this context the MnFe(P,X) system is of particular interest as it contains earth abundant ingredients that are not toxic. In this hexagonal system, the magnetic atoms occupy two inequivalent positions referred as *3f* (tetrahedral) and *3g* (pyramidal). One intriguing aspect is the disappearance of the magnetic moments on the *3f* sites when crossing T_C, whereas there is only a limited decrease on the *3g* site. This observation has led to a cooperative description of the FOT linking the loss of long range magnetic order at T_C with the loss of local moments on 3f. This mechanism has recently been shown to be at the origin of the G-MCE observed in MnFe(P,Si)[2].

[1] G.J.M. Velders et al., *Proc. Natl Acad. Sci. USA* **106**, 10949–10954.
[2] M.F.J. Boeije et al., *Chem. Mater.* **28**, 4901-4905 (2016).

FRONTIERS OF MAGNETOPHOTONICS AND MAGNETOPLASMONICS OF FUNCTIONAL NANOSTRUCTURES

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Modern magneto-optical materials perspective for various practical applications should possess reliable values of magneto-optical effects which can be significantly increased near spectrally narrow optical resonances. Magnetophotonic crystals (MPCs) that have resonances in the photonic density of states at the band-gap edge provide extensive opportunities for controlling the Faraday and Kerr effects. Under an external magnetic field applied to an MPC, an increase in the Faraday effect can be observed at the photonic-band-gap edge due to the slow light effect. A stronger enhancement of the Faraday rotation angle can be obtained at the narrow resonances of MPC reflectance spectra related to the multipass traveling of light in the MPC microcavity spacer. Another approach utilizes resonant plasmonic effects enhanced in periodic nanostructured materials. One of the modern techniques to observe magnetoplasmonic effects is the use of magnetoplasmonic crystals. Periodic nanostructuring of magnetoplasmonic crystals allows one to control propagation of surface plasmon polaritons (SPP) by the use of diffraction maxima to satisfy fulfill phase-matching for incident light and SPP. 2D-periodicity provides the opportunity of spectral tuning of the phase-matching conditions via superposition of two vectors of the reciprocal lattice.

In this presentation, recent results on realization of various magnetophotonic and magnetoplasmonic materials will be discussed. For example, we have observed the Fano-type Faraday rotation spectrum in a one-dimensional magnetophotonic crystal at the Bloch surface wave resonance and found that it is a result of the coupling between the s-polarized BSW and the p-polarized waveguiding modes of the magnetophotonic crystal [1,2]. The experimental observation of time-resolved polarization rotation within a single femtosecond laser pulse under conditions of slow light in magnetophotonic crystal will be discussed [3]. We also extend the concept of high-index resonant nanophotonics to the case of magnetically active materials and study the magneto-optical response of a dielectric metasurface covered with a thin magnetic film. We have reported on the demonstration of the magneto-optical effects enhanced by optically-induced magnetic dipole Mie resonances manifesting a strong interaction of magnetic properties with induced "optical magnetism" [4].

[1] M.N. Romodina, I.V. Soboleva, A.I. Musorin, Y. Nakamura, M. Inoue, A.A. Fedyanin, *Phys. Rev. B* **96**, 081401(R) (2017).
[2] M.N. Romodina, I.V. Soboleva, A.A. Fedyanin, *J. Magn. Magn. Mater*. **415**, 82 (2016).
[3] A.I. Musorin, M.I. Sharipova, T.V. Dolgova, M. Inoue, A.A. Fedyanin, *Phys. Rev. Appl.* **6**, 024012 (2016).
[4] D.A. Shilkin, M.R. Shcherbakov, E.V. Lyubin, K.G. Katamadze, O.S. Kudryavtsev, V.S. Sedov, I.I. Vlasov, A.A. Fedyanin, *ACS Photonics* **4**, 1153 (2017).

MAGNETIC METAMATERIALS: SPATIAL RESONANCES AND MRI ENHANCEMENT

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In this talk, I will briefly review the approaches to create artificial magnetic response with metamaterials, and highlight a range of interesting phenomena which can be observed in magnetic metamaterials and employed for applications.

First, some peculiarities of effective medium theory of magnetic metamaterials [1] will be introduced, with the emphasis on specific properties of finite-size samples [2], and enhanced role of metamaterial boundaries [3]. In addition, I will briefly outline the possibilities to achieve nonlinear magnetic response [4] by introducing novel degrees of freedom in metamaterial design, interlinking physical features of different nature [5].

Then, specific attention will be directed towards application of magnetic metamaterials for magnetic resonance imaging, with the aim of improving resolution and depth of imaging [6]. On this track, I will demonstrate that remarkable deviations can be observed between predictions of the effective medium theory and precise calculations for practically relevant samples [7]. With this respect, I will also mention the recent achievement in MRI applications of metamaterials from other groups [8].

Time permitting, I will also briefly discuss non-resonant designs [9], suitable for strong artificial diamagnetism, with a potential for light-weight and reconfigurable magnetic levitation.

[1] M. Gorkunov, M. Lapine, E. Shamonina, K.H. Ringhofer, *Eur. Phys. J. B* **28,** 263–269 (2002).
[2] M. Lapine, R.C. McPhedran, C.G. Poulton, *Phys. Rev. B* **93,** 235156 (2016).
[3] M. Lapine, L. Jelinek, R. Marqués, *Opt. Express* **20,** 18297–18302 (2012).
[4] M. Lapine, I.V. Shadrivov, Y.S. Kivshar, *Rev. Mod. Phys.* **86,** 1093–1123 (2014).
[5] M. Lapine, I.V. Shadrivov, D.A. Powell, Y.S. Kivshar, *Nature Materials* **11,** 30–33 (2012).
[6] M.J. Freire, L. Jelinek, R. Marqués, M. Lapine, *J. Magn. Resonance* **203,** 81–89 (2010).
[7] M. Lapine, L. Jelinek, M. Freire, R. Marqués, *Phys. Rev. B* **82,** 165124 (2010).
[8] A.P. Slobozhanyuk et al., *Advanced Materials* **28,** 1832-1838 (2016).
[9] M. Lapine, A.K. Krylova, P.A. Belov, C.G. Poulton, R.C. McPhedran, and Y.S. Kivshar, *Phys. Rev. B* **87** 024408 (2013).

DEVELOPMENT OF GOLD-MAGNETITE HYBRID NANOPARTICLES FOR BIOMEDICAL APPLICATION

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Nanobiotechnology, the combination of nanotechnology and molecular biology is a tremendously powerful technology. It holds a huge promise for the design and development of many types of novel products with potential applications in the fields of biology and medicine, including early disease detection through advanced noninvasive medical imaging, treatment through high site-specific drug delivery and protein purifications. Gold-Magnetite Hybrid magnetic nanoparticles have received significant attention recently and are actively investigated owing to their large potential for a variety of applications. As a bifunctional nanoparticle, gold-iron oxide nanoparticle can inherit excellent surface chemistry characteristics, unique optical properties (attributed to Au) and superparamagnetic characteristics attributed to Fe-oxides. Drugs attached to these bifunctional nanoparticles can have more advantages over ordinary drugs.

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STANDARDIZATION METHODS FOR THE SYNTHESIS OF MAGNETIC NANOPARTICLES FOR MEDICAL APPLICATIONS

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In the last decade, there have been huge advances in the synthesis of magnetic nanoparticles for biomedical applications fitting the requirements in terms of size, surface and colloidal stability under physiological conditions intrinsic to each particular application [1]. Although numerous studies have reached the clinical use of these nanoparticles as magnetic resonance imaging contrast agents, for other applications such as hyperthermia treatments, tissue regeneration, magnetically driven transfection of stem cells or delivery of genetic materials, nanoparticles' use in an efficient and safe manner remains to be assessed.

In general, cost-effective, environmental friendly and large-scale synthesis methods have been pursued keeping good control of size, shape, and composition of magnetic nanoparticles, which is a difficult task considering that the difference of only few nanometers in particle size means huge differences in volume resulting in a functional or failed product [2]. Reproducibility of current synthetic methods, which are able to manufacture high quality MNPs in large scale, is still a major challenge [3,4]. On the other hand, uniformity is a critical point in order to establish the relationships between the physicochemical properties of the nanostructures and their behavior in vitro and in vivo, which is currently poorly understood. On top of that, there is a fundamental and pressing need to develop more sustainable protocols, less toxic nanomaterials in a more efficacious manner.

[1] L. Gutiérrez, R. Costo, C. Grüttner, F. Westphal, N. Gehrke, D. Heinke, A. Fornara, Q.A. Pankhurst, C. Johansson, S. Veintemillas-Verdaguer, M.P. Morales, *Dalton Transactions* **44** (7), 2943-2952 (2015).
[2] G. Salas, S. Veintemillas-Verdaguer, M.P. Morales, *International Journal of Hyperthermia* **29** (8), 768-776 (2013).
[3] H. Gavilán, O. Posth, L.K. Bogart, U. Steinhoff, L. Gutiérrez, M.P. Morales, *Acta Materialia* **125**, 416-424 (2017).
[4] Y. Luengo, M.P. Morales, L. Gutiérrez, S. Veintemillas-Verdaguer, *J. Mater Chem. C* **4**, 9482-9488 (2016).

BIOMEDICAL APPLICATIONS OF MAGNETIC NANOPARTICLES

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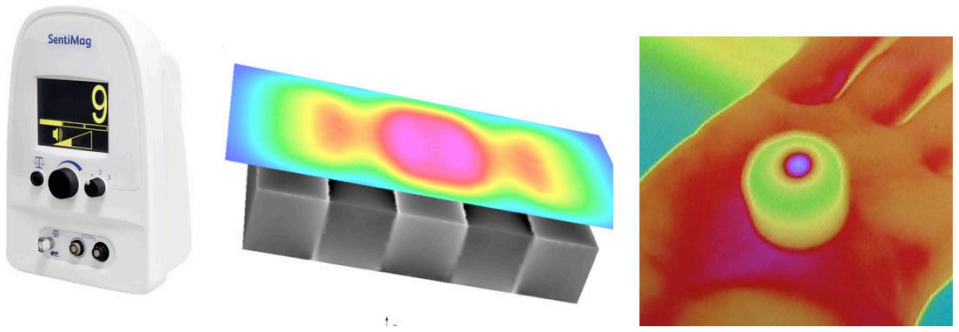
'Healthcare Biomagnetics' – the sensing, moving and heating of magnetic nanoparticles in vitro or in the human body – is a rapidly changing field that is attracting much interest worldwide [1]. It offers the potential to develop safe and convenient alternatives for a diverse range of therapeutic and diagnostic healthcare applications, using injectable materials of proven safety and reliability. In doing so, it makes use of the three fundamental 'action-at-a-distance' properties of magnetic materials – their ability to act as remote sensors [2], mechanical actuators [3], and sources of heat in both hyperthermia and thermoablation [4].



Representative images related to (from left to right): magnetic sensing, actuation and hyperthermia.

The versatility of the field is also leading to the emergence of multi-modal applications, combining two or more of the sensing-moving-heating properties in the same product. Certain applications are now entering or are close to beginning Phase I/II clinical trials, or in the case of in vitro products, are already entering the marketplace. Accordingly, in this lecture a selection of examples of recent work in healthcare biomagnetics will be presented and discussed [5].

[1] Q.A. Pankhurst et al., *J. Phys. D* **36**, R167, (2003); *ibid* **42**, 224001 (2009).
[2] U.A. Gunasekera et al., *Targeted Oncology* **4**, 169 (2009); M.R. Loebinger et al., *Cancer Research* **69**, 8862 (2009); K.L. Vigor et al., *Biomaterials* **31**, 1307 (2010).
[3] E. Stride et al., *Ultrasound Med. Biol*. **35**, 861 (2009); J. Riegler et al., *Biomaterials* **31**, 5366 (2010); J. Riegler et al., *J. Phys. D* **44**, 055001 (2011).
[4] M. Kallumadil et al., *J. Magn. Magn. Mater.* **321**, 3650 (2009); L.A. Thomas et al., *J. Mat. Chem.* **19**, 6529 (2009); K. Parcell et al., *Thorax* **65**, A41 (2010).
[5] G.M. da Costa et al., *J. Phys. Chem. B* **118**, 11738 (2014); R.R. Wildeboer et al., *J. Phys. D* **47**, 495003 (2014); C. Blanco-Andujar et al., *Nanoscale* **7**, 1768 (2015); J. Bai et al., *Theranostics* **6**, 342-56 (2016); C. Blanco-Andujar et al., *Nanomedicine* **11**, 121-36 (2016).

DESIGNING MAGNETIC NANOMATERIALS FOR BIOMEDICAL APPLICATIONS

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Design of magnetic nanomaterials for specific biomedical applications (e.g. Drug Delivery, Magnetic hyperthermia, MRI) means to control the matter at the nanoscale, correlating magnetic properties, micro and mesostructure and molecular coating. Taking into account all of these points, this communication will focus on the design of magnetic nano-architectures (MNA) for biomedical applications, discussing some recent synthesis and functionalization of magnetic nanomaterials[1–3]. These MNA are typically of core-shell morphology and their shell may be composed of polymers, surfactants or mesoporous silica, which typically serve for embedding the therapeutic agents within their framework. Selectivity of the treatment is ensured through employing magnetic field-responsive homing of the nanocarriers to the therapeutic area, along with possibilities for alternating magnetic field hyperthermia-resulted treatment of the ill tissues. The induced hyperthermia may be therapeutically active through causing denaturation of biomolecules in the treatment area, or/and through mediating release of the cargo therapeutic agents.

[1] G. Singh, B.H. McDonagh, S. Hak, D. Peddis, S. Bandopadhyay, I. Sandvig, A. Sandvig, W.R. Glomm, *J. Mater. Chem. B* **5**, 418–422 (2017).
[2] D. Peddis, G. Muscas, R. Mathieu, P.A. Kumar, G. Varvaro, G. Singh, I. Orue, D. Gil-Carton, L. Marcano, A. Muela, *et al., Faraday Discuss.* ***0***, 1–12 (2016).
[3] N.Z. Knezevic, C.M. Jimenez, M. Albino, A. Vukadinovic, A. Mrakovic, E. Illes, D. Janackovic, J.-O. Durand, C. Sangregorio, D. Peddis, *MRS Adv.,* 1–8 (2017).

DEVELOPMENT OF HIGH ENERGY X-RAY MICROSCOPY FOR MATERIAL RESEARCH

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The development of 3rd generation synchrotron radiation (SR) sources in parallel with recent advances in the technology of X-ray microfocusing elements like refractive (Compound refractive lenses/CRL) optics, makes possible to realize X-ray microscopy with X-ray energy superior to 2 keV. In addition to conventional X-ray microscopy techniques like X-ray micro-spectroscopy and micro-diffraction techniques, coherence properties of new synchrotron radiation sources allow to perform coherent imaging including holography, full-field phase contrast imaging and microtomography. The concept of combining these three techniques as a high-energy microscopy has been successfully realized at different SR beamlines.

The microscope was applied for study of natural and synthetic self-organized structures, metal inverted photonic crystals and colloidal suspensions. The combination of the direct-space imaging and high resolution diffraction provide a wealth of information on their local structure and the long range periodic order. The development of the hard x-ray microscope emerged concomitantly with the realization of the 4th generation SR sources with greatly enhanced brilliance and fraction of coherent light, and this will open entirely new frontiers in materials imaging. Short acquisition times allow to extend the microscope to time-resolved studies of the crystallization dynamics, response of the mesoscopic structures to external stimuli such as mechanical strain, temperature jump or temperature gradient as well as external electric and magnetic fields.

MAGNETIC NANOSTRUCTURES AS HYPERTHERMIA AGENTS: ROLE OF HYSTERESIS LOSSES

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Magnetic nanostructures raised interest for biomedical applications, such as contrast agents in magnetic resonance imaging, drug delivery systems and hyperthermia. The magnetic moment is therefore exploited for target-directed delivery, detection, separation, and manipulation. Among the open issues preventing their full exploitation as therapeutic agents, reliable and reproducible methods of measuring the functional capability have to be established. In case of magnetic hyperthermia, traceability of specific absorption rate (SAR) is far to be gained. In particular, a careful characterization of the magnetic properties regarding both the fundamental properties of the studied particles (magnetization curves, hysteresis losses) and their thermal properties during hyperthermia treatments is required. Indeed, these data are often available from different setup operating in different experimental conditions that make difficult to ensure measurements traceability. In this context, magnetic hysteresis loops areas and their role on the heat released have been studied with the aim of providing reliable and reproducible methods to measure the specific absorption rate (SAR). The SAR of two sets of Fe_3O_4 nanoparticles (one displaying superparamagnetic features and the other ferromagnetic ones) has been measured with three approaches using ad-hoc developed set-ups: static hysteresis loops areas, dynamic hysteresis loops areas and hyperthermia of a water solution. The latter has been fully modelled to provide a direct measurement of the SAR of the magnetic nanoparticles by taking into account the heat exchange with the surrounding environment in non-adiabatic conditions and the parasitic heating of the water due to ionic currents [1].

To support the therapeutic application of magnetic nanoparticles a careful control of geometrical parameters is needed to tune the magnetic properties of interest. Recently, NiFe nanodisks characterized by a magnetic vortex state have been proposed as promising nanostructures for hyperthermia being characterized by high saturation magnetisation and zero remanence [2]. Free-standing nanodisks having 30 nm thickness and diameters D = 200 and 650 nm have been fabricated by self-assembling of polystyrene nanospheres. The energy product values have been measured by the hysteresis loop area assumed to be one of the dominant contribution in the hyperthermia process. Specific absorption rate has been calculated. The energy product decreases with increasing nanodisks diameter. Micromagnetic simulations have been performed to analyze the effect on magnetization reversal process and hysteresis losses of the patterned film geometrical properties, i.e. dot diameter and thickness and inter-dot distance. In-vitro toxicity assessment of the nanodisks will be here discussed together with the evaluation of cellular uptake.

[1] M. Coïsson et al., *Biochimica et Biophysica Acta (BBA)*, In Press, (2017).
[2] D.H. Kim et al., *Nat Mater*. **9**, 165 (2010).

BIOMEDICAL APPLICATIONS OF GLASS-COATED MICROWIRES

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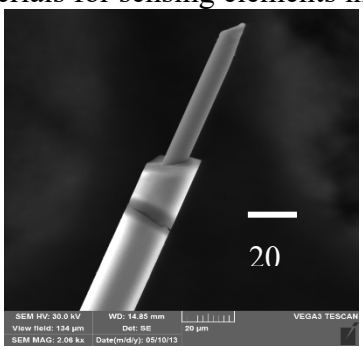
Glass-coated microwires are composite materials (see fig.) that consists of metallic nucleus (diameter from 1-50 μm) that is covered by glass (thickness 2-20 μm). Having positive magnetostriction, such wires are characterized by magnetic bistability (static magnetization has only two values + or - M_s) where switching between the two magnetization appears at the switching field. The switching field is sensitive to temperature, mechanical stress or any other parameter that can be transformed into them. Due to their small dimensions and glass-coating (that provides biocompatibility), they are ideal materials for sensing elements in biomedicine [1,2].



In the given contribution, the examples of applications of glass-coated microwires for biomedical sensing will be shown. Firstly, applications of microwires for sensing the temperature in titanium implants will be presented. Secondly, application of microwires for monitoring stress and temperature in spinal cord, muscles and bones will be discussed. Moreover, technical problems connected to biocompatibility and practical usage will be outlined.

[1] I. Sulla et al., *Journal of Electrical Engineering* **66**, 7/s, 161-163 (2015).
[2] R. Sabol et al., accepted for *Acta Phys. Pol.* A (2017).

NOVEL APPLICATIONS OF NANO-MAGNETISM TO BIOMEDICINE

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One of the major goals of medicine is the development of low cost and portable diagnostic tools for screening a large number of patients, and a wide range of medical conditions involving point of care diagnosis closer to citizen. The tools developed so far to achieve single-molecule manipulation and detection are highly complex, require accurate calibration and can produce substantial heating. Recent advances in nano-magnetism, reviewed in this talk, might allow overcoming these issues.

Regarding on-chip manipulation, we proposed and used a special type of domain walls in magnetic-nanostructures, the so called constrained magnetic domain walls, as easily moveable traps for magnetic nano- and micro-particles [1]. We designed magnetic domain wall nano-conduits and fabricate them by advanced lithography on functional substrates suitable for bio- and microfluidic-applications [2]. We have demonstrated precise, and robust manipulation of magnetic nanoparticles [3,4] and bio-entities (proteins and cells) [1,5] labeled with magnetic particles in solution with nm-scale precision, solely by means of an externally applied magnetic field, which allowed for remote on-chip operation.

Another recent and extremely promising application of nano-magnetic structures is to bio-detection. Plasmonic biosensors based on metallic nanoparticles are currently attracting great attention due to their intrinsically small size and localized sensing volume/area, which is essential for parallel readout. Typical plasmonic sensing utilizes the localized surface-plasmon (LSP) resonance shift due to the local refractive index change upon molecular adsorption. We have recently shown that the use of ferromagnetic nanoparticles allows for a phase sensitive detection scheme thanks to the simultaneous presence of LSP and magneto-optical activity [6], through which one can achieve substantially improved performances with a sensitivity down to the single molecule level [7].

Together with the Technical University of Denmark, the University of Barcelona, and the Danish company Bluesense Diagnostics, we are developing further this approach and its integration into practically applicable biomedical sensing methodologies and device components [8]. More specifically, we are exploring the use of specially designed “janus” particles made of 100-nm-diamter silica nanospheres are half covered with multilayers of Fe/Au or Co/Au. They display simultaneous and large anisotropic magnetic and plasmonic properties to be conveniently used in our recently proposed opto-magnetic approach [8] that is being already exploited in a real portable device commercialized by Bluesense Diagnostics.

[1] M. Donolato et al., *Adv. Mater.* **22**, 2706 (2010).
[2] M. Donolato et al., *Adv. Mater.* **25**, 623 (2013).
[3] Torti et al., *Appl. Phys. Lett.* **101**, 142405 (2013).
[4] A. Sarella et al., *Adv. Mater.* **26**, 2384 (2014).
[5] M. Donolato et al., *Lab Chip* **11**, 2976 (2011).
[6]N. Maccaferri et al., *Phys. Rev. Lett.* **111**, 167401 (2013).
[7] N. Maccaferri et al., *Nat. Commun.* **6**, 6150 (2015); R. Verre et al., *Nanoscale* **8**, 10576 (2016).
[8] M. Donolato et al., Anal. Chem. **87**, 1622 (2015); J. Yang et al., *Biosensors and Bioelectronics* **75**, 396 (2016).

CYLINDRICAL NANOWIRES AND THEIR ARRAYS: MAGNETIC TECHNOLOGICAL APPLICATIONS

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Metallic nanowires are currently synthesized by electrochemical route that benefits of its less-expensive character combined with a large versatility to prepare a wide spectrum of samples out of single metallic elements and alloys. They are grown by electrodeposition inside the nanopores of self-assembled anodic alumina membranes under controlled electrochemical parameters to result into designed final cylindrical nanowires. Their shape can be tailored to be modulated in the radial (i.e., nanotubes, core/shell nanowires) and axial (i.e., periodically notched and antinotched diameter, and multisegmented) directions. Ferromagnetic cylindrical nanowires are increasingly attracting specific interest because they constitute nearly ideal systems to study fundamental magnetization processes and magnetic phenomena.

Cylindrical nanowires, either individually or as 3D arrays, are being investigated for advanced technological applications. Among others, in information storage as magnetic recording media as well as reading heads; in specific spintronics and logic devices; microwave and high-frequency systems; plasmonics and magnetooptical devices; thermo-elctro-magnetic new phenomena; magnetic and magnetoelastic sensing; and so on.

In this presentation we will firstly describe the details of the controlled electrochemical synthesis to design the geometry of nanowires, as well as the general magnetic and structure characteristics of nanowires to reach control on the magnetic domains, magnetic anisotropy and domain structure. Second, we will review in more detail those above mentioned applications.

We will review specific investigations carried out in our group applications on cylindrical nanowires as: novel hard magnetic systems and alloys free of rare earth elements and the mechanism of magnetization hardening [1-3]; magneto-polymers core/shell hybrid systems [4-6]; and discuss recent results for magnetic resonance agents, chemical and environmental biological devices obtained in multisegmented nanowires [7, 8].

[1] C. Bran et. al., *J. Phys. D:A Appl. Phys.* **50**, 065003 (2017).
[2] E. Palmero et. al. *Nanotechnology* **27**, 365704 (2016).
[3] N. Minguez et. al., *Microporous & Mesoporous Materials* **225**, 192 (2016).
[4] J. Ovejero et. al., *JMagnMagnMater* **389**, 144 (2015).
[5] C. Mijangos et. al., *Ind. Eng. Chem. Res.* **54**, 13005 polymers.
[6] Y. Ivanov et. al., *Sci. Reports* 624189 DOI 10.1038srep24189 harsh environment.
[7] C. Bran et. al., *Nanotechnology* **28**, 095709 (2017).
[8] M. Bañobre et. al., *J. Mater. Chemistry B*, DOI 10.1039c7tb00574a (2017).

ORAL TALKS

MAGNETOCALORIC EFFECT IN MnAs-BASED MULTIFERROIC COMPOSITES

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In recent years, multiferroics are considered as a perspective materials for solid-state refrigerators due to the coexisting of the magnetocaloric (MCE), electrocaloric (ECE) and elastocaloric (BCE) effects. Multiferroics with two or more caloric effects are called multicalorics. In particular, the caloric effects of multicalorics near the phase transition temperatures are increased due to the interaction of the electric and magnetic subsystems and called multicaloric effect. In this regard, a search for multicalorics with magnetic and ferroelectric transitions around the room temperatures was conducted recently.

Thus, the measurements of the direct and indirect MCE were performed for the multiferroic composites consist of the modified PMN-PT relaxor-type ferroelectric ceramics with formula $Pb_{(1-z)}Ba_z(Mg_{1/3}Nb_{2/3})_m(Zn_{1/3}Nb_{2/3})_y(Ni_{1/3}Nb_{2/3})_nTi_xO_3$ (z=0.10, m = 0.4541, y= 0.0982, n = 0.1477, x=0.3) and ferromagnetic compound of MnAs. Both components have the ferroelectric (FE) and magnetic (FM) ordering around 315 K. MnAs is a ferromagnet with its Curie temperature of 317 K. The ferromagnetic–paramagnetic transition is the first-order type accompanying by a structural transition from hexagonal type to orthorhombic type. The (x)MnAs-(1-x)PMN-PT (x=0,2; 0,3) composites were prepared by a cold pressing method of powders of PMN-PT and MnAs under hydrostatic pressure with value of 3GPa at room temperature, which previously were milled and mixed in different proportions. The structure of the composite was studied using X-ray powder diffractometer and scanning electronic microscope.

Differences in values of entropy (ΔS) and temperature (ΔT) changes of MCE between pure MnAs and composites were observed from direct and indirect magnetocaloric measurements. If the peaks of ΔS and ΔT near 315 K for pure MnAs have only magnetic field induced origin, anomaly of ΔS and ΔT for (x)MnAs-(1-x)PMN-PT composites can be observed due to the stress of the FE phase on magnetic component, where FE phase has anomalous increasing thermal expansion near 315 K. The (x)MnAs-(1-x)PMN-PT composite with x=0.2 demonstrates larger direct MCE compositing with a lower content of magnetic phase, x=0.3, which can be explained by elastocaloric contribution in total multicaloric effect.

METAMAGNETISM IN $ErCo_4Al$: SINGLE-CRYSTAL STUDY

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A high-field magnetization study of an $ErCo_4Al$ single crystal (hexagonal crystal structure of the $CaCu_5$ type) revealed that the compound is a ferrimagnet (T_C = 500 K, M_s = 3.5 μ_B at 4.2 K) with strong uniaxial magnetic anisotropy and exhibits in fields applied along the easy *c* axis field-induced phase transitions above 40 T corresponding to remagnetization of the Co sublattice towards the Er one. The transitions are accompanied by pronounced longitudinal and transverse magnetostriction, showing strong magnetoelastic interactions in the compound (Fig. 1). Anomalies in acoustic properties confirm that there are indeed two transitions (Fig. 2).

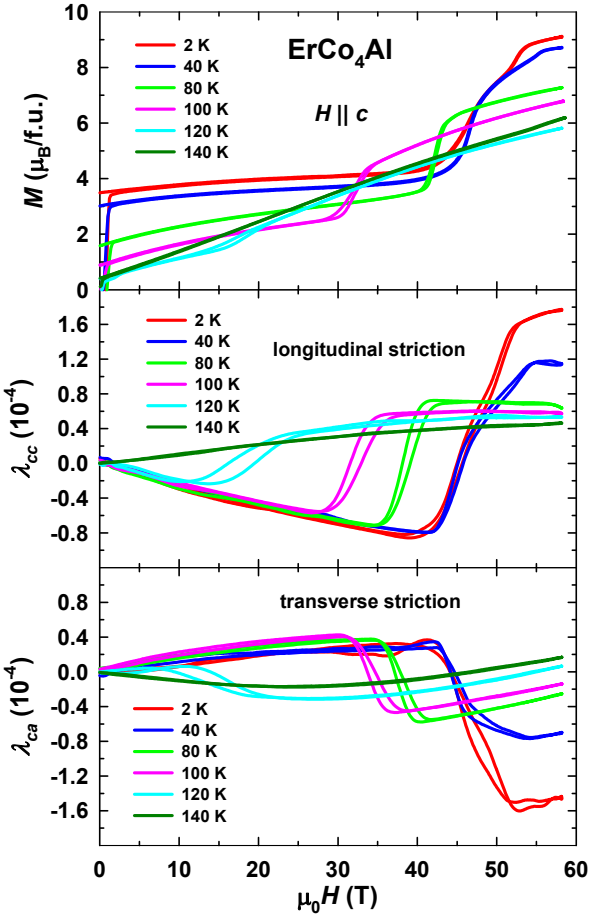

Fig. 1 (left). Magnetization and magnetostriction (longitudinal and transverse) of $ErCo_4Al$ single crystal in field applied along the *c* axis at different temperatures.

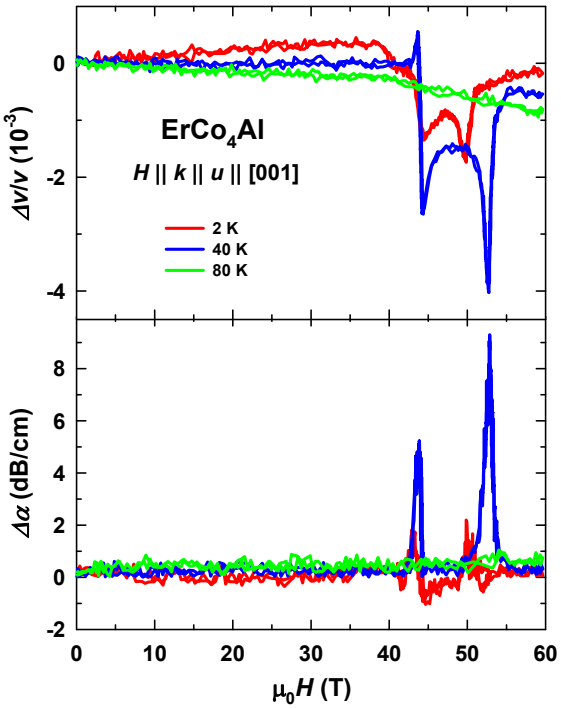

Fig. 2. Field dependences of changes in sound velocity and attenuation (longitudinal geometry) at different temperatures in field along the *c* axis.

Acoustic anomalies exhibit non-monotonous behavior being maximally sharp at 40 K. They disappear at 80 K whereas magnetization and magnetostriction show anomalies up to the compensation point (128 K). In 60 T, magnetization reaches 9 μ_B which corresponds very well to the magnetic moment of the Er atom. Therefore, we can interpret the transitions as demagnetization of the Co sublattice, 3 atoms on 3g site at ~45 T and 1 atom on 2c site at ~50 T. At higher fields, transformation to the forced ferromagnetism is expected also by two transitions.

STABLE COLLOIDS OF STRONTIUM HEXAFERRITE NANOPARTICLES WITH SILICA COATING

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Ferrofluids containing hard ferrite particles are of great interest because of their distinctive features — high magnetocrystalline anisotropy of the material and platelet-like anisotropic particle shape. Such colloidal solutions can be used as material for production of magnetic coatings, films, nanocomposites, and nanostructures. Surface modification of the magnetic particles is an important step towards their further practical application. Silica coated magnetic particles are perspective for use as magnetic nanocontainers for biomedical *in vitro* applications in diagnostics; by coating magnetic nanoparticles with large non-magnetic shell the polydispersity of a system can be considerably reduced allowing self-organization into highly symmetric mesostructures like magnetically controllable optically active colloidal crystals. However, preparation of hexaferrite-based magnetic fluids is hindered by strong inter-particle magnetic interactions that lead to their agglomeration and subsequent sedimentation.

Colloids of hard-magnetic strontium hexaferrite nanoparticles were obtained using glass-ceramics method; shortly we obtained oxide glasses in the $4Na_2O–9SrO–5.5Fe_2O_3–4.5Al_2O_3–4B_2O_3$ and $13SrO–6Fe_2O_3–6B_2O_3$ systems; then heat-treated it at 640–700°C forming glass-ceramics, which were grounded and then treated with 3% HCl at 50°C with simultaneous sonication. The magnetic nanoparticles were magnetically separated from the solution by decantation; finally, water was added to disperse the particles. For obtaining silica coated material we used two different methods based on modified Stöber process and acidic silicate hydrolysis.

According to XRD colloidal particles possess strontium hexaferrite structure; magnetic measurements of dried powders showed that particles exhibit hard-magnetic behaviour with a saturation magnetization of 30–60 emu/g and a coercivity of 3200–4000 Oe. According to TEM colloidal particles are plate-like with mean diameter of the plate 50 and 16 nm and mean thickness 5 and 6 nm for different glass compositions correspondingly.

It was shown that in an aqueous medium colloidal nanoparticles are electrostatically stabilized due to a positive surface charge; colloids are stable in the pH range from 1 to 5 and concentration of a single-charged electrolyte less than 100 mmol/l. We observed condensation of the particles with forming concentrated liquid phase under the influence of gradient magnetic field; this concentrated liquid was investigated using AC and DC magnetic measurements and SAXS, which showed the presence of thread-like dynamic aggregates with periodic interparticle distance about 20 nm in the solution.

Using two different methods core-shell and plum pudding structures of silica-coated hexaferrite particles were obtained. According to TEM core-shell particles are flattened spheres of silicon dioxide with hexaferrite particle inside (the larger diameter more than 100 nm); plum pudding structures are silica particles gel with randomly dispersed hexaferrite particles inside. According to magnetic measurements of dried powders, these composites consist of more than 80 weight percent of silica.

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MAGNETIC PHASE TRANSITIONS IN B2 ALLOYS USING IONS

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Magnetic devices, for magnetic data storage, spin-transport or magnonic applications can benefit immensely from the ability to produce nanoscale magnets of desired geometries. We show how ion-beams can be used to generate nanomagnets in thin films of certain alloys such as B2 ordered $Fe_{60}Al_{40}$ and $Fe_{50}Rh_{50}$.[1,2] In these materials a large increase of the saturation magnetization is achieved by inducing subtle atomic displacements caused by collision cascades of penetrating light ions. The ions knock atoms from their ordered sites, generating antisite defects and causing an increase of the Fe-Fe nearest-neighbour interactions which are linked to the increasing magnetization. For instance, a weak magnetization of 0.04 μB per Fe-atom in B2-$Fe_{60}Al_{40}$ can be increased to 1.67 μB per Fe-atom by the irradiation of light noble gas ions such as He^+ or Ne^+.

The above ion-induced increase of magnetization can be manifested at the local scale and is termed positive magnetic patterning. Patterning can be performed either by irradiation through lithographed masks, or by a direct writing process using the highly focused ion-beam of a Gas Field Ion-Source.[1] Lateral magneto-resistive devices and magnetic arrays produced by ion-irradiation will be described. Insights gained so far, into the mechanism of disorder induced ferromagnetism will be discussed.

[1] S. Cybart, R. Bali et al., *Helium Ion Microscopy, Springer International Publishing* 415-445 (2016).
[2] A. Heidarian et al., *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* **358**, 251 (2015).

BIMAGNETIC CONCENTRIC CORE/SHELL MICROWIRES: A NOVEL PERSPECTIVE FOR ACTUATING

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Magnetism of wires is relevant because of their specific geometry characterized by a cylindrical symmetry and large length to diameter aspect ratio. That implies a strong shape anisotropy which in addition to anisotropy contributions from crystal symmetry and magnetostrictive deformations confer them a unique magnetic behavior suitable for technological applications, particularly in sensor devices and actuators. Interest in recent years has been focused towards multilayer magnetic systems with high potential in magnetic recording and sensor devices (field, temperature or pressure sensors). These systems include a specific new type of bimagnetic phase microwires based on those glass-coated microwires where an external shell is electrodeposited [1].

In this work, a family of core/shell bimagnetic microwires is introduced consisting of a cylindrical magnetic core covered by a concentric but asymmetric external shell fabricated by combined rapid solidification and sputtering techniques. The two magnetic phases are isolated by an intermediate glassy microtube and are designed to show differential soft/soft or soft/hard magnetic behavior. Particular attention is paid to Fe-based magnetically soft core covered by either magnetically ultrasoft FeNi or harder Co external shell. Bulk magnetic properties of each magnetic phase are analyzed by vibrating sample magnetometry, VSM, and compared to local surface hysteresis loops determined by magneto-optical Kerr effect, MOKE. The SEM images allows us to confirm the asymmetry of the shell. Moreover, a phenomenological model of the interaction between the shell and the core was obtained taking into account the magnetostatic and magnetoelastic energies. The results suggest for the possibility of creation the magnetic manipulator based on bimagnetic concentric core/shell microwires with asymmetric external shell [ссыль на патент].

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[1] J. Torrejón, G. Badini-Confalonieri, M. Vázquez, *JAP* **103**, 07E712 (2008).

[2] Patent 300239362, M. Vázquez, R. Elkammouni, V. Rodionova, N. Perov, K. Chichay, I. Baraban.

SYNTHESIS AND PROPERTIES OF CORE-SHELL Fe_3O_4@Au NANOCOMPOSITES DESIGNED FOR BIOMEDICAL APPLICATIONS

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The «core-shell» nanocomposites based on iron oxides and noble metals (silver, gold, platinum and palladium) gained much attention as the materials with unique biocompatibility and high catalytic properties [1].

Size effects determine the specific properties of such nanoscale structures and they significantly differ from the properties of bulk analogues. Such nanomaterials can be used in several advanced functional applications, in particular, for biomedical targeted drug delivery and treatment of traumatic injury of spinal cord with its simultaneous regeneration.

In this work, the «core-shell» Fe_3O_4@Au nanocomposites were obtained with a new method by $HAuCl_4$ reduction in the presence of Fe_3O_4 nanoparticles and their further stabilization by polyethylene glycol. Obtained nanostructures were investigated with powder X-ray and electron diffraction, high resolution electron microscopy (HRTEM), optical, Raman and Mössbauer spectroscopy.

The HRTEM and Raman spectroscopy data approved the complete gold covering of magnetite nanoparticles in the Fe_3O_4@Au nanocomposites.

The Mössbauer data revealed different magnetic properties of Fe ions in the interior areas and in the surface layer of Fe_3O_4 nanoparticles. This is associated with break of the exchange bonds at the particles surface leading to decrease of the effective magnetic moment.

It was found out that the gold coating leads to the formation of bonds between gold, oxygen and iron atoms and stabilizes the magnetic properties of the magnetite surface layers, approaching them to the properties of inner layers of magnetite.

[1] S. Venkateswarlu, et al, *Physica B: Condensed Matter* **457**, 30 (2015).

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SURFACE MAGNETISM OF OXIDED SEMICONDUCTOR CLUSTERS WITHOUT MAGNETIC ATOMS

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Semiconductor nanoparticles are among the most popular nanoscale systems due to their unique properties, that differ them both from bulk samples and individual atoms. These unusual properties hold great promise for many applications, such as electronics, solar energetics, photocatalysis, biomedicine, etc. In numerous applications it is highly desirable to obtain materials that possess both semiconductor and magnetic features. One way to their development is the doping of semiconductor particles by Mn and other magnetic 3d-elements, which is analogous to the diluted magnetic semiconductors and shares many of its problems. Another way employs spin polarization existing at the surface of semiconductor nanoparticles. Such spins, in particular, were detected experimentally at the surface of CdSe nanocrystals passivated by TOPO (tri-n-octylphosphine oxide) [1]. As was argued later [2], the reordering of spins activates the radiative recombination of dark excitons in CdSe nanocrystals, that is, the photoluminescence of these quantum dots is controlled by spin flip-flop processes at the nanocrystal surface. This activation mechanism has been supported by the measurements of temperature-dependent recombination rate and light emission however a first-principles justification of this model was not given.

The existence of spin polarization at the surface of semiconductor nanoparticles was validated by the first-principles calculations of Mg_nO_m [3] and Si_nO_m [4] nanoclusters. These calculations showed that in oxygen atmosphere the equilibrium Mg_nO_m and Si_nO_m nanoclusters have excessive O atoms, comparing to the stoichiometric MgO and SiO_2 compositions. They are precisely those O atoms, which are responsible for spins at the cluster surface. The present first-principles study analyses the origin of a spin polarization of surface O atoms, its connection with the characteristic groups of atoms at the cluster surface and competition between ferromagnetic (FM), ferrimagnetic, and antiferromagnetic (AFM) spin orderings. We calculate the energy difference $\Delta E=E_{AFM}-E_{FM}$ and consider its dependence on nanocluster characteristics: the surface geometry of a cluster, distance between spin-polarized atoms, occupation of electron levels, etc. We expect that these features are typical of most oxide nanoparticles and many of them take place in semiconductor nanoparticles of different types.

[1] M.S. Seehra, P. Dutta, S. Neeleshwar, Y.-Y. Chen, C. L. Chen, S. Wei Chou, C.C. Chen, C.-L. Dong, C.L. Chang, *Adv. Mater.* **20**, 1656-1660 (2008).
[2] A. Rodina, Al.L. Efros, *Nano Lett.* **15**, 4214 (2015).
[3] S. Bhattacharya, S.V. Levchenko, L.M. Ghiringhelli, M. Scheffler, *Phys. Rev. Lett*. **111**, 135501 (2013).
[4] S. Lepeshkin, V. Baturin, E. Tikhonov, N. Matsko, Yu. Uspenskii, A. Naumova, O. Feya, M. Schoonen, A. Oganov, *Nanoscale* **8**, 18616-18620 (2016).

COUPLED ELECTRON-PHONON MODES IN MULTIFERROIC $PrFe_3(Bo_3)_4$ SUBJECTED TO A MAGNETIC FIELD

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If a phonon and an electronic excitation of a crystal are in resonance, interaction between them leads to formation of coupled electron-phonon modes. This phenomenon is typical of a very broad class of stoichiometric *f* and *d* materials and is accompanied by an energy renormalization and redistribution of intensities in the low-frequency part of the spectra. As just this part of the energy spectrum governs thermodynamic and magnetic properties of the compound, it is important to understand physics of coupled electron-phonon modes and of their behavior in external magnetic fields.

In this presentation, we report on a new effect associated with the electron-phonon interaction, namely, appearance of nonzero gap in the spectrum of coupled electron-phonon modes in an antiferromagnetically (AFM) ordered compound subjected to an arbitrarily small external magnetic field. The effect was observed in the far-infrared (terahertz) reflection spectrum of a $PrFe_3(BO_3)_4$ single crystal.

The temperature dependence of the spectra in a zero magnetic field, in the region of the lowest-frequency nondegenerate phonon and electronic level of the same symmetry evidences formation of coupled phonon – 4*f* electronic excitations. A successful modeling of this process on the basis of a quadratic equation derived in the frame of the theory of coupled electron-phonon modes results in a value $|W|=14.8$ cm^{-1} for the electron-phonon coupling constant [1]. The behavior of coupled modes in paramagnetic and AFM spin-flop phases in magnetic fields up to 30 T, parallel to the *c* axis is explained on the same ground [2].

In the case of the easy-axis AFM phase, there are two electronic branches and a phonon, the quadratic equation converts into a cubic one and bifurcations corresponding to an abrupt appearance of the third root are observed. The field behavior of the spectrum of excitations differs qualitatively from the behavior in the absence of electron-phonon coupling, in particular, a nonzero energy gap between two electronic modes exists at an arbitrarily small external magnetic field. Again, the field behavior of the coupled modes is successfully simulated using the same set of parameters [2].

Support of the Russian Foundation for Basic Research (Grant No 15-02-07451a) and the President of the Russian Federation (Grant MK-3577.2017.2) is acknowledged.

[1] K.N. Boldyrev, T.N. Stanislavchuk, A.A. Sirenko, L.N. Bezmaternykh, M.N. Popova, *Phys. Rev. B Rapid Comm.* **90**, 121101(R) (2014).
[2] K.N. Boldyrev, T.N. Stanislavchuk, A.A. Sirenko, D. Kamenskyi L.N. Bezmaternykh, M.N. Popova, http://arxiv.org/abs/1609.02125; *Phys. Rev. Lett*., accepted (2017).

MAGNETIC AND TRANSPORT PROPERTIES OF THE EPITAXIAL Fe_3Si FILM ON A Si SUBSTRATE

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The iron silicides have a number of useful physical properties, such as: high Curie temperature, low magnetocrystalline anisotropy, high electrical resistance and high value of spin polarization (about 43%). The use of such materials in spintronic devices seem to be very promising.

We report about the magnetic and transport properties of the Fe_3Si film, which was epitaxially grown on atomically clear boron doped Si(111) substrate by thermal evaporation in ultrahigh vacuum[1].

The magnetization and ferromagnetic resonance (FMR) measurements revealed the uniaxial magnetocrystalline anisotropy, with an anisotropy field of 21Oe. The conductivity of the film has metallic type with a curve bend at 250K. We assume, that this bend can be related with a current channel switching. The AC transport measurements of the Fe3Si/Si(111) diode showed the giant magnetoresistance (GMR) effect about 300%. The temperature dependence of the resistance at helium temperatures has a maximum at 18K (at 1 kHz frequency of AC signal) which is related to the interface centers recharge. The measurements of the non-local voltage in a three terminal geometry showed a Hanle curve at the room temperature, which is related to the spin attenuation in perpendicular magnetic field and demonstrates the possibility to control the spin polarization in the Fe3Si/Si(111) structure.

[1] I. A. Yakovlev, S. N. Varnakov, B. A. Belyaev, et al., *JETP Lett.* **99** (9), 527 (2014).

PECULIARITIES OF PHONONS IN Ni-Mn-Ga ALLOYS: AB INITIO STUDIES

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It is well known that in Ni_2MnGa Heusler alloys the phonon anomaly develops under the cooling in the high-symmetry $L2_1$ structure [1]. The phonon anomaly is believed to be the precursor for the modulation of the structure. The density functional theory can reproduce the phonon anomalies in stoichiometric Heusler alloys [2]. It was also demonstrated that the phonon instability can be controlled by the gradual changes in the chemical composition and the electronic structure [3]. The electron concentration, *e/a*, was suggested as a relevant parameter. The approach used in [3] allowed for tuning the phonon instability within a short range of *e/a* by simply adding or removing electrons from the system, and using a uniform background compensation – a "trick" available in electronic structures methods. Using the electron addition and removal approach was shown to be consistent with direct substitution of the *sp*-elements in Heusler alloys, where *sp*-element is the Z atomic species in X_2YZ formula. The disadvantage of that approach is that it did not allow for an actual observation of a crossover from stable to unstable crystal structure. Nevertheless, it was a clear demonstration that the phonon anomaly can be tuned by the variations in the chemical composition. However, what exactly happens in the electronic structure at this transition point of *e/a* is a matter of debates, and even the parameter *e/a* itself, as the relevant physical quantity, is in question as well. It was shown that the phonon instability develops linearly with the changes in *e/a* [3]. This implies that some properties of Heusler alloys can be varied smoothly by gradual changes in their chemical compositions. If properties of interest can be turned on and off by slight changes in the alloy chemistry this would allow for the isolating of the key parameters of the electronic structure that control instabilities in the system. For this type of problems, data based approaches can be very efficient. Systematic computational data can reveal chemical trends and phase boundaries that can be examined more rigorously with accurate approaches. The density functional theory can reproduce chemical trends and it will lead to a deeper fundamental understanding, and may help to reveal the critical chemical compositions that we are looking for in order to uncover the nature of Heusler instabilities.

In this work, the phonon dispersion curves for Ni-Mn-Ga alloys with different compositions are calculated with the help of ab initio packages: VASP, PHONON and PHON [4, 5, 6]. By the ab initio calculations it is shown that really the change of composition leads to removing the phonon anomaly in Ni-Mn-Ga alloys. The nature of phonon instabilities in Ni-Mn-Ga Heusler alloys is discussed.

[1] A. Zheludev, S. M. Shapiro, P. Wochner, L. E. Tanner, *Phys. Rev. B* **54**, 15045 (1996).
[2] A.T. Zayak, P. Entel, K.M. Rabe, W.A. Adeagbo, M. Acet, *Phys. Rev. B* **72**, 054113 (2005).
[3] A.T. Zayak, W.A. Adeagbo, P. Entel, K.M. Rabe, *Appl. Phys. Lett*. **88**, 111903 (2006).
[4] G. Kresse, J. Furthmuller, *Phys.Rev. B* **54**, 11, 169 (1996).
[5] K. Parlinski, Z.Q. Li and Y. Kawazoe, *Phys.Rev.Lett.* **78**, 4063 (1997).
[6] D. Alf`e, (1998). Program available at http://chianti.geol.ucl.ac.uk/~dario.

NOVEL MODELS OF MAGNETIC DYNAMICS FOR CHARACTERIZATION OF NANOPARTICLES BIODEGRADATION IN A BODY FROM MÖSSBAUER AND MAGNETIZATION MEASUREMENTS

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Mössbauer spectroscopy and magnetization measurements are powerful methods for study of structural, magnetic and thermodynamic properties of magnetic nanomaterials including those delivered in a body. The principal problem in interpreting such experimental data taken on magnetic nanoparticles injected into a living organism is to decompose them into partial contributions of exogenous iron atoms in nanoparticles themselves and endogenous iron atoms contained, for example, in ferritin and hemoglobin of the organism [1]. For solving the problem one has to define a model of the magnetic dynamics in order to fit self-consistently the whole set of the experimental data, particularly, the evolution of Mössbauer spectral shape with temperature and external magnetic field as well as the magnetization curves taken on the same sample. Earlier, we have developed such models for describing magnetic dynamics in the system of homogeneously magnetized single-domain ferromagnetic (FM) particles [2-4]. These models allowed us to perform an analysis of the temperature- and magnetic field-dependent spectra and magnetization curves and to reliably evaluate changes in the residual nanoparticles characteristics and their chemical transformation to paramagnetic ferritin-like forms in different mouse's organs as a function of time after injection of nanoparticles [5,6].

However, such an approach suffers from one shortcoming: ferritin and its derivatives are antiferromagnetic (AFM) so that one should apply a model of magnetic dynamics of not FM, but rather AFM nanoparticles for characterizing the corresponding experimental data. In the present contribution I will discuss mainly the quantum-mechanical and macroscopic models of magnetic dynamics recently developed just for describing thermodynamic properties of an ensemble AFM nanoparticles [7,8]. These models clarify principally the difference in thermodynamic behavior of FM and AFM particles revealed in spectroscopic measurements. In particular, one can now qualitatively describe specific (non-superparamagnetic) temperature evolution of the Mössbauer spectra of ferritin and related proteins, which has been often observed in previous studies [9]. Generalization of the approach for ferrimagnetic nanoparticles allows one to take directly into account the magnetic nature of nanoparticles in analyzing the corresponding experimental data, including a large amount of those collected so far.

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[1] M.A. Chuev, V.M. Cherepanov, S.M. Deyev, et al*., AIP Conf. Proc.* **1311**, 322 (2010).
[2] M.A. Chuev, *JETP* **108**, 249 (2009).
[3] M.A. Chuev, *J. Phys.: Condens. Matter.* **23**, 426003 (2011).
[4] M.A. Chuev, *JETP* **114**, 609 (2012).
[5] D.M. Polikarpov, V.M. Cherepanov, M.A. Chuev, et al*., IEEE Trans. Magn.* **49**, 436 (2013).
[6] M. Polikarpov, V. Cherepanov, M. Chuev, et al*., J. Magn. Magn. Mater.* **380**, 347 (2015).
[7] M.A. Chuev, *JETP Lett.* **95**, 295 (2012).
[8] M.A. Chuev, *JETP Lett.* **103**, 175 (2016).
[9] G.C. Papaefthymiou, *Biochim. Biophys. Acta* **1800**, 886 (2010).

OPTICAL EFFECTS IN PHOTONIC-MAGNONIC CRYSTALS

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The photonic-magnonic crystals (PMCs) are complex multifunctional one-dimensional (1D) systems which combine properties of magnonic and photonic crystals (PCs) and possess the band gaps (PBGs) in GHz and PHz regimes for spin waves and light, respectively [1]. In this communication we study the optical properties of PMCs which are bi-periodic structures $[C(AB)^N]^MC$ with the equidistant magnetic yttrium-iron garnet ($Y_3Fe_5O_{12}$) layers C spaced by dielectric PCs $(AB)^N$, where A and B are the silicon oxide (SiO_2) and titanium oxide (TiO_2) (Figure 1). We focus on investigation of the transmittivity spectra, Faraday rotation and Goos-Hänchen shift (GHS) of the light passing through the finite size PMCs.

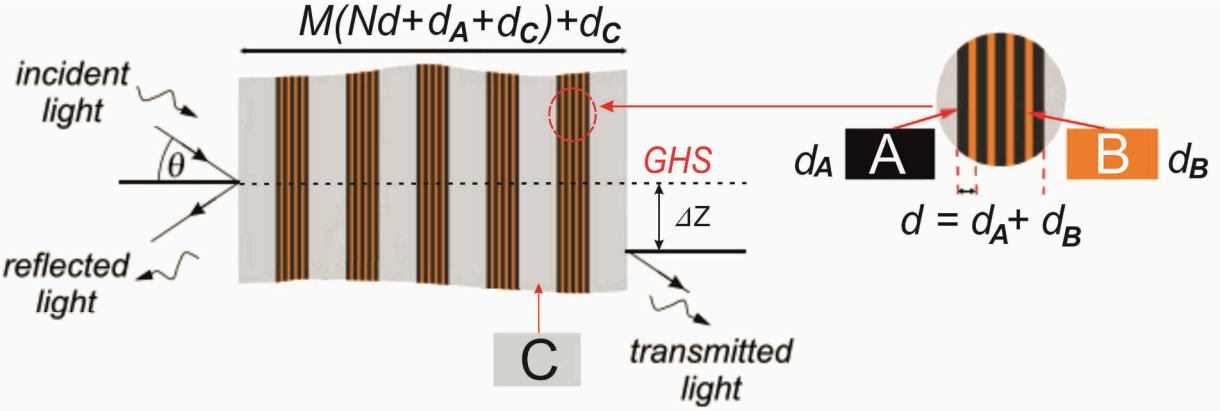

Figure 1. The schematic of a 1D PMC.

The transmittivity spectra of the PMCs contain the inside-PBG bands of complex structure [1]. We sowed the increase of GHS and Faraday rotation at the frequencies of inside-PBG modes and enhancement of the shift peaks due to the linear magneto-electric effect in the magnetic layers of the system for the case of s- (p-) polarized transmitted beam produced by p- (s-) polarized incident beam. The magneto-electric coupling in the magnetic layers results in significant increase of the positive maxima of the polarization plane rotation angles of *s*-polarized incident light and decreases the negative ones, whereas the Faraday rotation of *p*-polarized light almost doesn't change in presence of the magneto-electric interaction.

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[1] J.W. Kłos, M.Krawczyk, Yu.S. Dadoenkova, N.N. Dadoenkova, and I.L. Lyubchanskii, *J. Appl. Phys.* **115**, 174311 (2014); *ibid.* **120**, 073903 (2016).

HIGHER MANGANESE SILICIDE – FERROMAGNETIC MULTIFUNCTIONAL MATERIAL

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Higher manganese silicide is known for the set of possible application including spintronics [1] and thermoelectric power converters [2]. The application of Mn_xSi_{1-x} as thermoelectric power supply source is associated with the set of its unique properties, such as low thermal conductivity and relatively high electrical conductivity [2]. The modern trends of the thermoelectricity however demand improvement of the Mn_xSi_{1-x} properties in order to increase the efficiency. The latter can be estimated via the thermoelectric quality factor

$$ZT = \alpha^2 \cdot \sigma \cdot T/\lambda, \quad (1)$$

where α is the Seebeck coefficient, σ – electrical conductivity, T – temperature of the sample, λ – thermal conductivity.

In the present paper we report on the fabrication of higher manganese silicide layers as an active element of the thermoelectric energy converters. Such materials are considered prospective option for hole-conductivity part thermoelectric elements in 300-500°C temperature range [2]. The increase of *ZT* values was achieved by nanostructuring of the fabricated materials, in particular a multi-layer Mn_xSi_{1-x}/Si superlattice structure was fabricated. It is expected that the nanostructuring will lead to decrease the phonon component of thermal conductivity due to increased phonon scattering at the interfaces and independently increase the electrical conductivity due to the dependence of conductivity on superlattice parameters.

The fabrication of thin Mn_xSi_{1-x}/Si multilayer structure was carried out by pulsed laser deposition technique at the deposition temperature of 300°C. The layers were deposited on Si (100) substrate. The Mn_xSi_{1-x} layers (~ 2 nm thick) were grown by means of alternating sputtering of Si and Mn targets. The composition of layers (x) was set by the variation of relative Mn and Si sputtering times. In the present work t_{Mn}/t_{Si} = ¼, which approximately corresponds to $Mn_{0.2}Si_{0.8}$ composition. Si layers (also ~2 nm thick) were deposited by sputtering of only Si target. The total thicknes of the structure was ~ 40 nm. The basic thermoelectric coefficients were measured within this work: Seebeck coefficient, electrical conductivity and thermal conductivity. The thermal conductivity values were calculated via the 3ω technique, which was especially developed for the thin film measurements [4]. The *ZT* values were calculated.

It was obtained that the thermo-voltage values are maximal at the temperature of ~ 400 °C (α≈0,12 mV/K). Both electrical conductivity ant thermal conductivity values relatively weakly depend on the measurement temperature in the investigated range (300-500°C). The value of *ZT* with respect to the Mn_xSi_{1-x}/Si thickness was about 0,4 for the temperature of ~ 400 °C. The obtained *ZT* values as well as the temperature position of the maximum are in good agreement with the data for higher manganese silicide discussed in [2]. It is suggested that the optimization of nanostructures parameter (Mn_xSi_{1-x}/Si superlattice period, Mn_xSi_{1-x} and Si layers relative thickness, etc.) will lead to the increase of *ZT* values above the mentioned level.

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[1] E.S. Demidov, et.al., *JETP Letters.* **96**, 706 (2013).
[2] L.D. Ivanova. A.A. Baikov, *J. of Thermoelectricity* **3**, 60 (2009).
[3] S.-M. Lee , et.al., *Appl. Phys. Lett.* **70**, 2957 (1997).

SIZE EFFECTS IN THE MAGNETIC PROPERTIES OF ε-Fe_2O_3 NANOPARTICLES

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Trivalent iron oxide ε-Fe_2O_3 characterized for the first time in 1998 [1] has unique properties and can find wide applications. This oxide exists in the form of nanoparticles up to 25–100 nm in size with a significant (~ 20 kOe) room-temperature coercivity [2-5], which makes these particles promising for application in magnetic recording. Such objects also are in great demand in modern medical and biological research as promising media for controlled drug transport, isolation and tracing of cells, magnetic hyperthermia of tumors, etc., as well as in modern high-tech devices requiring the use of liquid magnetosensitive media.

In this work the results of comparative analysis of magnetic properties of the systems based on ε-Fe_2O_3, nanoparticles with different average sizes (from ~ 3 to 9 nm) and dispersions are shown. The experimental data for nanoparticles higher than 6–8 nm in size are consistent with the available data, specifically, the transition to the magnetically ordered state occurs at a temperature of ~ 500 K and the anomalies of magnetic properties observed in the range of 80–150 K correspond to the magnetic transition. At the same time, Mossbauer and ferromagnetic resonance spectroscopy data as well as the results of static magnetic measurements show that at room temperature all the investigated samples contain ε-Fe_2O_3 particles that exhibit the superparamagnetic behavior. It was established that the magnetic properties of nanoparticles significantly change with a decrease in their size to ~ 6 nm. According to high-resolution electron microscopy and Mossbauer spectroscopy data, the particle structure can be attributed to the ε–modification of trivalent iron oxide; meanwhile, the temperature of the magnetic order onset in these particles is increased, the well-known magnetic transition in the range of 80–150 K does not occur, the crystallographic magnetic anisotropy constant is significantly reduced, and the surface magnetic anisotropy plays a decisive role.

This is apparently due to redistribution of cations over crystallographic positions with decreasing particle size, which was established using Mossbauer spectra. As the particle size is decreased and the fraction of surface atoms is increased, the contribution of an additional magnetic subsystem formed in a shell of particles smaller than ~ 4 nm becomes significant, which manifests itself in the static magnetic measurements as paramagnetic contribution.

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[1] E. Tronc, C. Chaneac, and J. P. Jolivet, *J. Solid State Chem.* **139**(1), 93 (1998).
[2] L. Machala, J. Tucek, and R. Zboril, *Chem. Mater.* **23**, 3255 (2011).
[3] J. Tucek, R. Zboril, A. Namai, and S. Ohkoshi, *Chem. Mater.* **22**, 6483 (2010).
[4] M. Gich, A. Roig, C. Frontera, E.Molins, J.Sort, M. Popovici, G. Chouteau, D. Martın y Marero, J. Nogues, *J. Appl. Phys.* **98**(4), 044307 (2005).
[5] S. Ohkoshi, S. Sakurai, J. Jin, and K. Hashimoto, *J. Appl. Phys.* **97**, 10K312 (2005).

FMR INVESTIGATIONS OF EXCHANGE BIASED NiFe/IrMn/NiFe TRILAYERS WITH HIGH AND LOW NI RELATIVE CONTENT

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A compromise between different magnetic properties in ferromagnetic (F) layers, in particular in materials with appropriate saturation magnetization, exchange bias and coercivity is very important. Here we report on investigations of exchange bias and saturation magnetization of F layers in F/AF/F trilayer structures with different thickness of AF layers for two different NiFe relative contents in F layer. Two sets of experimental samples Si/Ta 30nm/NiFe 10nm /IrMn t_{AF}/NiFe 10nm/Ta 30nm where t_{AF} = 2 – 50 nm with $Ni_{75}Fe_{25}$ and $Ni_{40}Fe_{60}$ F layers were deposited by magnetron sputtering. For each sample ferromagnetic resonance (FMR) field angular dependence was obtained and fitted by equation

$$Hr = Hr_0 - H_{EB}\cos(\varphi - \alpha) - H_K\cos 2\varphi, \quad [1]$$

where Hr_0 – intrinsic resonance field, H_{EB} –exchange bias, H_K – unidirectional magnetocrystalline anisotropy, α – angle between directions of exchange bias field and the magnetic field, applied during the film deposition. For trilayers with $Ni_{75}Fe_{25}$ F layers FMR spectra contained two peaks corresponding to upper (AF/F) and lower (F/AF) interfaces while for trilayers with $Ni_{40}Fe_{60}$ only single peaks were observed. Trilayers with both F layer compositions had FMR angular distribution with non-zero angle α at low t_{AF}. This angle had a maximum value at t_{AF}, at which exchange bias occurs (4 nm for $Ni_{40}Fe_{60}$ and 8 nm for $Ni_{75}Fe_{25}$), then decreased with t_{AF} increase and converged to zero at t_{AF} = 15 nm for $Ni_{40}Fe_{60}$ and 20 nm for $Ni_{75}Fe_{25}$.

For trilayers with $Ni_{75}Fe_{25}$ the exchange bias monotonically increased to 60 and 80 Oe at F/AF and AF/F interfaces, respectively, and above t_{AF} = 15nm didn't significantly change. In case of trilayers with $Ni_{40}Fe_{60}$ F layers non-monotonical dependence of exchange bias at t_{AF} from 4nm to 20 nm was observed. In all tAF range investigated exchange bias of structures with $Ni_{40}Fe_{60}$ F layers was lower than that of both interfaces in structures with $Ni_{75}Fe_{25}$ having close values at t_{AF} = 15 and 50 nm. Along with higher $Ni_{40}Fe_{60}$ coercivity it can be caused by strong FCC (111) texture and small grain size in $Ni_{75}Fe_{25}$.

NOVEL PLATFORM FOR BREAST AND LIVER DISEASES THERANOSTICS ON THE BASIS OF MAGNETITE-GOLD HYBRID NANOPARTICLES

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During last decades magnetite and gold nanoparticles (NPs) attract a deep interest of scientists due to their potential application in therapy and diagnostics. Fe_3O_4 NPs have the ability to enhance T2-contrast in magnetic resonance imaging (MRI) and deliver drugs to certain tissues using an external magnetic field. In turn, Au NPs are characterized by high stability, biocompatibility, and can also be covalently functionalized by a wide spectrum of thiol-containing ligands. The idea of Fe_3O_4-Au hybrid material creation is the combination of magnetite and gold promising properties as well as the presence of two types of surfaces that differ in chemical properties.

Hybrid magnetite-gold NPs were obtained by the decomposition of iron pentacarbonyl on the surface of gold NPs. As a result, so-called dumbbell-like structures were obtained where magnetite with spherical (sample D-1) or cubic (sample D-2) shape and spherical gold NPs were connected together pairwise. The study of structural and magnetic properties revealed a very high quality of Fe_3O_4 NPs with a mean size of 23±2 nm and a saturation magnetization of 86 Am^2/kg close to the bulk value of 92 Am^2/kg. Further, we obtained an epitaxial relation between Fe_3O_4 and Au NPs.

Samples D-1 and D-2 were transferred into water by means of block-copolymer Pluronic F127, and then MRI-characterization was performed. R2-relaxivity rates at the level of 167 and 385 $mM^{-1}s^{-1}$ were obtained for samples D-1 and D-2, respectively; the latter value is a record value for hybrid Fe_3O_4-Au NPs, exceeding the similar characteristics of commercial contrast agents twice. When D-1 and D-2 samples were intravenously administered to Wistar rats at a dose of 7 mg Fe/kg, the accumulation of NPs in the liver was predominant (more than 60% of the input dose) and they effectively increased the contrast of MRI liver images.

The sample D-1 was also used for the selective functionalization of Fe_3O_4 NPs surface with anti-cancer drug doxorubicin and Au NPs surface – with the ligand of prostate specific membrane antigen (PSMA). Obtained NPs were found to have dose-related toxicity for human prostate cancer cells (LNCaP cell line) and got into the intracellular space after 45 minutes of incubation (according to fluorescence microscopy data). Presumably, this can be explained by the affinity of the LNCaP cells to the PSMA ligand.

Thereby, in this work magnetite-gold hybrid NPs, which have a strong potential for biomedical application, particularly in targeted drug delivery to liver and prostate cells, and magnetic resonance imaging, were synthesized and characterized. That paves the way to the development of a new theranostic approach.

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STATIONARY, HIGH FIELD AND PULSED EPR FOR STUDYING SUBSTITUTED BY METAL IONS CALCIUM PHOSPHATES

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Calcium phosphates (CaP)-based materials are widely recognized as the most suitable matrix for bone tissue engineering. The cationic and anionic substitutions of CaP structure by the elements and groups of biological importance seem to be the effective ways to improve the properties of CaP-based substances to achieve the material's desired parameters but interconnection between the doping, structure, and biological response is still undefined. The review is devoted to different aspects of studying of CaP powders and ceramics (mainly hydroxyapatites, HA and tricalcium phosphates, TCP) doped with Pb^{2+}, Mn^{2+}, Cu^{2+}, or Fe^{3+} by the variety of the commercially realized methods of electron paramagnetic resonance (EPR) gathered at the Institute of Physics of Kazan Federal University [1-6]. Among them (1) high-frequency approaches – for measuring small (less than 0.4 mm in cross section) samples exploiting the increased sensitivity and spectral resolution; (2) pulsed methods - to separate contributions from surface and internal paramagnetic centers (PCs), using differences in their electronic relaxation times and to study the effects of the co-doping by different sorts of ions; (3) double electron-nuclear resonance (ENDOR) - to determine the structure and localization of PCs; (4) quantum-mechanical calculations in the framework of models of the density functional theory for correlating the experimentally obtained EPR parameters with the structure of the materials studied.

[1] B.V. Yavkin et al., *Phys Chem Chem Phys* **14**, 2246 (2012).
[2] T.B. Biktagirov et al., *J. Phys. Chem. A* **118**, 1519 (2014).
[3] M. Gafurov et al., *JETP Lett* **99**, 196 (2014).
[4] M.Gafurov et al., *Phys Chem Chem Phys* **17**, 20331 (2015).
[5] M.Gafurov et al., *Phys. Solid State* **58**, 469 (2016).
[6] I. Fadeeva et al., *BioNanoSci.* doi:10.1007/s12668-016-0386-7 (2017).

INVERSE-DIRECT MAGNETOCALORIC EFFECT CROSSOVER IN Ni-Mn-In-(Cu) IN CYCLIC MAGNETIC FIELDS

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In this paper we present the results of direct measurement of the MCE in Ni-Mn-In-Cu Heusler alloys in a cyclic magnetic field of 1.8 T in heating and cooling runs.

Fig. 1 depicts the temperature dependence of MCE in Ni-Mn-In-(Cu:0.5) in the magnetic field of 1.8 T in heating and cooling runs. The maximum value of direct effect in the field of 1.8 T is 1.24 K and revealed at T=314 K. The inverse MCE accompanying with a wide hysteresis (14-20 K) is observed near the magnetic structural transition. The value of the inverse effect depends on the rate of a sample temperature change (heating or cooling), the higher the rate is, the higher the inverse effect value.

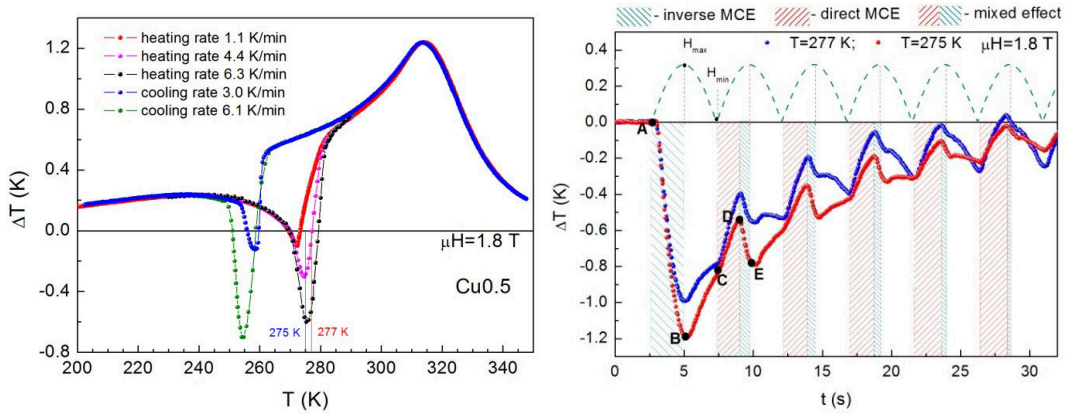

Fig.1. a) Temperature dependences of MCE for Cu0.5 sample in magnetic field of 1.8 T. b) Time dependence of MCE near magnetostructural phase transition.

Such behavior is explainable if to follow a detail change in the MCE under the cyclic magnetic field. The time dependence of MCE was measured at two temperatures (T=275 and 277 K) in the region of the temperature hysteresis (Fig.1. b). As is evident from the figure, under cyclic magnetic fields application a gradual inverse MCE - direct MCE crossover takes place. The observed effect can be explained in terms of an example of ΔT(t) dependence at T=275 K. When applying the magnetic field, the inverse MCE caused by a transition from low-temperature antiferromagnetic martensite to high-temperature ferromagnetic austenite (A-B area) is revealed in the first cycle. However, the transition into the ferromagnetic phase occurs not in the whole sample, only a part of martensite transforms into austenite. In further cycles of magnetic field applying, a gradual decrease in the inverse MCE is revealed owing to decreasing the martensite phase.

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STRUCTURAL, MAGNETIC AND ELECTRONIC PROPERTIES OF $Fe_{1+x}Ga_{2-x}O_4$ NANOPARTICLES PROMISING FOR MAGNETIC-RESONANCE CONTRAST IN BIOMEDICINE

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The advantages of magnetic resonance imaging (MRI) in medical diagnosis are well known: highly informative, noninvasiveness, excellent spatial resolution, real-time monitoring ability and so on. Specific contrast agents allow improving the visibility of internal body structures in magnetic resonance imaging.

Commonly the gadolinium-based compounds are used for contrast enhancement. Iron oxides, due to their high magnetization and biocompatibility are widely studied as promising materials for MRI agents.

As shown recently [1], the $FeGa_2O_4$ nanoparticles reveal a high-performance in lowering of the transverse relaxation time T_2, thus improving the contrast on the MRI image. This ability together with good biocompatibility makes these nanoparticles an effective nano-MRI contrast agent.

Due to the lack of information about structural, magnetic and electronic properties of nanosized $FeGa_2O_4$ we synthesized and studied several samples with the mean particle size in the range of 2 – 30 nm. XRD, TEM, EDX, Raman and Mössbauer spectroscopy, and magnetization measurements from 4 – 400 K were used to study physical properties of the nanoparticles. We found that nanoparticles have cubic spinel-type crystal structure. Basing on XRD, Raman and Mössbauer spectroscopy data we concluded that not only $FeGa_2O_4$ phase but a new phase γ-$FeGaO_3$ similar to cubic spinel γ-Fe_2O_3 and γ-Ga_2O_3 is presented in the samples. Low-temperature Mössbauer spectra indicate a non-homogeneous magnetic system with frustrated interactions specific of spin-glasses with ordering temperature at about 26 K. Unusual transformation of the Mössbauer spectra was observed in paramagnetic temperature region 30 – 300 K, which is associated with charge redistribution between octahedral and tetrahedral sites of the spinel structure [2]. It was established that this effect was initiated by the Jahn-Teller distortion of the tetrahedral coordination of the Fe^{2+} ions. Such an effect, however, was not observed in bulk $FeGa_2O_4$ material.

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[1]C.-C.Huang,C.-H. Su,M.-Y. Liao, C.-S.Yeh, *Phys. Chem. Chem. Phys.* **11**, 6331 (2009).
[2] I.S. Lyubutin, S.S. Starchikov, N.E.Gervits, Chun-Rong Lin, Yaw-Teng Tseng, Kun-Yauh Shih, Jiann-Shing Lee, Yu.L. Ogarkova, A.O.Baskakov, K.V. Frolov, *J. Phys. Chem. C* **120** (44), 25596–25603 (2016).

HARD FERRITE MATERIALS WITH RECORD-HIGH COERCIVITY AND FMR FREQUENCIES

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Magnetic materials with large coercivity have broad applications ranging from permanent magnets and data storage media to high-frequency electromagnetic wave filters. The only known ferrite material exhibiting coercivity over 20 kOe (also considered as “giant coercive force”) at room temperatures is ε-Fe_2O_3 [1]. Also it shows millimeter wave absorption up to 210 GHz [2]. However, ε-Fe_2O_3 is a rare iron oxide and its production as pure phase is quite complex. Hard magnetic ferrites ($MFe_{12}O_{19}$, M = Ba, Sr, Pb) also possess high magnetocrystalline anisotropy but their coercivity is significantly lower and rarely exceeds 6 kOe for pure phase. The doping by aluminum could lead to coercivity rise up to 18 kOe, however the magnetization in this case is significantly lower than of ε-Fe_2O_3 [3].

Here we report a simple synthesis of Ca-Al double substituted strontium hexaferrite $Sr_{1-x/12}Ca_{x/12}Fe_{12-x}Al_xO_{19}$. The rise of the substitution ratio x leads to decrease of magnetization, but significant increase of coercivity. At x = 4 the sample the coercivity is 21.3 kOe, which is higher than for ε-Fe_2O_3 with the same magnetization of 15 emu/g. At x = 5.5 the coercivity reaches 36 kOe, which is the highest value known for ferrite materials. The coercivity could be further improved by alignment of the hexaferrite particles dispersed in a polymer by the magnetic field. Such oriented composites possess nearly square hysteresis loops with coercivity up to 40 kOe while magnetized in alignment direction. Also we have studied the millimeter wave absorption properties of the samples. The high anisotropy fields result in very high ferromagnetic resonance frequencies. The FMR frequency increases with substitution ratio and reaches the record-high values of 180 – 240 GHz for x = 4 – 5.5. Also we have studied the features of the crystalline structure of the samples by high precision synchrotron radiation diffraction and revealed that the presence of calcium results in shrinking of oxygen surroundings in bipyramidal iron position, which could be a reason of the increase of magnetocrystalline anisotropy compared to simple aluminum doping of strontium hexaferrite.

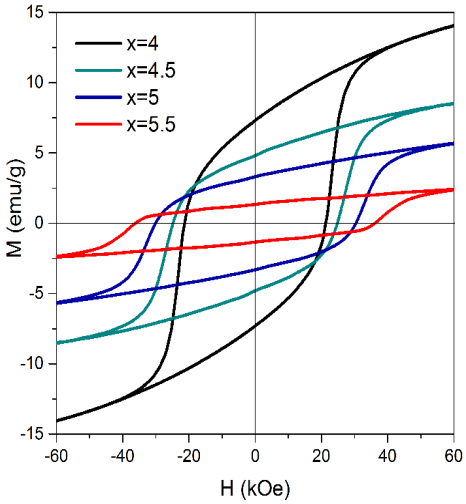

Figure 1. Hysteresis loops of $Sr_{1-x/12}Ca_{x/12}Fe_{12-x}Al_xO_{19}$ samples.

Support by RFBR Grant 15-03-04277 is acknowledged.

[1] J. Tuček, R. Zbořil, A. Namai, S. Ohkoshi, *Chem. Mater.* **22**, 6483 (2010).
[2] A. Namai, et. al., *Nat. Commun.* **3**, 1035 (2012).
[3] H. Luo, *J. Magn. Magn. Mater.* **324**, 2602 (2012).

ULTRASENSITIVE FLUX-GATE MAGNETOMETER BASED ON IRON GARNET FILM FOR BIOMEDICAL APPLICATIONS

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At present, for such important biomedical applications as the Magnetocardiography (MCG) or Magnetoencephalography one uses SQUID magnetometers [1], which are expensive, bulky, and difficult to maiantain. At the same time, modern commercial cheap, easy to use and compact flux-gate magnetic field sensors are notsuitable for biomagnetic applications and new biomedical areas such as magnetorelaxometry (MRX) [2] because the conventional flux-gate technology does not allow one to reduce the noise level below 100 $pT/Hz^{1/2}$. The present work is devoted to the research and development of the new flux-gate magnetometer, based on the iron garnet film, which is capable of measuring a biomagnetic signals and relaxation signals of the magnetic nanoparticles. The magnetometer is successfully tested on the MCG signal measurements of a human [3] and small animal [4]. As the parts of the further work the method of direct vector measurement of the MCG map was developed and new MRX technique of the magnetic nanoparticles in the body of an experimental animal was proposed.

The proposed sensor shows a noise level of about 100 $fT/Hz^{1/2}$ and allows the simultaneous measurements of the in-plane magnetic field vector components Hx and Hy: the corresponding to each component EMF signal occurs with a specific phase shift. Additionally, we have developed a method of vector MCG mapping and received spatial distributions of the three vector components of the human heart magnetic field. Finally, we have proposed a new method of Magnetic Particle Imaging (MPI) techniques based on MRX measurements of the magnetic nanoparticles using the proposed magnetometer, which allows one to determine the particles concentration, relaxation constant at known scanning speed or the speed of nanoparticle (if the measurements take place in dynamics, for example in the bloodstream) at a known relaxation constant.

[1] D. Robbes, *Sensors and Actuators A:* Physical **129(1)**, 86-93 (2006).
[2] J. Lange, R. Kötitz, A. Haller, L. Trahms, W. Semmler, W. Weitschies, *Journal of Magnetism and Magnetic Materials* **252**, 381-383 (2002).
[3] P.M. Vetoshko, N.A. Gusev, D.A. Chepurnova, E.V. Samoilova, A.K. Zvezdin, A.A. Korotaeva, V.I. Belotelov, *Biomedical Engineering* **50(4)**, 237-240 (2016).
[4] P.M. Vetoshko, N.A. Gusev, D.A. Chepurnova, E.V. Samoilova, I.I. Syvorotka, I.M. Syvorotka, A.K. Zvezdin, A.A. Korotaeva, V.I. Belotelov, *Technical Physics Letters* **42(8)**, 860-864 (2016).

THE POSSIBILITIES OF USING COMBINED MAGNETIC FIELD SENSORS IN MAGNETOCARDIOGRAPHY AND MAGNETIC RESONANCE IMAGING

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Magnetocardiography (MCG) allows to register cardio diseases. High MCG indices are achieved by the use of numerous magnetic field sensors in them with a threshold sensitivity of $\delta B \leq 1$ pT.

The purpose of this paper is to compare the parameters of superconducting quantum interference devices (SQUID) and combined magnetic field sensors (CMFS) with the possibility decrease of their overall dimensions.

The MCG includes several tens or hundreds of SQUIDs with $\delta B \leq 1$ pT, and their dimensions are determened in the sizes of the receiving ring with a diameter of $D \sim 5 \div 10$ mm.

CMFS contains a magnetic field concentrator (MFC) and a structure based on the giant magnetoresistance (GMR) effect as a magnetosensitive element (MSE).

Considered CMFS based on MFCs from a superconducting film (niobium, critical current density $\geq 10^{10}$ A/m^2, London penetration depth 50 nm, thickness 100 nm) and MSE from a GMR resistor with a relative magnetosensitivity of ~ 10%/mT. The MFC had a nanostructured active band, which consisted of alternating parallel superconducting branches and slits with widths of 20÷500 nm. Similar nanostructuring of active bands of CMS was investigated in [1, 2].

The following parameters are obtained. SQUID on the basis of a high-temperature superconductor (HTSC): energy equivalent to noise $E_n \sim 10^{-27}$ J/Hz, magnetic field equivalent to noise $B_n \sim 0.03$ pT/Hz$^{1/2}$, $D \sim 1$ cm. CMFS consisting of the above parameters: $E_n \sim 10^{-27}$ J/Hz, $B_n \sim 0.1$ pT/Hz$^{1/2}$, $D \sim 0.2$ cm. These values are an order of magnitude better than those obtained in the CMFS in the composition of an MFC with a non-nanostructured active band [1].

Thus, in the CMFS with nanostructured MFC the parameters close to HTSC SQUIDs are reached, and the dimensions are several times smaller than them. The use of multiple CMFS along with SQUIDs will significantly improve the MCG capabilities in recording the signs of the onset of cardiodiseases. These CMFSs have the potential to be used both in the traditional magnetic resonance imaging (MRI, 1.5÷4.5 T), so in the new direction of the MRI of a weak magnetic field (≤100 mT) [2].The combination of magnetic systems MCG/MRI can significantly improve the accuracy of the functional state and localization of cardiac diseases, and they will be demand in medical practice.

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[1] L.P. Ichkitidze and A.N. Mironyuk., *Physica C* **472(1)**, 57 (2012).
[2] L.P. Ichkitidze. *AIP Advances* **3(6)**, 062125 (2013).
[3] M. Pannetier-Lecoeur et al., *Rewiew of scientific instruments* **84**, 095116 (2013).
[4] A.N. Matlachov et al., *Proc. of BIOMAG 2004* (Boston) **39** (2004).

LOCAL ANISOTROPY IN EPITAXIAL Mn_5Ge_3/Ge(111) THIN FILMS PROBED BY ^{55}Mn NMR

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Ferromagnetic hexagonal Mn_5Ge_3 compound has been a subject of intensive study in recent years. The combination of high spin polarization, good epitaxial growth on Ge and high Curie temperature makes the Mn_5Ge_3 system a material of choice in future spintronic devices. Noteworthy is the fact that epitaxial Mn_5Ge_3 thin films grown on Ge (111) reveal perpendicular anisotropy and stripe domain structure in films as thin as 20 nm [1,2], leading to potential applications in both, emerging spintronics and next-generation data-storage technologies.

With the aim to understand better the sources of magnetocrystalline anisotropy, we performed an extensive study of local magnetic properties in two crystallographic positions of Mn in Mn_5Ge_3 structure using the NMR method. ^{55}Mn NMR experiments have been carried out in two configurations: (a) on 300 nm thick film, monitoring the evolution of ^{55}Mn NMR spectra as the magnetic structure of Mn_5Ge_3 thin film transforms from a multi-domain to a single domain structure enforced by DC external magnetic field - for the DC field orientation in film plane and out of plane, (b) at zero external field, as a function of film thickness in the range corresponding to reorientation of the magnetization easy axis from in-plane to out-of-plane orientation.

^{55}Mn NMR spectrum recorded from 300 nm thick film reveals two resonance lines corresponding to two Mn sites (denoted as Mn_I and Mn_{II}) in the crystal lattice (space group P63/mcm). The line centered at 207 MHz, (referred to as Mn_I) corresponds to the site 4(d). The well-resolved quadrupolar structure evidences strong electric field gradient at this site, characterized by uniaxial local symmetry. The structure-less line at 429 MHz originates from the 6(g) sites (Mn_{II}), where the local crystallographic environment has much lower symmetry. Experiments in the DC magnetic field applied in the out-of-plane direction, i.e. along the magnetization inside the domains [2] show that after saturation both lines shift towards lower frequencies with a slope determined by ^{55}Mn gyromagnetic ratio, proving that the observed signals correspond to magnetization oriented along the easy axis of magnetization. When tilting the magnetization towards in-plane orientation by applying the in-plane DC field, two effects are observed: (a) the resonance frequency of ^{55}Mn corresponding to both Mn crystallographic sites increases, revealing the anisotropic orbital contribution to Mn hyperfine field due to the unquenched anisotropic orbital momentum, (b) magnetically non-equivalent positions are created among the six Mn_{II} sites, splitting the NMR line in two components and revealing the presence of in-plane hyperfine field anisotropy at the Mn_{II} site. The evolution of zero-field NMR spectrum as a function of sample thickness during reorientation from the in-plane magnetization in very thin films to out-of-plane above $t>20$ nm, is fully consistent with the above observations. These results suggest that magnetocrystalline anisotropy has its counterparts in anisotropy of the Mn hyperfine field and both can be linked to the anisotropy of the Mn orbital momentum.

[1] L. A. Michez et al., *J. Appl. Phys* **118,** 043906 (2015).
[2] R. Kalvig et al., *J. Phys. D Appl. Phys.* **50,** 125001 (2017).

KINETICS OF PHASE TRANSITIONS INDUCED BY TEMPERATURE AND MAGNETIC FIELD IN MAGNETOCALORIC MATERIALS

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The problem of the rate of phase transitions (PT) requires immediate solution because it is crucial for the creation of the new refrigeration technology based on magnetocaloric effect (MCE) in solid state magnetic materials. The rate of PT limits the frequency of thermodynamic cycles, and the power of refrigeration will depend on the frequency of cycles. The comparative study of the kinetics of PTs of the prospective magnetic functional materials is very important for creation of the novel devices based on MCE. We present a new technique for experimental study of kinetics of PTs and direct measurement of the MCE in pulsed magnetic fields by using the fast response temperature probe with infrared fiber optical (IRFO) sensor. As demonstration of the new technique, the results are presented of MCE measurements for $Fe_{48}Rh_{52}$ sample at initial temperature 305.1 K: ΔT_{ad} = -4.5 K under pulsed magnetic field $\mu_0 H$ = 8.5 T, see Fig.1. The energy losses on magnetization near the 1st order PT were calculated from the results of direct measurements of magnetization versus time for $Fe_{48}Rh_{52}$ sample: W = 45 J/kg [1]. The new system demonstrates the fast response (better than 1 ms) and higher noise immunity than existing systems based on micro-thermocouples and thin film thermoresistors.

Other technique for experimental study of the kinetics of the magnetic PTs under low alternating magnetic field. The new dynamic thermo-magnetometer (DTM) is proposed for solving the problem of the rate of the magnetic PT at low fields. DTM is designed for measuring the time dependence of the magnetic susceptibility of thin plates of ferromagnets at an abrupt temperature change in water flow. As a result of experiments for Gd near T_C = 20C relaxation time of magnetization is 50 ms [2]. Recently DTM was developed for working on materials with the 1st order PTs. The last experiments shown big difference at heeting and cooling in relaxation time at PT in Ni-Mn-Ga(Fe) Heusler alloys. This difference may achieves hundreds of milliseconds.

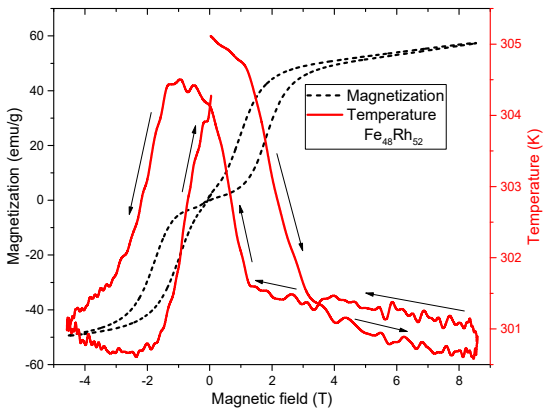

Fig. 1. Measurements of MCE by the IRFO temperature probe on $Fe_{48}Rh_{52}$ sample: temperature and magnetization vs magnetic field.

[1] A.P. Kamantsev, et al., *J. Magn. Magn. Mater*, in press (2017).
[2] A.P. Kamantsev, et al., *Solid State Phenom.* **215**, 113 (2014).

CORE-SHELL MAGNETIC NANOPARTICLES IN BIOMEDICAL APPLICATIONS

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The nanoparticles has opened up new avenues in many different fields of applications along with other nanomaterials. The major advantages of nanoparticles over larger sized particles are its high surface-to-volume ratio and hence higher surface energy, unique optical, electronic, and excellent magnetic properties and so on. The high surface area also allows it to be modified. The magnetic nanoparticles (MNPs) are playing an important role in the wide range of various applications. At resent MNP with core-shell structures have attracted considerable attention because of their unique properties and various applications. Also, the synthesis of engineered core-shell structures MNP (CSMNP) has attracted practical interest because of potential applications in different areas such as ferrofluids, medical imaging, drug targeting and delivery, cancer therapy, separations, and catalysis.

CSMNP have a core made of a material coated with another material on top of it. CSMNP are a promising system for biomedical applications, because they combine a core (iron) with a high magnetic moment and a shell (iron oxide) with good biocompatibility. In biological applications CSMNP have major advantages over simple nanoparticles leading to the improvement of properties such as less cytotoxicity, increase in dispersibility, bio- and cyto-compatibility, better conjugation with other bioactive molecules, increased thermal and chemical stability and so on. It requires the development of multifunctional nanoparticles with biocompatibility, high relaxivity, high heat-generation power, controlled drug release, and tumor targeting.

Among various methods to the modification or functionalization of the surfaces of CSMNP with materials such as polymers, organic monolayers, oxides, and metals, one of the most important systems involves magnetic nanoparticles coated with gold shells.

This review focuses on the recent progress in synthesis and characterization of engineered magnetic core-shell structures in terms of their fundamentals of magnetism, hyperthermia applications, magnetic resonance imaging, and drug delivery, as well as the synthesis approaches and application examples. Because the quality and surface chemistry play important roles in biomedical applications, this review focuses on the surface modifications of CS nanoparticles. In review are discussing some of the recent findings in the investigation of the synthesis, characterization and application of one intriguing class of CSMNP, i.e., magnetic nanoparticles coated with a gold shell.

THE EFFECT OF THE SHAPE OF IRON OXIDE NANOPARTICLES ON THE MAGNETIC AND MRI CONTRAST PROPERTIES AND CYTOTOXICITY TOWARDS PC3 AND LNCaP HUMAN PROSTATE CANCER CELL LINES

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Magnetic nanoparticles (MNP) attract particular interest for usage in different areas of biology and medicine, such as targeted drug delivery, magnetic resonance imaging and magnetic hyperthermia. Widespread use of magnetite nanoparticles in biomedicine became possible due to their magnetic properties, low toxicity and biodegradability. It is also known that the shape and size of the MNP can affect their magnetic and structural properties. Thus the aim of the study is to reveal the effect of particles shape on magnetic and contrast properties and cytotoxicity towards the PC3 and LNCaP prostate cancer cell lines.

The following forms of particles were obtained by method of high-temperature thermal decomposition: spherical, cubic, octahedral, hexagonal and tetragonal prisms, plates. X-ray phase analysis confirmed the presence of the inverse spinel phase in all samples.

Table 1.

Sample (shape / characteristic)	Size, nm	Crystallite size, nm	H_c, kA/m (E)	$4\pi I_s$, $A \cdot m^2/kg$	T_2- relaxivity, $mM^{-1} \cdot s^{-1}$
Spheres	20	16	2,3 (29)	34,2	240,6
Cubes	18	21	4,7 (59)	44,7	262
Hexagonal prisms	55	47	8,3 (104)	88,3	15,1
Octahedrons	19	17	2,2 (28)	73,8	236,5
Tetragonal prisms	19	24	3,6 (45)	87,4	241,3
Nanoplates	12x12x2,5	5	4,8 (60)	52,1	280,3

The cytotoxicity of nanoparticles has been tested on human PC3 and LNCaP cell lines. Cell survival with the addition of MNP suspensions in concentration varying from 2.5 to 50 μg/ml was 80-100%, except octahedral and cubic particles, which demonstrated slightly higher cytotoxicity on LNCaP culture.

Temperature change measurements of MNP suspensions from the exposition time under an external magnetic field (H = 95 Oe, f = 100 kHz) resulted in the following values of the temperature: nanoplates - 99° C, hexagonal prisms - 60° C, spheres - 41° C, octahedrons - 40° C.

It was shown that the hexagonal prisms possess the greatest coercive force and saturation magnetization. Nanoplates of the smallest size had low toxicity and the highest T2-contrast, which makes them promising MNP for targeted drug delivery and MRI. They also showed higher heating temperature under magnetic field and can find application in hyperthermia.

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FERROMAGNETIC AMORPHOUS MICROWIRES FOR ENDOVASCULAR INTERVENTIONS

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In recent years, a new research direction has emerged in medicine related to the development of microrobots ("microswimmers"), which represent a new class of artificial particles of nano- and micro scale particles capable to convert external energy into motion [1]. Moving along the physiological fluids, microrobots can perform diagnostics, deliver medicines to the different parts of the human body, and realize surgical interventions. At the present time to move microrobots various methods are offered: chemical reactions, light, acoustic waves, electromagnetic fields. The experimental data obtained by now showed that magnetic fields proved to be the most effective, because they did not require using the toxic chemicals and interacted with microrobots through tissues without any interference. Currently, the most popular forms of microrobots are elongated ellipsoids, rotating spiral fibers, and magnetic heads with an elastic tails. However, the problem of creating new configurations of microrobots, including based on magnetic materials, remains relevant. The most promising for these purposes are amorphous microwires, characterized by unique magnetically soft properties.

In this paper, the results on the investigation of the influence of twisting stresses on the magnetic characteristics of the $Co_{69}Fe_4Cr_4Si_{12}B_{11}$ amorphous microwires and also three microrobots, made on their basis, are presented. The $Co_{69}Fe_4Cr_4Si_{12}B_{11}$ amorphous microwires were produced by the modernized Ulitovsky–Taylor method. The diameter of the magnetic core of microwires was equal to 60 microns. Three microrobots were produced in the form of spirals with a diameter of 0.2 mm and a length of 10 mm. Two of them had practically circular head with diameter approximately equal to 0.32 and 0.56 mm and a length of 1 mm, created by winding microwire at the end of the spirals into one and three layers. Considering the fact that the microrobots must move in a confined space (in the capillaries), the investigation of the microwires was performed both in a free and capsulated state.

The following results were received. The magnetic characteristics of the initial microwire in the free and capsulated state do not differ within the experimental error. Due to this fact, data, obtained only for capsulated samples, are given below. The saturation field, Hs, of microwire, twisted by 0.33 rev/cm, increases in 1.5 times, and Hs of strongly twisted pair of microwires – in 2.5 times in comparison with the initial sample. Herewith, the magnitude of Hs of microrobot without a head increases almost in 70 times, and with a single- and three-layered head –in 400 and 350 times, respectively. The change of Hs of microrobots in comparison with the initial microwire was explained by the influence of demagnetizing field, caused to their form. The speeds of movement of microrobots along artificially created microcapsules were estimated. Support by the Russian Foundation of Basic Research, Grants 15-02-02077.

[1] K. Jagajjanani Rao, Fei Li Long Meng, Hairong Zheng, Feiyan Cai , Wei Wang, *Small* **1**, **(**2015). www.small-journal.com

SCANNING PROBE MICROSCOPY OF MAGNETIC NANOINCLUSIONS IN DILUTED MAGNETIC SEMICONDUCTOR MATRIX

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Magnetic composite materials, as diluted magnetic semiconductor (DMS)/ferromagnetic semimetal are suitable candidates for utilizing in high – temperature (above 300 K) spintronic devices [1].

Thin hybrid InSb(GaSb)/MnSb films were synthesized by pulsed laser deposition using mechanical droplet separation and characterized by scanning probe microscopy in atomic (AFM) and magnetic (MFM) force regimes at T = 303 – 393 K (Fig. a, b). The ferromagnetic MnSb particles with mean size 50 – 100 nm incorporated into InMnSb DMS matrix are demonstrated size-depended anisotropy Hopkinson effect which was observed earlier for bulk InSb/MnSb poly- and monocrystalls [2, 3]. It is surprisingly that magnetization of MnSb nanoparticles into GaMnSb matrix do not reveal the Hopkinson peak and behavior of low-field (B < 0.05T) magnetization is similar to bulk isotropic ferromagnetic materials with Curie temperature about 600 K.

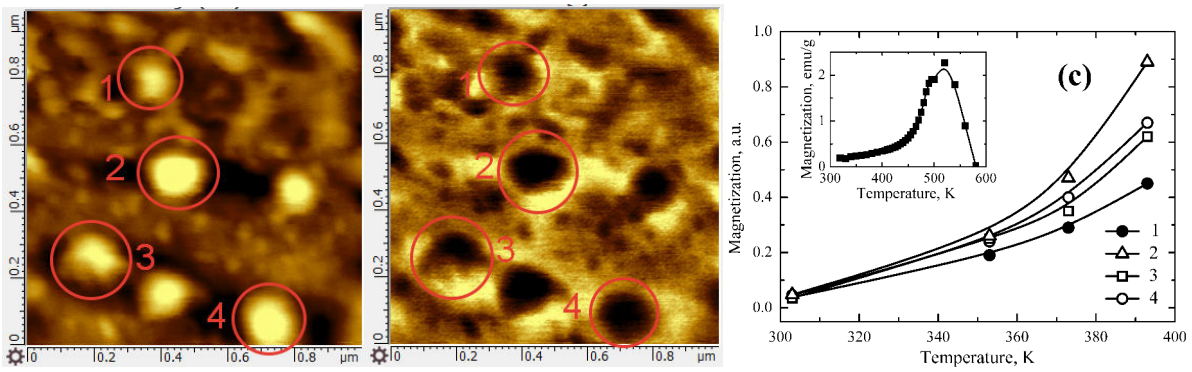

Figure. Scanning probe microscopy of the InSb/MnSb film at T = 393 K carrying out in AFM (a) and MFM (b) regimes. c) The temperature dependencies of magnetization for magnetic inclusions with different sizes which are labelled on (a) and (b) parts. Inset: The temperature dependence of low-field magnetization for a monocrystalline InSb-MnSb eutectics composition.

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[1] S.F. Marenkin et.al., *Russ. J. Inorg. Chem.* **60**, 295 (2015).
[2] A.V. Kochura et.al., *J. Appl. Phys.* **113**, 083905 (2013).
[3] V.M. Novotortsev et.al., *Russ. J. Inorg. Chem.* **56**, 1951 (2011).

SYNTHESIS OF BIOCOMPATIBLE MULTIFERROIC MFe_2O_4@$BaTiO_3$ CORE-SHELL NANOPARTICLES FOR BIOMEDICAL APPLICATIONS

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Malignant tumors are one of the most dangerous types of life-threatening diseases. This indicates the great importance of effective antitumor drugs development. Chemotherapy is one of the key methods of anticancer therapy at the present time. Unfortunately this kind of therapy has lots of drawbacks, such as low selectivity, toxicity etc.

In this work the core-shell nanoparticles of ferrites and $BaTiO_3$ are suggested as perspective drug delivery carries. These kinds of core-shells are classified as a multiferroic, because they have a magnetoelectric effect, which means combination of ferroelectric and ferromagnetic properties. The effect gives ability to manipulate electric charge of the nanoparticles via external magnetic field. It is also well-known that the charge of nanocarriers effect on their cellular uptake efficiency. Finally this kind of core-shells gives opportunity to control the process of drug delivery via external magnetic field. It is particularly actual in the case of cancer cells showing other value of membrane potential than regular cells [1]. The following methods were used during the experiments:

№	Core	Medium	Precursors	Colloidal stability	Core size (nm)
1	Fe_3O_4	Benzyl alcohol	Metallic barium, titanium isopropoxide,	Stable	10
2	Fe_3O_4	Deionized water, anhydrous isopropanol	$Ba(OH)_2$, ethylenediamine, titanium isoropoxide,	Unstable	10
3	Fe_3O_4	Deionized water, triethylene glycol	$Ba(OH)_2$, titanium isopropoxide	Stable	10
4	$CoFe_2O_4$	Deionized water, anhydrous ethanol	$BaCO_3$, titanium isopropoxide, citric acid	Stable before annealing, unstable after	15
5	Fe_3O_4				15

1th and 3rd methods allow to obtain stable sols of core@shell nanoparticles with proper size for subsequent *in vivo* and *in vitro* experiments. The hydrodynamic sizes of core@shells in stable sols are less than 100 nm. According to XRD analysis the samples 1 and 2 have amorphous shell while BaTiO3 phase is detected in sample 3. Only the crystalline shell is suitable for multiferroics formation. The 4 and 5 samples are stable but there is no crystalline shell is detected before annealing. After annealing the samples are non-redispersible because of the sintering. The best method for required multiferroic core@shell nanoparticles synthesis is hydrolysis of precursors in glycolic medium. Glycols inhibit fast hydrolysis of titanium precursor and stabilize surface of as-formed core@shells as well as initial magnetic core. In other cases titanium precursor hydrolyze too fast with formation of amorphous shell and/or aggregation of nanoparticles.

[1] M. Yang, W. J. Brackenbury, *Frontiers in Physiology* **4**, 1-10 (2013).

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UNUSUAL PROPERTIES OF MAGNESIUM DIBORIDE - MANGANITE NANOCOMPOSITE

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The development of innovative technologies leads to the creation of new materials with properties that are absent in the parent components. In addition to transport and magnetic properties, it is necessary to investigate percolation characteristics in such systems. The percolation effects are of fundamental importance for understanding the current flow in real multicomponent systems, where it is possible to form both percolation networks and the appearance of new properties due to the mutual influence of the components of such systems [1, 2].

The percolation features of nanocomposites of magnesium diboride - manganite with different concentration composition of the components are investigated. The features of the systems under consideration consist in an essential difference in the dimensions of the components and their mutual influence (proximity effect). Namely, the nanocomposite consists of microgranules ~ 5 μm of magnesium diboride MgB_2 superconductor and nanogranules ~ 50 nm of $La_{0.7}Ca_{0.3}MnO_3$ manganite. The transport characteristics of these composite have been studied in a wide range of temperatures (from room temperature to helium temperatures), magnetic fields and high hydrostatic pressures [3, 4].

It is established that the physics of the percolation grid formation in the nanocomposite is different above and below the critical temperature of the MgB_2 superconductor (T_C). In the case of $T>T_C$, the main characteristics of the nanocomposite (the current-voltage dependence, percolation threshold) are determined by the geometry of the components (the granule size effect). At $T<T_C$, in addition to the component geometry, the proximity effects (ie, the mutual influence of the components) have a significant influence on the parameters of the percolation transition in the composite (superconducting transition temperature, critical current, current-voltage dependences). It means that in the structure of magnesium diboride-manganite overlapping of the wave functions of two different electronic phases occurs and a new state appears with the characteristics of both phases.

As a result, new materials with properties absent in the original components are obtained.

[1] D. Stauffer, *Introduction to Percolation Theory. - L.: Taylor* (1992).
[2] A. Bunde, *J. Electroceram* **5** (2), 81 (2000).
[3] V.V. Kononenko, *Solid State Phenomena* **215**, 100 (2014).
[4] V.V. Kononenko, *Fiz. Nizk. Temp.* **41**(3), 262 (2015) (In Russian).

THE DIFFRACTION STUDY OF LOW-DIMENSIONAL SPIN FRUSTRATED FAMILY OF MATERIALS $M^{+}Sb_2O_6$ (M=Mn, Co, Cu)

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In the quasi-two-dimensional magnets with acentric (chiral) crystal structure and a triangular lattice of magnetic atoms in a layer, the competition between exchange interactions, frustrations and anisotropy can revolutionary affect the fundamental mechanisms of spin ordering and the corresponding phase transitions. Low-dimensional spin frustrated systems assume noncollinear incommensurate spin orderings in order to reduce the degree of their spin frustration. It is inherent in $MnSb_2O_6$, a magnet with a chiral crystal and a cycloidal magnetic structure, a multiferroic with a unique ferroelectric switching mechanism [1, 2].

We have discovered and synthesized a new form of layered trigonal $MnSb_2O_6$, very different, according to its X-ray diffraction pattern, from known layered multiferroic form mentioned above [1]. The $MnSb_2O_6$ sample was characterized by Rietveld analysis of the neutron powder diffraction patterns, magnetic susceptibility and specific heat temperature dependence measurements. A new rosiaite-type (s.g. *P-31m*) form of $MnSb_2O_6$ is isostructural with $MnAs_2O_6$ and differs from the known form of $MnSb_2O_6$ (s.g. *P321*).

The appearance of additional reflections related to the antiferromagnetic ordering organization of the $MnSb_2O_6$ sample below T_N=8.5 K is clearly visible on the low-temperature neutron powder diffraction patterns measurement by the SPODI neutron powder diffractometer at Munich, Germany.

Magnetic structure is described by the propagation vector k = (1/3, 1/3, 1/5). The carried out analysis of the spin interactions of resulting magnetic structure indicates that spin exchange interactions is not determining factor leading to the superstructure. At the same time the magnetic dipole-dipole interactions play important role in forming the magnetic superstructure.

We also have studied other members of the family $M^{+}Sb_2O_6$ (M= Co, Cu, Ni) [3]. Neutron diffraction data shown, that the compound $CoSb_2O_6$ has a similar magnetic structure, which characterized propagation vector **k** = (1/3, 1/3, 1/6).

Comparing magnetic behaviour of trirutile- (s.g. *P4₂/mnm*) and rosiaite-type (s.g. *P-31m*) $M^{+}Sb_2O_6$ families, the most drastic difference is seen for M = Cu. The low-temperature neutron diffraction study of $CuSb_2O_6$ confirmed absence of long-range magnetic order down to 1.5 K [3].

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[1] R.D.Johnson, K.Cao, L.C.Chapon, F.Fabrizi, N.Perks, P.Manuel, J.J.Yang, Y.S.Oh, S.-W. Cheong, P.G. Radaelli, *Phys. Rev. Lett. V.* **111**, 017202 (2013).
[2]. M. Kinoshita, S. Seki, T.J. Sato, Y. Nambu, T. Hong, M. Matsuda, H.B. Cao, S. Ishiwata, Y. Tokura, *Phys. Rev. Lett. V.* **117**, 047201. (2016).
[3]. A.Yu. Nikulin, E.A. Zvereva, V.B. Nalbandyan, I. Shukaev, A.I. Kurbakov, M.D. Kuchugura, G.V.Raganyan, Y.Popov, V.D.Ivanchenko, A.N.Vasiliev, *Dalton Trans.* (2017), DOI: 10.1039/C6DT04859E.

MAGNETORESISTANCE MODELLING OF EXCHANGE BIASED FILMS UNDER ELASTIC DEFORMATION

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The strain-magnetoresistive effect (SMR) is a magnetoresistance change of a sample under elastic stresses. It reflects the interplay of anisotropic magnetoresistive effect (AMR) and magnetostriction. Functional materials combining these effects can be used in designing of transducers for pressure and deformation sensors. Thin magnetic films of 3d-metal alloys are the striking example of such materials. Their application in multilayer films with exchange bias is able to reduce magnetic hysteresis and improve functional properties [1]. This work was dedicated to micromagnetic modelling and experiments on the SMR effect in films of rectangular shape with unidirectional anisotropy.

Computer modelling was performed in OOMMF program where the finite difference method is implemented. The modelling object was a parallelepiped with varied film-like proportions. Magnetic anisotropy containing unidirectional and induced uniaxial ones was set. The OX axis, directions of uniaxial compressive stress and of electric current were oriented along the longest side of the object. The magnitude of stress was linearly varied along the OX starting with zero at ends and reaching the maximum in the middle of the side (Fig.1, right). An example of calculated micromagnetic structure of the object is shown in Fig.1 (left).

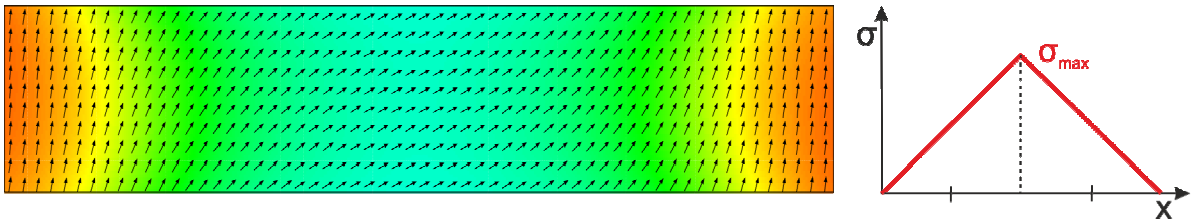

Figure 1. Micromagnetic structure of the exchange biased film (left) under nonuniform compressive stress with maximum value of $\sigma_{max}= 6\cdot10^{8}$dyn/cm^2 (right).

Dependencies of the magnetoresistance in $Fe_{10}Ni_{90}$ films on the value of σ_{max} varying both external magnetic field and orientation of induced magnetic anisotropy axis were obtained from the calculations. These results were compared with experimental data.

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[1] Balymov K.G., Kudyukov E.V. et al., *KnE,* 11-16 (2016).

NEUTRON AND SYNCHROTRON DIFFRACTION STUDIES OF THE LOW-DIMENSIONAL FRUSTRATED MAGNETISM OF OXIDE MATERIALS WITH SPECIAL MAGNETIC, ELECTRICAL AND REDOX PROPERTIES

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High-resolution neutron and synchrotron diffraction studies of the crystal and magnetic structures of $Na_3Co_2SbO_6$, $Li_3Ni_2SbO_6$, $Na_2Ni_2TeO_6$ and $K_2Ni_2TeO_6$ layered oxides with a honeycomb superstructure within the layer are presented. These compounds are expected to be promising materials as solid electrolytes or electrode materials, thermoelectric materials, superconductors and unusual magnets with magnetic ordering at low temperatures, low-dimensional and spin-glass behavior, spin-flop transitions, etc. Their magnetic properties are important because the processes of ionic transfer are connected with the change of the valence and spin states of transition metals. Despite an essential difference in the crystal structure of all studied compounds, namely in the packing of honeycomb layers along c-axis, structure of each M_2Sb/TeO_6 layer containing the magnetic ions is the same. AFM type interaction within the magnetic layer between nearest neighbors J_1 and additional frustrated exchange intralayer interaction with second and third nearest neighbors, J_2 and J_3, can lead to frustration in the magnetic subsystem and the emergence of unusual types of magnetic moments ordering. In our case, magnetic structures for all samples in the ground state determined from neutron diffraction data can be considered as zigzag FM chains AFM coupled. However, the zigzag type is very different for each compound and depends on the type of 3d-ions, character of stacking of layers and the distance between the layers determining the strength of the interlayer interaction J_4.

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PRODUCTION OF IRON-NICKEL NANORODS AND THEIR MAGNETIC PROPERTIES

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Recently, great deal of efforts has been done in order to produce new high-energy permanent magnets because of so-called "rare-earth crisis". Amongst all rare-earth free systems, FeNi $L1_0$ (tetrataenite) has the highest theoretical value of energy product (320 kJ/m^3), which is the figure of merit in a hard magnetic material.

In the FeNi binary system, the chemically ordered $L1_0$ structure is only marginally more stable than the disordered face-centered cubic A1-type structure, which is entropically stabilized above the temperature of equilibrium chemical order-disorder T_{eq} = 320 °C. Below T_{eq} Fe-Ni alloys have extremely low diffusivity of constituent elements. Due to such slow diffusion, $L1_0$ FeNi is only naturally found in meteorites, in which the phase forms over billions of years and the synthesis of $L1_0$ FeNi in the lab is the actual but challenging task.

Previously, we successfully applied approach of cyclic oxidation and reduction heat treatment, proposed by E. Lima et al [1] on $Fe_{50}Ni_{50}$ nanopowders to stabilize desired phase. DSC results showed presence of endothermic peak, which is attributed to disordering of ordered $L1_0$ phase, in the powder that was subjected to 10 cycles of heat treatment. Our next goal is to assemble nanoscale particles together in an aligned structure. It is a challenge because nanoparticles tend to aggregate in clusters. To solve this problem FeNi nanorods were produced.

For production of FeNi nanorods we used galvanic method [2] with two-electrode cell setup. This approach allows to improve hard magnetic properties due to additional contribution of shape anisotropy, and to enhance the rate of $L1_0$ phase formation process, thanks to the presence of preferred direction of growth.

Polycarbonate Merck Millipore Isopore membranes were used as a template for electrodeposition of nanorods. A layer of Cu was sputtered on one side of the membrane to provide electrical contact. The carbon electrode was used as inert anode. The electrolyte consisted of lactic acid and solutions of $FeSO_4 \cdot 7H_2O$ and $NiSO_4 \cdot 7H_2O$ salts in distilled water. As shown in Fig.1 this method allows to produce oriented nanorods. After that FeNi nanorods were heat treated with cyclic oxidation and reduction technique to stabilize tetrataenite phase.

We investigated the influence of heat treatment regime and phase composition of obtained nanorods on their magnetic properties.

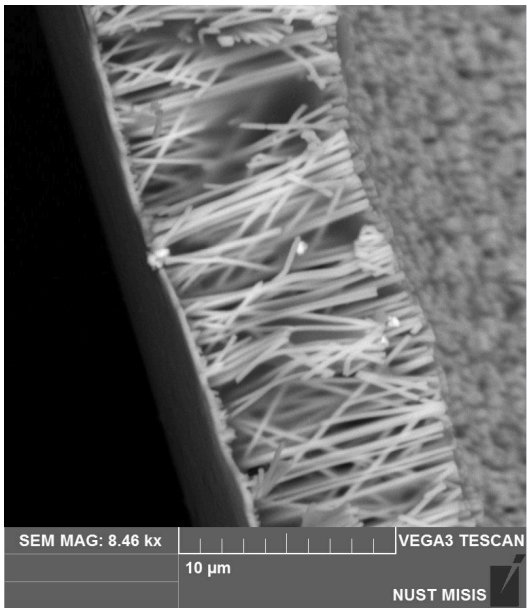

Figure 1. SEM image of FeNi nanorods

[1] E. Lima Jr. et al, *Phys. Stat. Sol.*, **187** (2001).
[2] S. Xue et al, *Thin Solid Films,* **517** (2009).

ELECTRONIC AND MAGNETIC PROPERTIES OF ACENTRIC B20 COMPOUNDS: EXPERIMENT AND AB INITIO SIMULATIONS

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Non-collinear magnets provide a possibility to couple electric and magnetic degrees of freedom, which is of great interest for future spintronics applications. Among such materials, transition metal monosilicides and monogermanides with acentric B20-type crystal structure attract growing attention due to a rich variety of exotic phenomena. A well-known example is MnSi, where, because of lack of inversion symmetry in the B20 structure, the Dzyaloshinski–Moriya interaction leads to a long-period helical magnetic order.

Here, we report on the experimental and theoretical study of high-pressure-synthesized B20 compounds $Mn_{1-x}Rh_xGe$, which demonstrate various electronic and magnetic properties. For example, the $x = 0$ end member, MnGe, is a helical magnet with $T_c = 170$ K [1], while RhGe exhibits the coexistence of very weak ferromagnetism (7×10^{-4} μ_B/f.u., $T_m = 140$ K) and superconductivity ($T_c = 4.3$ K) [2]. Our *ab initio* simulations were done using the FP-LAPW method (Wien2k package) and the pseudopotential method (Quantum Espresso package). We investigated the compressibility, electronic properties, emission spectra and other physico-chemical characteristics of $Mn_{1-x}Rh_xGe$ compounds under normal and high pressure. The obtained results were compared with available experimental data. In particular, we consider the electric field gradient (EFG), created on a nucleus by its environment. The EFG is determined by non-spherical components of the charge density near the nucleus. The experimental EFG was measured on $^{111}In/^{111}Cd$ probe nuclei using the time-differential perturbed angular γγ-correlation (TDPAC) method. The comparison of measured and calculated EFGs provides information on local environment of metal and metalloid sites in the B20 lattice.

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[1] O.L. Makarova, A.V. Tsvyashchenko, G. Andre, F. Porcher, L.N. Fomicheva, N. Rey, I. Mirebeau, *Phys. Rev. B* **85**, 205205 (2012).
[2] A.V. Tsvyashchenko, V.A. Sidorov, A.E. Petrova, L.N. Fomicheva, I.P. Zibrov, V.E. Dmitrienko, *J. Alloys Compd.* **686**, 431 (2016).

OPTICAL AND MAGNETIC INVESTIGATIONS OF STRUCTURES FORMED BY FERROLUID-BASED SYSTEMS

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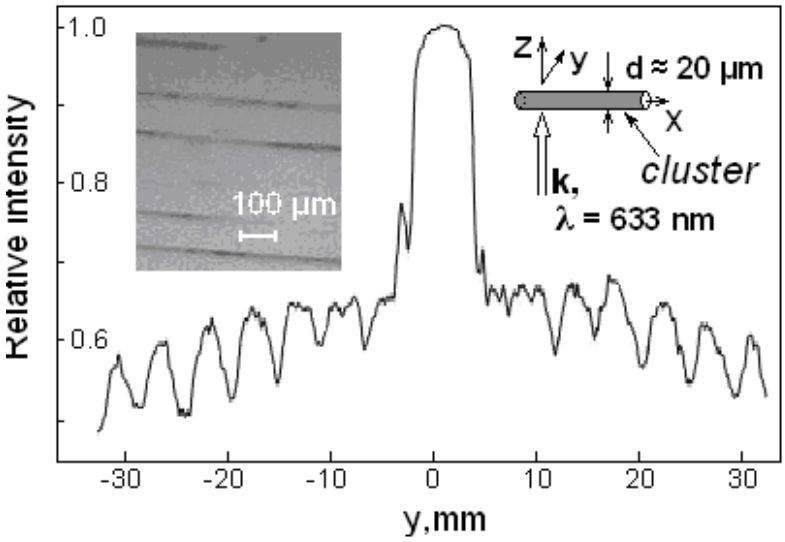
Ferrofluids are colloids, the solid phase of which is a magnetic material. In fact, these are magnetic nanostructures that possess special properties and can find applications in different areas. In particular, of great interest are a possible use ferrofluids in biology and medicine. Therefore, it is important to investigate the behavior of magnetic nanoparticles in complex composite systems.

In this report we analyze the structures formed in different media by ferrofluid particles under the influence of an external magnetic field. For the studies, magnetometric and optical methods were used. The solutions of magnetite (Fe_3O_4) in kerosene and water, including those with the addition of coagulating impurities, were investigated. Specific features of agglomeration which manifested themselves, in particular, in the visualized extended clusters which could be studied by light diffraction [1] (an example for the kerosene solution at external field of 1800 Oe is shown in the Figure) were revealed. Optical characteristics of model media, such as ferrofluid-filled porous materials with different channel sizes and also the samples obtained from solvents with the addition of SiO_2 microspheres, were obtained. It was found that the microspheres in an aqueous solution stimulate the nucleation of large agglomerates. Static magnetization curves and frequency dependences of the magnetic susceptibility were compared with the data obtained by the optical technique.



The possibility to obtain information on properties of ferrofluids and composites based on them by nuclear magnetic resonance is considered.

[1] A.V. Prokofiev, I.V. Pleshakov, E.E. Bibik, Yu.I. Kuzmin, *Tech. Phys. Lett.* **43**, 194 (2017).

MAGNETIC PROPERTIES OF $Fe_{1-x}Ga_x$: AB INITIO AND MONTE CARLO STUDY

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$Fe_{1-x}Ga_x$ alloys very interesting due to their giant magnetostriction observed at room temperature in low magnetic fields [1], which make their attractive for energy-harvesting applications. A study of phase transitions in Fe-Ga alloys shows that a large influence on the magnetic properties is exerted by the technological process of fabrication [2]. Moreover, the magnetostriction coefficient and its sign can be sufficiently affected by the different atomic arrangements in the A2, B2, and $D0_3$, $L1_2$ structures [1].

In this study we investigate the magnetic properties of $Fe_{1-x}Ga_x$ alloys (x = 0.0-0.3) by means of the density functional theory and Monte Carlo simulation. The ground state calculations were carried out by using the Spin-Polarized Relativistic Korringa-Kohn-Rostoker (SPR-KKR) [3]. Structural optimization was performed using the exchange-correlation potential in the approximation of the generalized gradient (GGA). The calculations of optimized lattice parameters were carried for compositions with $x = 0$ up to 0.30. The following crystal lattices of cubic symmetry were taken into consideration: A2 (Im-3m, #229), $D0_3$ (Fm-3m, #225), and $L1_2$ (Pm-3m, #221). The optimized lattice parameters a_0, equilibrium ground state energies E_0 and total magnetic moments M_0 were calculated in dependence on the Ga excess in $Fe_{1-x}Ga_x$ (x = 0.0 − 0.30) for A2, $D0_3$, and $L1_2$ crystal structures. It was shown that the lattice parameter increases linearly, while the total magnetic moment decreases linearly for all phases studied with increasing Ga content. For the optimized lattice parameter, the Heisenberg exchange interaction parameters J_{ij} for all considered phases A2, $D0_3$, $L1_2$ were calculated using the expression proposed by Liechtenstein et al. [4]. In the next step, we calculated Curie temperatures with the help of the Monte Carlo simulation and classical three-dimensional Heisenberg model using calculated exchange parameters [5]. Obtained values of Curie temperature are in a good agreement with experimental data.

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[1] I.S. Golovin, *Mater. Design.* **88**, 577 (2015).
[3] I.S. Golovin et al., *J. Alloy. Compd.* **675**, 393 (2016).
[3] H. Ebert et al., *Rep. Prog. Phys.***74**, 096501 (2011).
[4] A.I. Liechtenstein et al., *J. Magn. Magn.Mater.* **67**, 65 (1987).
[5] V.V. Sokolovskiy et al., *Phys. Rev. B.* **86**, 134418 (2012).

CONTINUAL MODEL OF MAGNETIC DYNAMICS FOR ANTIFERROMAGNETIC PARTICLES IN ANALYSING SIZE-EFFECTS ON MORIN TRANSITION IN HEMATITE NANOPARTICLES

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It is well known that bulk hematite undergoes the Morin transition from antiferromagnetic (AFM) ordering of the magnetic moments along the trigonal axis below $T_M \approx 260$ K to the weak ferromagnetic (WFM) state above T_M with sublattices magnetizations lying in the perpendicular plane and canting by the Dzialoshinski interaction. At the same time, the critical temperature in nanocrystalline hematite decreases and for crystal size of about 20 nm the phase transition disappears completely [1]. Such peculiarity is commonly ascribed to strong surface and imperfections effects in nanosize grains. Among plenty of techniques using to study specific magnetic behavior of hematite Mössbauer spectroscopy is one of the most informative [2]. On the other hand, it is a powerful tool for investigating specific thermodynamics of nanostructured magnetic materials, whose main character is the predominant role of shape anisotropy as compared with magnetocrystalline interactions [3]. Indeed, application of modern models for excitation spectrum of AFM particles [4, 5] to the numerical analysis of the Mössbauer spectra for extremely fine hematite nanoparticles (~ 4 nm) revealed that easy magnetization axes in the particles are uniformly distributed in regard to the crystalline axes [6].

The main aim of this work is to present new results obtained for larger hematite particles (of about 20 nm and 70 nm) by accurate analysis of their Mössbauer spectra within generalized model of magnetic dynamics for AFM particles which takes into account the Dzialoshinski contribution. For the first sample (~ 20 nm) we ascertained non-uniform distribution of the magnetization axes relative to the crystalline directions, which concentrates in the vicinity of the plane perpendicular to the trigonal axis and reflects the magnetocrystalline, shape and Dzialoshinski contributions to the total magnetic energy. For the second sample (~ 70 nm) we observed a gradual 'Morin transition' that looks like a superposition of the AFM and WFM phases in the temperature range between 200 K and 260 K and can be associated with a broad distribution of the particles over their sizes with different temperatures of the Morin transition.

Authors thank Russian Ministry of Education and Science for the financial support (project № 14.587.21.0027, ID RFMEFI58716X0027).

[1] Ö. Özdemir, D.J. Dunlop, T.S. Berquó, *Geochemistry, Geophysics, Geosystems* **9**, 10 (2008).
[2] F. van der Woude, Phys. Stat. Sol. **17**, 417 (1966).
[3] M.A. Chuev, *J. Phys.: Condens. Matter* **23**, 426003 (2011).
[4] M.A. Chuev, *JETP Lett.* **95**, 295 (2012).
[5] M.A. Chuev, *JETP Lett.* **103**, 175 (2016).
[6] I. Mischenko, M. Chuev, *Hyperfine Interact* **237**:21 (2016).

ELECTRICAL AND MAGNETIC PROPERTIES OF $La_{0.7}Ca_{0.3}Mn_{0.9}Co_{0.1}O_3$ EXHIBITING THE CROSSOVER OF FIRST- AND SECOND-ORDER PHASE TRANSITIONS

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In this work, a polycrystalline sample of $La_{0.7}Ca_{0.3}Mn_{0.9}Co_{0.1}O_3$ was prepared by solid-state reaction method. Our results point out that this compound exhibits crossover of the first- and second-order phase transitions. Coexistence of magnetoresistance (MR) and magnetocaloric (MC) effects in the $La_{0.7}Ca_{0.3}Mn_{0.9}Co_{0.1}O_3$ compound, which takes place around the metal-insulator (MI) transition with T_{MI} = 155 K and the ferromagnetic-paramagnetic (FM-PM) transition with T_C = 188 K, respectively, has been observed. Considering temperature dependence of resistivity both in the presence and in the absence of the magnetic field, $\rho(T)$, data could be described by the phenomenological percolation model of phase segregation. This indicates electron-electron and electron-magnon scattering processes are dominant at temperatures below T_{MI}. Further, based on modified Arrot plot and scaling analysis, the critical behavior around FM-PM phase transition of sample has been done. The obtained results suggest an existence of the ferromagnetic short-range order in $La_{0.7}Ca_{0.3}Mn_{0.9}Co_{0.1}O_3$ compound. This nature of the observed phenomena is discussed thoroughly by mean of the coexistence and competition of magnetic interactions.

SCAFFOLD-FREE AND LABEL-FREE MAGNETIC LEVITATION OF TISSUE SPHEROIDS

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Tissue spheroids have been proposed as building blocks in 3D spheroids-based biofabrication [1]. Magnetic forces-driven 2D patterning of tissue spheroids requires cell labelling by magnetic nanoparticles [2]. Label-free approach for magnetc levitation has been introduced recently[3]. Here we report for the first time rapid assembly of 3D tissue construct using scaffold-free and label-free magnetic levitation of tissue spheroids.

Tissue spheroids, particularly, chondrospheres, of standard size, shape and capable to tissue fusion have been biofabricated from primary sheep chondrocytes using non-adhesive technology. Label-free magnetic levitation has been performed using experimental prototype device with permanent magnets in presence of gadolinium in culture media, which enables magnetic levitation. Potential toxic effects of gadolinium have been systematically evaluated in advance.

Mathematical modeling and computer simulations have been used for prediction of magnetic field and kinetics of tissue spheroids assembly into 3D tissue constructs. Polysterene beads were used first as analogs of tissue spheroids for determination of an optimal settings for magnetic levitation in presence of gadolinium. Second, it has been shown that chondrospheres were able to assemble rapidly into 3D tissue construct in the permanent magnetic field in the presence of gadolinium.

It has been demonstrated also that laser could be used for manipulation (translocation, rotation, elongation and fission) of assembled 3D tissue constructs. Our modeling demonstrates that under microgravity condition in Space the described label-free magnetic forces-driven rapid bioassembly of tissue spheroids into 3D tissue construct would be possible to realize using lower and non-toxic concentrations of gadolynium.

Thus, label-free magnetic levitation of tissue spheroids is a promising approach for rapid scaffold-free 3D biofabrication and attractive alternative to label-based magnetic forces-driven tissue engineering.

[1] V. Mironov et al, *Biomaterials.* **12**, 2164 (2009).
[2] B. Whatley et al*, J. Biomed. Mater. Res A.* **102**,1537 (2014).
[3] S. Tasoglu et al, *Adv. Health Mat.* **10**, 1469 (2015).

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MICRO DEVICES BASED ON FERROFLUID

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The motion of samples with ferrofluid in magnetic fields can be used to design micro devices and to create micro robots. Applications of micro fluidics and flow manipulation are already known [1–3]. A possibility to create a pump using the lifting of the ferrofluid surface over a ferromagnetic body in a uniform magnetic field is discussed in [4].

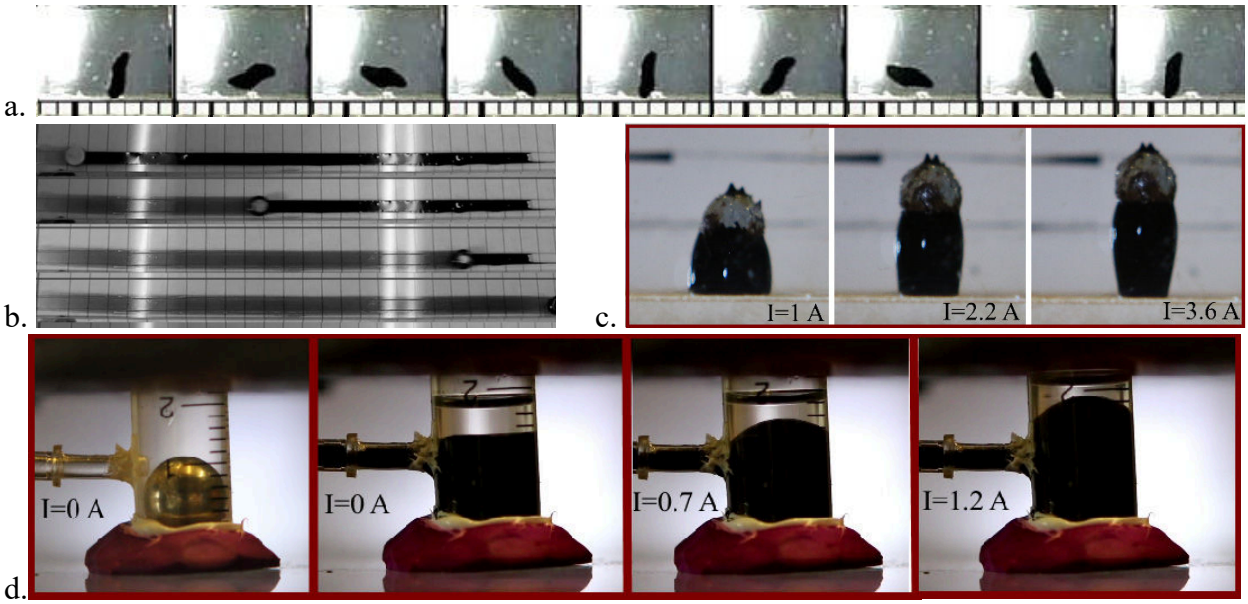

Fig.1. Ferrofluid locomotion systems.

Fig. 1 presents locomotion systems using a ferrofluid to create a motion: 1,a – the motion of a ferrofluid droplet along the vessel bottom in a rotating magnetic field; 1,b - the motion of a magnet along a thin magnetic fluid layer; 1,c – the valve made from magnetizable sphere immersed in a ferrofluid drop in vertical magnetic field; 1,d – the pump using magnetizable sphere surrounded by variable ferrofluid volume in vertical magnetic field. In the last two examples, the inhomogeneity of the magnetic field is created by distortion of the applied uniform field by well magnetizable bodies (concentrators).

In this work, deformation of variable volume of magnetic fluid around the spherical concentrator in a uniform applied magnetic field is studied experimentally and theoretically. Above the magnetic fluid is placed nonmagnetic immiscible fluid. When the surface of ferrofluid deforms, a non-magnetic fluid rises. Thus, it is possible to pump and dose fluids. The dependence of the pumped volume on the applied magnetic field is plotted experimentally and numerically.

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[1] B.Ando, A. Ascia, S.Baglio, N. Pitrone, *IEEE I. T. Instrum. Meas.* **58** (9), 3232 (2009).
[2] S. Afkhami, Y.Renardy, M.Renardy, J.S.Riffle, T. St Pierre, *J. Fluid Mech*. **610**, 363 (2008).
[3] K. Zimmermann, I. Zeidis, V.Bohm, J. Popp, *J. Phys., Conf. Ser*. **149**, 012116 (2009).
[4] D.A. Pelevina, V.A. Naletova, V.A. Turkov, *MHD* **49**, 3-4, 536 (2013).

MAGNETOELECTRIC EFFECT IN THE THIN LAYERED COMPOSITES AMORPHOUS ALLOY – PIEZOELECTRIC

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The magnetoelectric effect (ME) in composites consisting of thin layers of a ferromagnet and a piezoelectric is currently being intensively investigated because of the numerous possibilities of its use for technical applications in various fields. The ME effect consists in the appearance of an alternating electric voltage on the boundary of the piezoelectric layer under the influence of an alternative magnetic field.

Since amorphous ferromagnets are magnetostrictive materials, a ferromagnetic layer is necessary to create mechanical stresses in the piezoelectric. Thus, an alternating magnetic field is converted into an electrical voltage whose frequency is equal to the double frequency of the magnetic field. Therefore, in the next stage of ME studies, the problem arises of achieving the maximum magnetoelectric effect. One of the most rational methods for solving it is, along with the use of materials with maximum magnetostrictive and piezoelectric properties, the creation of conditions for the realization of the phenomenon of resonance in the mechanical system of a ferromagnet-piezoelectric. This will improve the efficiency of converting the magnetic field strength into electrical voltage by several orders of magnitude. There are natural questions: how to calculate the resonant frequencies and amplitudes of oscillations in a mechanical system, the components of which have different mechanical characteristics? Solving these problem is one of the most important goals of this work. Considering the nature of the oscillatory processes, we performed averaging of the mass, elastic, and geometric components of the ferromagnet-piezoelectric composite, allowing to determine the mechanical parameters included in the equations of its bending and longitudinal oscillations.

The solution of the problem of bending vibrations of a composite sample, which makes it possible to determine the amplitudes of its oscillations and resonant frequencies, is obtained.

A comparison is made of the experimentally determined resonance frequencies of flexural and longitudinal oscillations of a composite sample with values calculated theoretically. The maximum discrepancy does not exceed 20%, which indicates the validity of the proposed calculation methods.

METAL NANOCOMPOSITES AS A DUAL MODAL MAGNETIC RESONANCE/COMPUTED TOMOGRAPHY IMAGING: *IN VITRO*

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Metal Nanomaterials are playing a progressively more significant role in multifunctional molecular imaging in diagnosis. Developing novel contrast agents for efficient magnetic resonance and X-ray computed tomography imaging (MRI/CT) sensitivity is very essential for early diagnosis of various diseases. In the present work, we have prepared non-toxic nanocomposites as efficient MRI/CT contrast agents. Superparamagnetic iron oxide nanoparticles (SPION) were prepared by co-precipitation method and functionalized with dimercaptosuccinic acid (DMSA). The nanohybrid particles (SPION@AU) were developed by integrating SPION and gold nanoclusters into human serum albumin (HSA) matrix as a stabilizer. Then, physiochemical characterization and contrast enhancement of prepared nanomaterials were evaluated. *In vitro* (fibroblast cells) studies proved the favorable biocompatibility of the prepared nanocomposites with their distribution across the cytoplasm and nucleus in cells. It is also capable of enhancing the contrast in MR and X-ray CT imaging. Surface functionalization with a biocompatible DMSA/HSA matrix allowed us to obtain a novel targetable diagnostic and therapeutic tool. With this background, we can conjugate with drugs and targeted molecules and they will serve as a novel platform for multiple biomedical application.

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[1] C. Xu, B. Wang, S. Sun, *J. Am. Chem. Soc.,* **12,** 4216-4217 (2009).
[2] P. Prabu, W.S. Vedakumari, S. Bojja, B. Santhosh Kumar, T.P. Sastry, *Materials Chemistry and Physics,* **148,** 1212–1220 (2014).
[3] P. Prabu, W.S. Vedakumari, T.P. Sastry, *Nanoscale* **7,** 9676-9685 (2015).
[4] P. Prabu, T.P. Sastry, A. Suresh Kumar, K. Manickavasagam, *Biochim Biophys Acta.* **1861,** 2992-3001 (2017).

NON-EQUILIBRIUM CRITICAL DYNAMICS OF LOW-DIMENSIONAL MAGNETICS AND MULTILAYER STRUCTURES

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A significant interest has been recently focused on non-equilibrium processes in magnetic low-dimensional materials. The reduction of the dimension of magnets is accompanied by an increase in fluctuations of the spin density and the manifestation of the effects of critical slowing down and “aging” in the non-equilibrium behavior of low dimensional magnetic systems [1]. Thin films and low-dimensional demonstrates the slow critical evolution from a nonequilibrium initial state. Aging, coarsening and memory effects are nontrivial features in the non-equilibrium behavior of such systems with slow dynamics [2].

The magnetic properties of multilayer magnetic systems have been widely investigated over the past years, since they widely used in magnetic storage devices. Magnetic order in the multilayers is complex due to a strong influence of the shape and the magnetocrystalline anisotropies of the sample. Anisotropy effects leads to dimensionality crossover in Heisenberg films [3]. This study includes the Monte-Carlo simulation of the non-equilibrium critical evolution from different initial states of low-dimensional magnetics [4] and multilayers based on anysotropic Heisenberg films [5, 6].

This work was supported by the grant 17-02-00279 of Russian Foundation of Basic Research and by the grant MD-6024.2016.2 of Russian Federation President. The simulations were carried out on the Supercomputing Center of Lomonosov Moscow State University, Moscow Joint Supercomputer Center and St. Petersburg Supercomputer Center of the Russian Academy of Sciences.

[1] T. Mukherjee, M. Pleimling, Ch. Binek, *Phys. Rev. B* **82**, 134425 (2010).
[2] V.V. Prudnikov, P.V. Prudnikov, M.V. Mamonova, *Phys. Usp*., (2017).
[3] P.V. Prudnikov, V.V. Prudnikov, M.A. Menshikova, N.I. Piskunova, *JMMM* **387**, 77 (2015).
[4] I.S. Popov, P.V. Prudnikov, A.N. Ignatenko, A.A. Katanin, *Phys. Rev. B,* (2017).
[5] V.V. Prudnikov, P.V. Prudnikov, D.E. Romanovskiy, *J. Phys. D:Appl. Phys.* **49**, 235002 (2016).
[6] V.V. Prudnikov, P.V.Prudnikov, A.N. Purtov, M.V. Mamonova, *JETP Letters*, **104**, 776 (2016).

$La_{0,75}Sr_{0,25}MnO_3$ NANOPARTICLES WITH BLOCKING TEMPERATURE FOR SELF-CONTROLLED MAGNETIC HYPERTHERMIA

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Magnetic nanoparticles are extensively studied in recent years in the context of biomedical applications, in particular magnetic hyperthermia [1]. For magnetic nanoparticles used in magnetic hyperthermia it is highly desirable to have the maximum temperature over which the heating stops due to the intrinsic limiting mechanism.

In this work we investigated magneto-thermal properties of $La_{0.75}Sr_{0.25}MnO_3$ nanoparticles with diameter 43 nm in the physiologically tolerable range of frequencies and magnetic fields. The magnetic nanoparticles were heated in AC magnetic field for 600 second than the AC field was switched off and the cooling curve was written to estimate the heat power losses in the system. It was found that the heating rate depends on magnetic field amplitude but the maximum temperature is limited starting from amplitudes 180 Oe and higher (fig.1). This maximum temperature correlates with the blocking temperature ~340K at fig.2 obtained from zero field cooling and field cooling (ZFC-FC) measurements at magnetic field of 50 Oe.

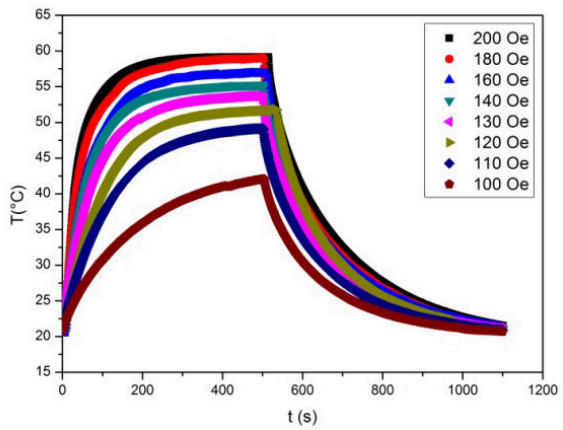

Fig. 1 The heating/cooling dynamics of LSMO nanoparticles for various amplitudes of AC magnetic field.

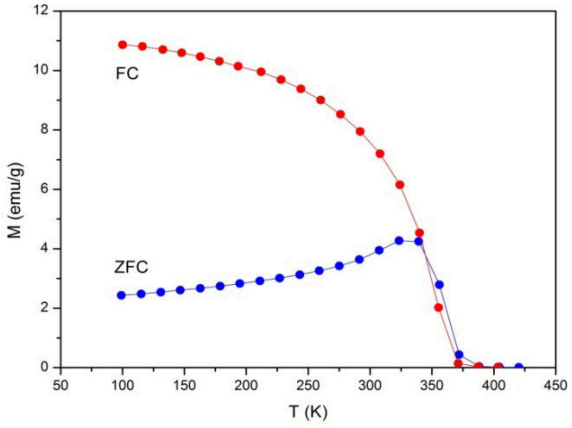

Fig. 2. Magnetization of LSMO nanoparticles: ZFC-FC curves

This principle can be used for making the magnetic nanoparticles with maximum temperature for self-controlled hyperthermia preventing overheating.

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[1] A. Perigo et al, *Appl. Phys. Rev.* **2**, 041302 (2015).

SUPERPARAMAGNETIC NANOPARTICLE BASED SUBCELLULAR FRACTIONATION FOR PLASMA MEMBRANE, ENDOSOME AND LYSOSOME ISOLATION.

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Here, we elaborate the methodology for SuperParaMagnetic NanoParticle (SPMNP) based subcellular fractionation for plasma membrane, endosomes and lysosomes. SPMNP based subcellular fractionation combines classical biochemistry with nanobiotechnology towards high pure and high yield organelle isolation. Particularly, methodologies for isolating plasma membrane (SPMNP-PM^{capture}), early or late endosomes (SPMNP-Endo^{capture}) and lysosomes (SPMNP - LYS^{capture}) are elucidated in this article. Depending on the target organelle, appropriate SPMNPs (SPMNP 1.0, 2.0 and 3.0) are synthesized, functionalized and applied to living eukaryotic cell for subcellular fractionation. SPMNP based fractionation strategy has several advantages compared to existing fractionation methodologies in terms of purity, yield, and isolating intact organelles under physiological conditions. Isolated magnetic organelles are available for generating its protein (proteomics), lipid (lipidomics), and glycan (glycomics) composition using mass spectrometry (MS) platform. Isolated organelles can be extended to protein/protein complex purification for biochemical and structural biology studies. SPMNP based subcellular fractionation is the technology that can complement existing tools for cell biology research.

INFLUENCE OF THERMAL DEFORMATION ON THE PHASE TRANSFORMATION AND MAGNETIC PROPERTIES OF AUSTENITIC STEELS

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It is known that the phase composition of the austenitic steels determines their operating properties. The main phase of the austenitic steels is austenite, γ-phase with fcc crystal lattice. To improve the high temperature plastic properties, austenitic steel contains the ferrite,α-phase with bcc crystal lattice. The austenitic structural materials can also contain the martensitic α′-phase. This phasecan arise in the austenitic steels under thermal deformation and promotes the dangerous embrittlement of the material. We present in this report the results of the control of the phase composition of the austenitic steels bymagnetic, structural and magnetic non-destructive methods.

Two phase samples(γ + α)withthedifferentcontentoftheferrite:2.7%, 6.8%, 11.6%, 23.4%, 34.9%, 59.8%,and 76.4%were used for the study. The coercive force (Hc) of the initial two-phase samples (undeformed state)was about 12- 15 A/cm, which was typical for the ferritic phase. Martensitic α'-phase was obtained by cold rolling of the samples which had been pre-cooled by liquid nitrogen. We studied the samples with the degree of deformation of 10%, 20%, and 30%.The magnetic properties of the deformed samples were measured by Lake Shore magnetometer and device for non-destructive magnetic control FerroCOMPASS. The phase composition and structure of the deformed samples were examined using a transmission electron microscope JEM-200CX.

Magnetic properties, phase composition, and structure of the studied samples after plastic deformation were significantly changed. The coercive force of the deformed samples increased by a factor of 2-4 and corresponded to the coercive force of the martensite phase. The saturation magnetization of the three phase samples (γ+α+α′), which was determined by the total number of ferromagnetic phases (ferrite and martensite) in the composition of the samples, was also increased.

These studies allowed us to develop a method for magnetic control of the phase composition of two and three-phase austenitic steels [1-2].

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[1] M.B.Rigmant, M.K.Korkh, D.I. Davidov, D.A.Shishkin, Yu.V. Korkh, A.P. Nichipuruk, N.V.Kazantseva, *Russian journal of non-destructive testing* **11**, 28 (2015).
[2] M.K. Korkh, M.B. Rigmant, D.I. Davidov, D.A. Shishkin, A.P. Nichipuruk, Yu.V. Korkh, *Russian journal of non-destructive testing* **12,** 20 (2015).

LOCAL MAGNETIC AND STRUCTURAL PROPERTIES OF NDFEB-BASED ALLOYS STUDIED BY XMCD TECHNIQUE

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X-ray magnetic circular dichroism (XMCD) technique was used to investigate local magnetic properties of microcrystalline $Nd_{10.4}Zr_{4.0}Fe_{79.2}B_{6.4}$ samples, oriented along either easy or hard magnetization direction. The Nd $L_{2,3}$ and Fe K edge XMCD spectra were measured at room temperature under a magnetic field of ±10 T. A very strong dependence of XMCD spectra on the sample orientation has been observed at the $L_{2,3}$ - edges of Nd, whereas the Fe K-edge XMCD spectra are found to be practically isotropic. This result indicates that magnetic anisotropy of NdFeB-based alloys originates from the Nd sublattice. In addition element selective magnetization curves have been recorded by measuring the intensity of XMCD signals as a function of an applied magnetic field up to ±17 T. To find a correlation between local and macroscopic magnetic properties of studied samples we compared these data with magnetization curves, measured by vibrating sample magnetometer up to 14 T. Results are important for understanding the origin of high-coercivity state in NdFeB-based intermetallic compounds.

Research was supported by Ministry of Education and Science of the Russian Federation (Agreement No 14.587.21.0028, unique number of project RFMEFI58716X0028). The authors acknowledge the European Synchrotron Radiation Facility (ESRF) for providing the opportunity of XMCD measurements at ID12 and BM23 beamlines and the International Laboratory of High Magnetic Fields and Low Temperatures (Wroclaw, Poland) for providing the opportunity of macroscopic magnetization curve measurements.

CONTRIBUTION TO MICROSCOPIC DERIVATION AND USE OF THE PHENOMENOLOGICAL LANDAU – LIFSHITZ – GILBERT – BLOCH EQUATIONS

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In the last decade rather intensive raise of interest to the various aspects of nanotecnology has taken place – in particular, in the fields of straintronics, magnetic friction etc. (see, e.g., [1-3]); it is important that, as a rule, nanodevices include some magnetic degrees of freedom. One of the main theoretical instruments for the study of magnetodynamics are the semi-phenomenological dynamic equations formulated long ago in the works of Landau and Lifshitz, Bloch and Gilbert; the most recent review of these topics may be found in [4].

Nevertheless, until now the full agreement concerning their concrete form is still lacking – in particular, it is not clear (see, e.g., [5]) in which manner one should consider the quantum and stochastic features of the Landau–Lifshitz–Bloch–Gilbert equations as compared to their classic and deterministic forms. In our talk the theoretical scheme is suggested in order to account more adequately for the fact that in the magnetic subsystem of many nanodevices rather strong exchange and anisotropy interactions of purely quantum nature are present.

In particular, we propose to use in the coefficients of damping and relaxation not the results of the molecular field approximation (MFA) but much more refined results of random phase approximation (RPA) known also as Tyablikov approximation [6]. We especially exploit the results by Medvedev [7] who studied the short-range magnetic order in an anisotropic ferromagnet by means of Green function method in Tyablikov decoupling scheme as well as the results by Yablonskyi [8] being especially valid for low-dimensional cases.

[1] M.P. Magiera et al., *EPL* **95**, 17010 (2011).
[2] K. Roy et al., *Appl. Phys. Lett.* **104**, 232403 (2014).
[3] A.K. Biswas et al., *Nanotechnology* **26**, 285201 (2015).
[4] U. Atxitia et al., *J. Phys. D* **50**, 033003 (2017).
[5] P. Nieves et al., *Phys. Rev. B* **90**, 104428 (2014).
[6] S.V. Tyablikov., *Methods in Quantum Theory of Magnetism, Plenum Press, NY*, (1967).
[7] M.V. Medvedev., *Phys. Met. Metallogr.* **106**, 444 (2008).
[8] D.A. Yablonskiy., *Phys.Rev. B* **44**, 4467 (1991).

THE PHASE TRANSITIONS IN DOMAIN BOUNDARIES AT THE SPIN-REORIENTATION IN THE UNIAXIAL MAGNETIC FILMS

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Two types of phase transitions (PT) in the domain boundaries (DB) caused by the temperature change in the anisotropy of the garnet type ferrite film were studied.

For the research, two films with different uniaxial anisotropy are selected: film №1 with a strong uniaxial anisotropy of the composition $(TmBi)_3(FeGa)_5O_{12}$ (Neel temperature T_N=437 K, magnetic compensation point T_K=120K) has axial anisotropy in a wide temperature range at $T>T_K$; film №2 with a weak uniaxial anisotropy of the composition $(YBi)_3(FeGa)_5O_{12}$ (T_N=421K, T_C=223K) has an axial phase in a narrow temperature interval at T>360K. The axis of easy magnetization of the films is <111>. Films have mixed anisotropy: crystall cubic anisotropy (K_1) and induced in the process of growth uniaxial anisontropy (K_U). The ratio of the anisotropy constants depends on the temperature, which is reflected in the peculiarities of the domain structure (DS). The domain structure is observed by the Faraday Effect. The spin-reorientation phase transition (SRPT) is determined by the color registration method. The study of the features of the DS is based on the theoretical modeling of visual experimental data.

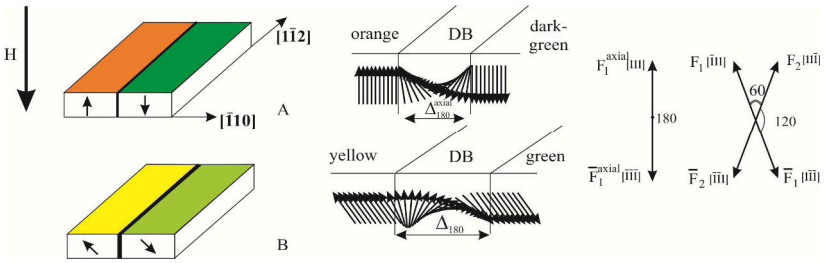

Fig.1. Models of DS and magnetization distribution in the DB of film № 2: A– 180^0 axial; B– 180^0 angular; (Δ is the DB width).

In both films, the spin flip process is observed on the CMD lattice. Domain boundary is the 180^0 Bloch one (Fig. 1A). There is a set of different spins orientations in the domain boundary, so it is most sensitive to a change in the ratio of the anisotropy constants.

As the temperature decreases, the uniaxial anisotropy decreases. Under the influence of cubic anisotropy, the spin orientation changes in some sections of the CMD boundaries. This leads to a change in the orientation of the spins in the regions close to the domain walls, i.e. There is a change in the color of the field and CMD. Angular phases appear.

Under the influence of cubic anisotropy, a PT occurs in the DB from the 180^0 th Bloch to the wider 180^0 domain boundary, in which the plane of the spin rotation is directed at an angle to the axis $<111>$ (Fig. 1B). A phase transition in the DB causes a first-order SRPT from the axial phase to the angular phase [1]. This SRPT occurs by nucleation; it is anhysteric. The nucleus of the new phase is the domain boundary of the initial phase. The temperature interval of the coexistence of the axial and angular phases was experimentally observed. Visually, the boundary between the axial and angular phases is not observed. The absence of a boundary between the axial and angular phases is explained by the concept of the nucleus of a new phase as a static soliton. It has been shown experimentally that the mechanism of the SRPT from the axial phase to the angular phase does not depend on the value of the ratio between the anisotropy constants.

[1] A.V. Bezus, A.A. Leonov, Ju.A. Mamalui, Ju.A. Siryuk, *FTT* **46** (2). 277-281 (2004).
[2] Ja.I.Granovskii, A.A.Leonov, Ju.A.Mamalui, Ju.A.Siryuk, *J. Functional Materials* **13** (3), 526-530 (2006).

X-RAY IN-SITU FULL-FIELD MICROSCOPY FOR MATERIAL CHARACTERIZATION

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Hard X-ray transmission microscopy based on refractive X-ray optics was employed as a tool in material science to investigate buried-in microstructures in two or three dimensions with spatial resolution approaching 100 nm [1-6]. In this microscope, the incoming beam goes through the condenser, illuminates the sample, goes through the objective lens, and hits the detector. The physical pixel size of the CCD/CMOS camera is typically around 0.65 μm. The inclusion of the X-ray lens further magnifies the image, making the effective pixel size even smaller. The X-ray magnification typically lies in the 5-100 range but is not strictly limited at either bound. With the extra magnification from X-ray optics, the maximum spatial resolution is no longer limited by the detector pixel size, but by the X-ray optical components. The use of a condenser lens and a beam decoherer can greatly improve the image quality.

Switching from monochromatic to radiation with a broader bandwidth, frame rates down to a few milliseconds can be realized, opening new possibilities for in situ studies of microstructure evolution and response to external fields at spatiotemporal resolutions that go well beyond previous benchmarks, demonstrated by ~200 nm resolution tomograms of eutectic microstructures acquired in less than 2 s [5]. The microscope can also be operated in Zernike phase contrast mode, which expands the range of possible applications to cases which otherwise would produce only very faint contrast [6].

Potential application areas of fast 2D and 3D microscopy have been demonstrated with a few selected test cases, comprising regular and irregular eutectic solidification microstructure formation in different Al-based alloys, and self-assembly of colloidal crystal systems composed of different polymer particles with diameters in the micrometer range. Operation of the microscope in Zernike phase contrast extends the range of possible applications to samples that otherwise would produce only faint contrast.

[1] A. Snigirev, V. Kohn, I. Snigireva, B. Lengeler, *Nature* **384**, 49-51 (1996).
[2] V. Kohn, I. Snigireva, A. Snigirev, *Opt. Comm.* **216**, 247-260 (2003).
[3] A. Bosak, I. Snigireva, K. Napolskii, A. Snigirev, *Adv. Mater.* **22**, 3256-3259 (2010).
[4] D. Byelov et al, *RSC Advances* **3**, 15670 (2013).
[5] K.V. Falch, et al, *J. Mater Sci* **52**, 3497-3507 (2017).
[6] K.V. Falch, et al, *Ultramicroscopy*, submitted.

MAGNETIC NANOPARTICLES AND DNA-APTAMERS CONJUGATES FOR CANCER THERAPY

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Recently, in the field of molecular cell surgery of malignant tumors is increasingly common term theranostics, it combined diagnosis and therapy. For these purposes it is widely used bionanoconjugates consisting of magnetic nanoparticles and DNA- aptamers. For the development of targeted drugs a vital role plays research of properties used bionanoconjugates.

A review of study of magnetic, optical and magneto-optical properties of some kinds bionanoconjugates consisting of different shapes metals nanoparticles immobilized DNA-aptamers for Ehrlich ascites carcinoma cell is given.

The magnetic core bionanoconjugates provides required magnetic properties for the provision of physical exposure to a low frequency alternating magnetic field. Magnetomechanical cell disruption using nano- and microsized structures is a promising biomedical technology using for noninvasive elimination of diseased cells. It applies alternating magnetic field for ferromagnetic microdiscs making them oscillate and causing cell membrane disruption with following cell death by apoptosis [1, 2]. It is shown that it is possible to replace microdisks with spherical nanoparticles decorated with gold.

The use of nanoparticles having plasmon resonance and the polarization spectroscopy, for instance, natural and magnetic circular dichroism and electrochemistry allows their use for the diagnosis of cancer [3, 4].

The relationship of shape, size, magnetic properties of bionanoconjugates and the possibility of their use in theranostics is discussed.

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[1] T. Zamay, O. Kolovskaya, A. Sokolov et.al, *Nucleic Acid Therapeutics*. **27**, 2 (2017).
[2] P. Kim, S. Zamay, A. Sokolov et.al, *Doklady Biochemistry and Biophysics* **466** (2016).
[3] G. Zamay, T. Zamay, A. Sokolov et.al, *Scientific Reports* **6,** 34350 (2016).
[4] A. Sokolov, S. Ovchinnikov, V. Zabluda et.al, *JETP Letters* **97**, 2 (2013).

TERNARY DIAGRAMS OF MAGNETIC PROPERTIES OF Ni-Mn-Ga HEUSLER ALLOYS FROM AB INITIO AND MONTE CARLO STUDIES

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Among the Mn-based intermetallic compounds and alloys, Ni-Mn-Ga Heusler systems have received significant attention regarding their magnetic shape memory properties for compositions close to stoichiometry and, in particular, their magnetocaloric properties at off-stoichiometric compositions [1–3]. The unique properties of Ni-Mn-Ga alloys resulting from the coupling between the magnetic and structural phase transitions. In general, Ni-Mn-Ga alloys exhibit remarkable richness of physical properties, varying significantly with their chemical composition.

The ability to obtain different compositional phase diagrams involving desired physical properties is a major challenge for improving Heusler-based technology [3]. Large efforts are made experimentally to find optimal compositions with better properties. On the one hand, compositional phase diagrams can be obtained experimentally by using composition spreads that allow for controlled simultaneous synthesis and characterization of large arrays of samples. On the other hand, compositional diagrams can be obtained theoretically by means of first-principles and Monte-Carlo approaches as example. At present, computational approaches on the level of density functional theory (DFT) have been quite successful in describing electronic, structural, magnetic and dynamical properties of Heusler alloys.

In this work, we performed a systematic study of magnetic properties of disordered Ni-Mn-Ga Heusler alloys using the DFT methodology and Monte Carlo method. *Ab initio* simulations have been carried out by the Spin-Polarized Relativistic Korringa-Kohn-Rostoker (SPR-KKR) package within generalized-gradient approximation [4]. In order to generating a complete set of disorder compositions, which will cover the whole area of the ternary diagram of Ni-Mn-Ga, the coherent potential approximation (CPA) was used. CPA is designed specifically to simulate disordered systems by composing weighted fractions of various chemical species. By using the equilibrium lattice constants, which have been obtained previously by our group [5], the magnetic exchange coupling constants were calculated for the cubic structure of selected alloys. In the next step, Monte Carlo simulations of the classical Heisenberg model with obtained magnetic exchange parameters as input were carried out. As the result, the magnetization curves as a function of temperature and Curie temperatures were obtained for the austenite structure of alloys studied in dependence on their compositions. It has been shown that calculated data are in a very good agreement with available experimental ones for Ni-Mn-Ga and allow us to predict properties of off-stoichiometric compositions.

This work is supported by Grant of the President RF MK-8480.2016.2.

[1] K. Ullakko et al., *Appl. Phys. Lett.* **69**, 1966 (1996).
[2] A.N. Vasiliev et al., *Physics-Uspekhi* **46**, 559 (2003).
[3] P. Entel et al., *J. Phys. D: Appl. Phys.* **39**, 865 (2006).
[4] H. Ebert et al., *Rep. Prog. Phys.* **74**, 096501 (2011).
[5] V. Sokolovskiy et al*., Mater. Sci. Forum* **845**, 130 (2016).

MAGNETIC HARDENING OF F_EC_O NANOWIRE ARRAYS AT 300 K

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Magnetic nanowires (NWs) are currently considered as potential candidates for rare-earth-free permanent magnets, magneto-electric logics or memory storage units [1-2]. Exploiting the large shape anisotropy of 3d-metal NWs yields a large magnetic energy product, i.e. high remanent magnetization (M_R) and large coercive field (H_C).

It has been shown recently that M_R and H_C can be significantly enhanced at low temperatures by oxidizing FeCo NW tips [2].

Here, we explore the possibility of magnetic hardening of $Fe_{30}Co_{70}$ NWs at room temperature by interfacing their tips with antiferromagnetic (AFM) $Fe_{50}Mn_{50}$ layers. For this purpose, $Fe_{30}Co_{70}$ NWs with a diameter of 40 nm and a length of 16 µm were grown in porous Anodic Aluminum Oxide (AAO) membranes. Both tips of NWs are laid open by chemical etching the AAO membrane, and AFM $Fe_{50}Mn_{50}$ was deposited by magnetron sputtering (*Fig. 1a*). As a result (*Fig. 1b*), M_R and H_C are increased by 24% and 49% at room temperature, respectively [4].

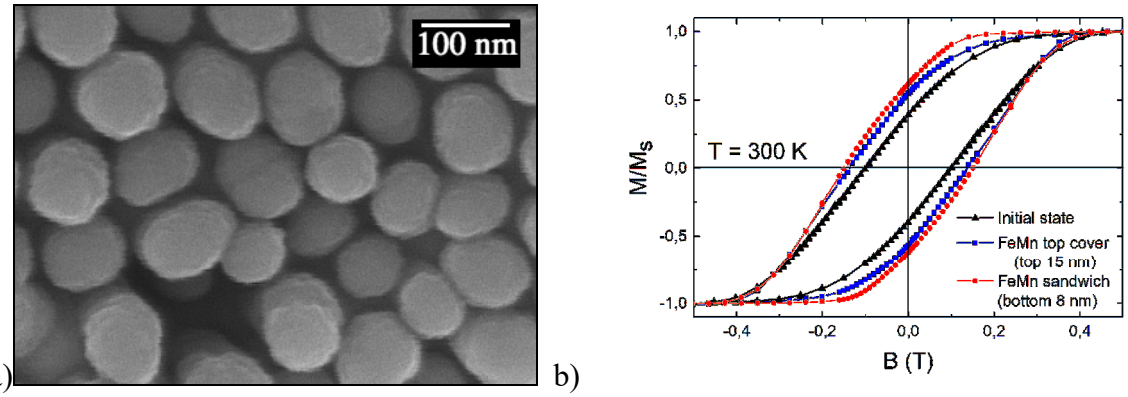

Fig. 1: a) Top view SEM image of the NW tips covered with a $Fe_{50}Mn_{50}$ layer. b) Magnetic hysteresis after different processing steps at room temperature.

[1] C. Bran et al., *Journal of Physics D:Applied Physics* **48**, 145304 (2015).
[2] S. Liébana-Viñas et al., *Nanotechnology* **26**, 415704 (2015).
[3] Fangzhou Wang et al., *Nanotechnology* **28**, 29 (2017).

Fe_3O_4/Ta_2O_5 NANOPARTICLES-BASED MAGNETICALLY RADIOMODIFIER

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Last time, the interest to studying the magnetic nanoparticles (NP) for purposes of their use in the cancer diagnostics and treatment has quickened. The important role in the above applications is played by the magnetic core–shell nanoparticles which can be controlled by the external magnetic field. Just control of motion and distribution of the magnetic nanoparticles forms the basis of using them for targeted drug delivery or delivery of magnetic nanoparticles to the cancerous tumors for the purpose of subsequent hyperthermia process or strengthening of the radiological therapy effect due to scattering of radiation by injected particles.

In recent times, a special interest is shown for creation of magnetically controlled nontoxic radiopaque contrast agents such as the core-shell nanoparticles Fe3O4/Ta2O5.

The aim of the work is to research the increase concentration of NPs at the site of localization of the neoplasm by means of a magnetic field, and the possibility of using core-shell nanoparticles as a radiomodifier in radiation therapy. We have synthesized the core/shell nanoparticles the cores of which consist of the iron oxide while envelope of the tantalum oxide. The average NP size was 43 nm. The shell of the tantalum oxide is to visualize the core-shell nanoparticles; to increase energy absorption effect during exposing with high-energy gamma rays; not have any toxic effects.

The presence of a magnetic moment in the NP allows with the aid of an inhomogeneous magnetic field, to concentrate core-shell nanoparticles in the tumor region, which substantially increases their radio modulating effect.

The installation was assembled to control the distribution of nanoparticles by the magnetic field, where recording the image brightness was performed using the digital microscope and, afterwards, the mathematical processing of images obtained was accomplished..

In order to check a possibility of controlling the distribution of nanoparticles by the magnetic field, the effect of the field nonuniformity on the nature of nanoparticles distribution in the solution was investigated. With the growth in the magnetic field force, the time of saturation attainment decreases and it was also established that the character of nanoparticles distribution is not practically influenced by their initial concentration. So, the basic parameters of magnetic field are definded with the aim to control of nanoparticles' distribution in volume.

MAGNETOCALORIC PROPERTIES OF HYDROGENATED Gd, Tb, Dy RARE-EARTH METALS

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Among the variety of magnetocaloric materials also the gadolinium metal and its alloys with terbium and dysprosium are widely used in the fabrication of magnetic refrigerators prototypes. The purpose of this paper is to study of the influence of gasouse impurities, namely hydrogen, on the magnetocaloric properties of high-purity Gd, Tb, and Dy rare-earth metals. For our needs the commercial Gd, Tb and Dy metals were purified by vacuum distillation. The final metal purity was about 99.96 wt.% (taking into account a gasouse impurities). To obtain a hydrogen solid-solution phase in Gd, Tb and Dy a Sieverts-type apparatus was used. Magnetization measurements were carried out over a wide temperature range (from 4.2 to 350 K) and magnetic field up to 10 T with the Bitter magnet. Magnetocaloric effect (MCE) was measured using direct (up to 1.8 T) and indirect methods (up to 10 T).

It was found that with an increase of hydrogen content in gadolinium samples the increase of the Curie temperature was observed which was probably caused by the enhancement of the Gd-Gd magnetic moment exchange interactions. The introduction of a hydrogen into Gd metal leads to an increase of the working temperature range, in which the higher values of the MCE (an increase in the relative cooling capacity) are observed. It is shown that a significant magnetocaloric effect in Tb and Dy is observed in a wide temperature range where the "order-disorder" and "order-order" transitions take place. However, the MCE in Tb and Dy after hydrogenation decreases with increasing hydrogen content (Fig.1).

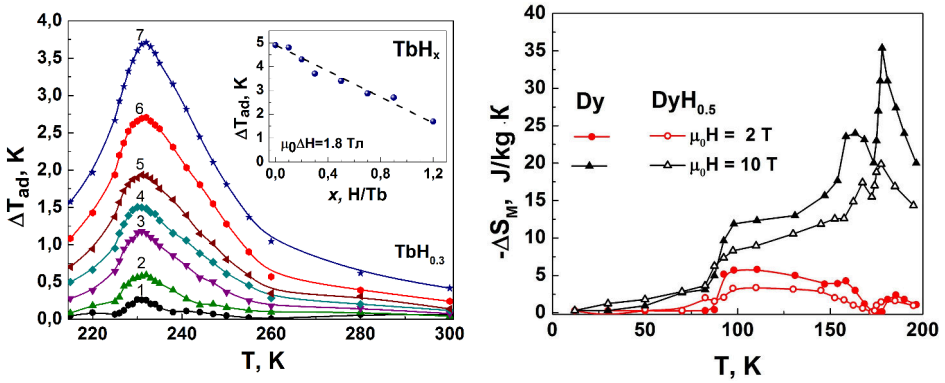

Fig. 1. Temperature dependencies of the MCE for Tb-H and Dy-H systems

The work is supported by the RFBR within the research project of 16-03-00612-a.

FEMTOSECOND LASER FRAGMENTATION FOR SYNTHESIS OF Fe AND Ni NANOPARTICLES FOR BIOLOGICAL APPLICATIONS

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A significant effort is now concentrated on synthesis and study of magnetic nanoparticles which can serve as a contrast agent for magnetic resonance imaging, drug delivery and other biomedical applications [1-2]. We present a method of ultra-short laser-assisted synthesis of some promising nanomaterials for biological applications. Unlike traditional chemical synthetic routes implying the employment of chemicals causing secondary toxicity and therefore limiting *in-vivo* application prospects of the nanoparticles, our laser-based method enables the production of pure nanoparticles, free of surfactants and toxic by-products. Our approach includes two steps: 1) generation of a raw suspension of micro- and nanoparticles by preliminary ablation of a target; 2) ultra-fast laser-induced fragmentation from the suspended colloids leading to the growth of stable, non-aggregated, low-size dispersed and crystalline nanoparticles. Such approach benefits form 3D-geometry of laser ablation and allows us to maintain relatively homogeneous conditions of nanoclusters formation in the absence of significant concentration gradients, yielding to a much better control of characteristics of formed nanoparticles. In particular, we show the possibility of tuning the mean size and stoichiometric compound of iron oxide nanoparticles by varying the laser fluence and the amount of dissolved oxygen in the solution. Such a tunability results in the variety of structural, optical and magnetic properties of produced nanoparticles. The proposed approach offers an efficient and versatile tool for the synthesis of magnetic nanomaterials for biomedical applications.

[1] D. Arboleda, J. Santillan, L. Mendoza Herrera, M. Fernandez van Raap, P. Zelis, D. Muraca, D. Schinca, L.Scaffardi, *J. Phys. Chem. C* **119**, 13184-13193 (2015).
[2] Y-X J. Wang, *Quant Imaging Med. Surg.* **1** 35-40 (2011).
[3] O. Veiseh, J.W. Gunn, M. Zhang, *Adv. Drug. Delivery Rev.* **62** 284-304 (2010).

STRUCTURE AND PROPAGATION OF DOMAIN WALL IN CYLINDRICAL AMORPHOUS FERROMAGNETIC MICROWIRE

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Over the last few years there is a sustained growth and increasing interest on domain wall (DW) propagation in thin amorphous glass-coated magnetic microwires. It is related with proposals of their application for logic and memory devices This is mainly because experimental evidence for the very fast DW propagation. The velocity can much higher values than the sound velocity in the magnetic wires..The most suitable microwires for achievement the fast and controllable results seem planar nanowires and circular cross-section amorphous microwires. In the present work the latter is considered.

Due to their typical size of one or a few micrometers, direct numerical simulation is extremely challenging for microwires. Therefore, exact analytical solutions are of a great value. The fabrication process of the wire is complicated and depends on many parameters which influence much on properties of the resulted wire. As a result complex internal stresses are applied on the core of the wire. In the inner core of the wire besides an effective axial easy axis anisotropy, radial and circumferential stresses should be taken into account. The latter ones are considered as a core-shell interaction, as become significant closer to the shell. This interaction is included into the model phenomenologically via Dzyaloshinskii-Moriya-like (DM-like) contribution or/and by letting the anisotropy constant to be dependent on the distance from the wire axis.

The aim of the paper is to develop and generalize the classification introduced by other authors via either generalizing the found solutions and taking into account the dependence of the anisotropy constant on the polar distance from the wire axis.

The work extends the known results for the very same model, introducing a much wider family of the DW configuration. An account of the dependence of the anisotropy constant allows to refine the planar DW solution, what makes it possible to explain the flexure of the planar DW,

which is observed in experiments. An explicit shape of the admissible DW is derived, as well as the DW velocity in single-domain regime is found.

SUPERPARAMAGNETIC RESPONSE FROM ENDOGENOUS NANOPARTICLES IN SPLENIC MACROPHAGES

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We have identified that murine macrophages in the red pulpa of the spleen harbor an enormous amount of endogenous nanoparticles with monodisperse crystal size and unexpected superparamagnetic properties [1]. It is well established that macrophages contain the 12 nm disk-shaped protein ferritin with an 8 nm cage that can buffer up to 4500 iron atoms, usually in the form of the non-toxic compound ferrihydrite $(Fe^{3+})_2O_3 \bullet 0.5H_2O$ [2]. Ferrihydrite is an antiferromagnetic compound with a tiny magnetic response and is rich in defects while its exact crystal structure is still under debate [3].

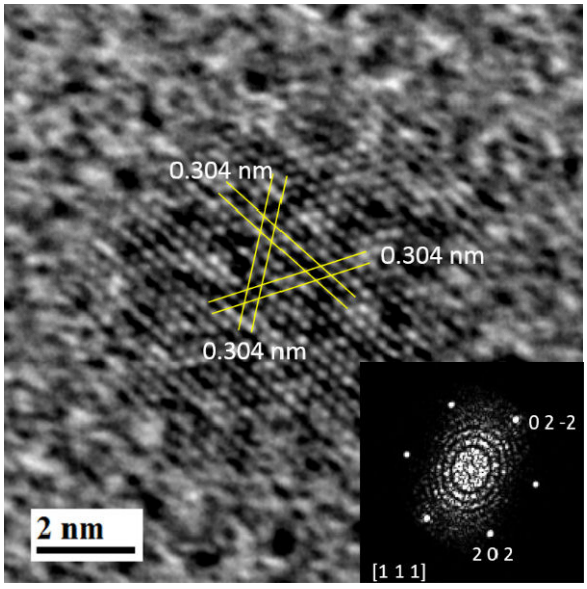

Figure 1: High-resolution TEM image of a nanoparticle isolated from spleen cells. The inset presents the Fourier transform pattern proving spinel structure [1].

Figure 1 presents a high-resolution transmission electron microscopy (TEM) image of a single nanoparticle isolated from spleen cells. Although the diameter and iron content identified by TEM support the presence of ferritin, we find a cubic spinel structure with a lattice parameter of a = 0.86±0.04 nm rather compatible to magnetite or maghemite. Moreover, the strong magnetic response is incompatible with the nature of ferrihydrite. We characterized these nanoparticles from splenic macrophages by SQUID magnetometry and found an average magnetic moment of $8600\mu_B$ per particle by Langevin fitting in the superparamagnetic state at T = 300 K. This finding indicates the presence of magnetic phases different from the expected antiferromagnetic ferrihydrite. As a result, the intrinsic superparamagnetism of splenic macrophages contaminates cell isolates in magnetic cell separation [1]. Possible medical implications of these findings on magnetic hyperthermia are discussed.

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[1] L. Franken et al., *Scientific Reports* **5**, 12940 (2015).
[2] P. M. Harrison et al., *Adv. Inorg. Chem*. **36,** 449 (1991).
[3] S. Gider et al., *Science* **268**, 77 (1995).

GROUND STATE AND MAGNETIC PROPERTIES OF THE Cr-DOPED Ni-Mn-(Ga, In, Sn) ALLOYS: INSIGHTS FROM AB INITIO STUDY

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A wide range of impressive physical effects such as magnetically and thermally induced shape memory effect, large magnetoresistance and giant magnetocaloric effect is a distinguishing feature of ferromagnetic (FM) Heusler alloys [1-3]. Ones of the most studied and well-investigated Heusler alloy are Ni-Mn-Z-based materials [1]. It is well known that the addition of fourth element (Fe, Co, Cr, Pt e.g.) into Ni-Mn-Z Heusler alloys can strongly affect the Curie temperature (T_C) and martensitic transformation temperature (T_m) [3-5].

In this work, we present results of *ab initio* investigations of the ground state and magnetic properties of Ni-Mn-(Ga, In, Sn) Heusler alloys with the help of density functional theory, implemented into VASP [6,7] and the SPR-KKR [8] packages. To perform the crystal structure optimization, we used the $L2_1$ structure (space group *Fm*-3*m*, No. 225). It consists of four interpenetrated *fcc* sublattices, where two Ni atoms placed at the 8*c* Wyckoff positions ((1/4, 1/4, 1/4) and (3/4, 3/4, 3/4) sites), while (Ga, In, Sn) and Mn atoms locate 4*a* and 4*b* positions ((0, 0, 0) and (1/2, 1/2, 1/2) sites), respectively. Additional Cr atoms are placed to the Mn positions. In our calculations, we considered 16-atom $L2_1$ supercell with three magnetic configurations. The first one was the ferromagnetic (FM) state, in which all magnetic moments are positive. The second one was the antiferomagnetic (AFM) state, in which magnetic moments of Ni and Mn atoms are positive and magnetic moments of Cr atoms are negative. The third one was the ferromagnetic (FIM) state, where magnetic moments of Ni and Mn atoms are positive and magnetic moments of Cr have an antiparallel arrangement. As a result equilibrium lattice parameters, bulk moduli, total magnetic moments, and formation energies of a wide range of Heusler alloys have been obtained. In the second step of study Heisenberg magnetic exchange parameters have been calculated for obtained equilibrium lattice parameters.

Support by Advanced research foundation of the Chelyabinsk State University is acknowledged.

[1] V.D. Buchelnikov and V.V. Sokolovskiy, *Phys. Met. Metallogr.* **112**, 633 (2011).
[2] P. Entel et al., *Eur. Phys. J. B* **86**, 65 (2013).
[3] P. Entel et al., *J. Alloys Compd.* **577**, S107 (2013).
[4] M. Khan et al., *Phys. Rev. B* **93**, 054419 (2016).
[5] M.A. Zagrebin et al*., Mater. Res. Express* **4**, 026105 (2017).
[6] G. Kresse and J. Furthmuller, *Phys. Rev. B* **54**, 11169 (1996).
[7] G. Kresse and D. Joubert, *Phys. Rev. B* **59**, 1758 (1999).
[8] H. Ebert et al., *Rep. Prog. Phys*.**74**, 096501 (2011).

THE LANDAU-LIFSHITZ EQUATION, THE NLS, AND THE MAGNETIC ROGUE WAVE AS A BY-PRODUCT OF TWO COLLIDING REGULAR POSITONS

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We present a new method for construction of exact solutions of the Landau-Lifshitz-Gilbert equation (LLG) for ferromagnetic nanowires. The method is based on the established relationship between the LLG and the nonlinear Schrödinger equation (NLS), and is aimed at resolving an old problem: how to produce multiple-rogue wave solutions of NLS using just the Darboux-type transformations. The solutions of this type –- known as P-breathers -- have been proven to exist by Dubard and Matveev, but that technique heavily relied on using the solutions of yet another nonlinear equation, Kadomtsev-Petviashvili I equation (KP-I), and its relationship with NLS. We have shown that in fact one doesn't have to use KP-I but can instead reach the same results just with NLS solutions, but only if they are dressed via the *binary* Darboux transformation. In particular, our approach allows us to construct all the Dubard-Matveev P-breathers. Furthermore, the new method can lead to some completely new, previously unknown solutions. One particular solution that we have constructed describes two “positon”-like waves, colliding with each other and in the process producing a new, short-lived rogue wave. We called this unusual solution (rogue wave begotten after the impact of two solitons) the «impacton».

POSTERS

PECULIARITIES OF MAGNETOCALORIC EFFECT IN CYCLIC MAGNETIC FIELDS

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Presently, one of the major requirements for a material to be used as a prospective magnetocaloric material is its capability to exhibit giant magnetocaloric effect (MCE). Because of a refrigerating machine is a device with periodic sweeps of cycles there is a substantial need to study the magnetocaloric properties of materials under frequent cyclic exposures to magnetic fields. Magnetocaloric properties of the materials exposed to alternating and constant magnetic fields can exhibit significantly different behavior for a variety of reasons. Even at low frequencies the field dependence of the magnetocaloric properties of materials may differ significantly from those measured after a single magnetic field applying. First of all, it refers to the first order phase transitions in which the temperature hysteresis can lead to irreversibility of phase transitions induced by an external field in certain temperature ranges. The MCE values on the first and subsequent cycles of the field application in these materials will vary significantly.

This report presents the results of the study of the magnetocaloric properties in various families of promising magnetocaloric materials. In the report the following issues will be discussed:

- Dependence of the MCE values on the frequency of the magnetic field change,
- Temperature and magnetic field ranges of observation of the reversible MCE, and methods for inducing reversible magnetostructural phase transitions in weak magnetic fields,
- Degradation of the magnetocaloric effect in cyclic magnetic fields,
- Methods for estimating the structural and magnetic contributions to the overall magnetocaloric effect,
- Difference of the MCE values in the region of magnetostructural phase transitions in the heating and cooling runs and others.

This work is supported by RFBR, research project № 17-02-01195.

MAGNETO-MECHANICAL ACTION OF MULTIMODAL FIELD CONFIGURATIONS ON MAGNETIC NANOPARTICLE ENVIRONMENTS

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The generation of mechanical forces via magnetic fields, the so called magneto-mechanical effect, is a powerful manipulation tool of magnetic nanoparticles inside variable environments. The combination of alternating, static or rotating magnetic field configurations with magnetic nanoparticles allows transformation of electromagnetic to mechanical energy. Thus, this option renders magnetic nanoparticles useful in biomedical research, as it is possible to functionalize them to specifically bind to malignant cell membranes and incur cell damages by exerting magneto-mechanical stresses. In order to produce these multimodal fields, a novel magneto-mechanical device was designed, manufactured and thoroughly characterized in terms of field parameters and MNPs properties. It consists of a rotating turntable, on which different magnetic field configurations were established by arranging appropriately commercial Nd-Fe-B permanent magnets. For each configuration, the field gradients and mechanical forces acting on different magnetic nanoparticles, in terms of size and material, were calculated numerically by using COMSOL 3.5a Multiphysics. Such a device may be further implemented, as a versatile magnetic force performer, on cellular environments, where the magnetic nanoparticles, following external magnetic field variations, may ignite cellular processes.

GMR SENSING OF MAGNETIC LABEL FIELD

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For precise positioning and displacement sensing, using spin valves (SVs), a reliable method of modeling of interaction of the magnetic field, produced by reference labels, with the magnetic layers in the GMR structure, is highly important. In the report, our method of calculation of the space configuration of magnetic field produced by a reference magnetic stripe of different shape is presented. In general, the space components of the magnetic field vector $\boldsymbol{H(r)} = \{H_x, H_y, H_z\}$ can be written as a gradient of electromagnetic potential ϕ:

$$\boldsymbol{H_{xi}(x,y,z)} = -\frac{\partial \boldsymbol{\phi(x,y,z)}}{\partial xi}, \qquad (1)$$

where $xi = \{x,y,z\}$. Using the Ostrogradky-Gauss theorem and taking into account the source of magnetic field is localized within the stripe-label we get

$$\boldsymbol{\phi}(\vec{r}) = -\frac{1}{4\pi}\iiint_{\Omega}(\vec{M}(\vec{r}^{\,\prime}) \cdot \vec{\nabla}^{\prime}\frac{1}{|\vec{r}-\vec{r}^{\,\prime}|})\boldsymbol{dV'}, \qquad (2)$$

where $\vec{M}$ is a local magnetic moment within the label. For the magnetic stripe with magnetic moment M_0 and thickness t, width w and length l, we obtain for the potential at any point (x,y,z):

$$\boldsymbol{\phi(x,y,z)} = \\ = \frac{M_0}{4\pi}\int_{-0.5t}^{0.5t} dx' \int_{-0.5w}^{0.5w} dy' \left(\frac{1}{\sqrt{(x-x')^2+(y-y')^2+(z-0.5l)^2}} - \frac{1}{\sqrt{(x-x')^2+(y-y')^2+(z+0.5l)^2}}\right) \qquad (3)$$

The magnetic field space distribution is used to estimate the effect of the field on the magnetoresistance of the SV structure displaced by a certain distance x_0 from the magnetic stripe. The efficiency of the magnetorsistive sensing effect of the GMR SV structure strongly depends not only from the strength of magnetic field exerted In a simple approximation, the magnetic field applied at 90° to the uniaxial anisotropy direction in the of the free layer in the SV structure rotates the magnetic moment by the angle

$$\varphi = \arccos(M_F H_F/2K_u), \qquad (4)$$

where M_F and H_F are magnetic moment and magnetic field acting in the free layer of SV structure. The magnetoresistance of the SV in this case is determined from approximate relation

$$R_{GMR} = R_{GMR}^{0}(1-\cos(\varphi))/2 \qquad (5)$$

In the report the sensing efficiencies will be considered for a variety of the mutual positioning of the GMR sensor and magnetic label.

The work is supported by Russian Foundation for Basic Research (grant 16-32-50191)

HARD X-RAY FOURIER TRANSFORM BASED ON COMPOUND REFRACTIVE LENSES AT LABORATORY SOURCE

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After first demonstration of microradian diffraction by using refractive lenses [1], X-ray optics Fourier transform method was used to study photonic crystals [2], acoustic waves on a crystal surface [3], periodically structured crystals [4] and porous matrix. The main advantages of this method are the possibility of an express analyse of the symmetry and periodicity of the object without preliminary sample preparation and possibility to analyse of the sample volume. For a long time Fourier transform method require a synchrotron X-ray source.

In this work was demonstrated for the first time the possibility to use X-ray Fourier transform method based on a refractive X-ray optics at laboratory. Experiment was conducted at SynchrotronLike Science and Educational Complex in Immanuel Kant Baltic Federal University. We used Excillum MetalJet microfocus X-ray source with Gallium liquid anode and main characteristic emission line 9.25 KeV. We used 17 beryllium parabolic lenses with radii of curvature 50 um. We obtained microradian diffraction pattern from Si grid with the period 1.5 um(Fig.1).

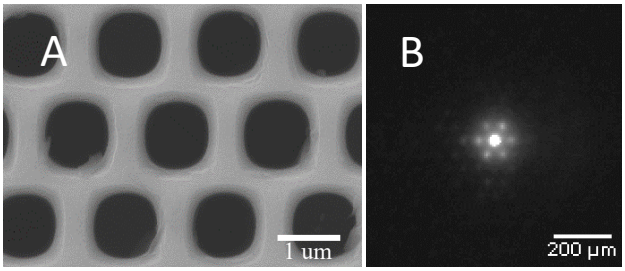

Fig.1. A. SEM image of the Si grid with 1.5um period. B. X-ray microradian diffraction pattern from Si grid, received by Fourier transform method at laboratory source.

[1] D. Michael, S. Anatoly, S. Irina, S. Jörg, *Applied Physics Letters*, 014102 (2005).
[2] A.V. Petukhov, J.H.J. Thijssen, D.C.T. Hart, A. Imhof, A.V. Blaaderen, I.P. Dolbnya, A. Snigirev, A. Moussaid, I. Snigireva, *Journal of Applied Crystallography* **39,** 137-144 (2006).
[3] D. Roshchupkin, D. Irzhak, A. Snigirev, I. Snigireva, L. Ortega, A. Sergeev, *Journal of Applied Physics* **110**, 124902 (2011).
[4] P. Ershov, S. Kuznetsov, I. Snigireva, V. Yunkin, A. Goikhman, A. Snigirev, *Damage to VUV, EUV, and X-Ray Optics IV; and EUV and X-Ray Optics: Synergy Between Laboratory and Space III,* Prague, (2013).

CONNECTION OF THERMOPOWER, MAGNETOTHERMOPOWER WITH RESISTIVITY AND MAGNETORESISTIVITY IN $Nd_{(1-x)}Sr_xMnO_3$ MANGANITES

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In this work thermopower *S*, magnetothermopower *ΔS/S*, electrical resistivity ρ and magnetoresistance Δρ/ρ were studied in single-crystals $Sm_{(1-x)}Sr_xMnO_3$ (x= 0.15, 0.2, 0,25, 0.3) and $Nd_{(1-x)}Sr_xMnO_3$ (x = 0.15, 0.2, 0.3). The study of the magnetic properties of these compounds showed that they consist of ferromagnetic clusters located in A-type antiferromagnetic matrix. Giant negative magnetoresistance, which was observed in these compounds, indicates that these ferromagnetic clusters belong to ferron type. A sharp increase of *S* and absolute value of negative *ΔS/S* were discovered near Curie temperature T_C, where $|\Delta S/S|$ reach giant values, up to $|\Delta S/S|$ = 94.5% in magnetic field of 13.2 kOe. This means that thermopower is caused by presence of ferrons, as the value of the thermopower slumps with the destruction of ferrons caused by magnetic field or heating of sample over T_C. Therefore, thermopower in doped magnetic semiconductors is determined by the doping level and volume of the sample. So, after dividing the sample in two parts thermopower of each part decreased proportionally the volume of the sample. Thus, in doped magnetic semiconductors the value of thermopower can be considerably increased by enlarging the volume of sample, the level of doping and furthermore, can be controlled by magnetic field.

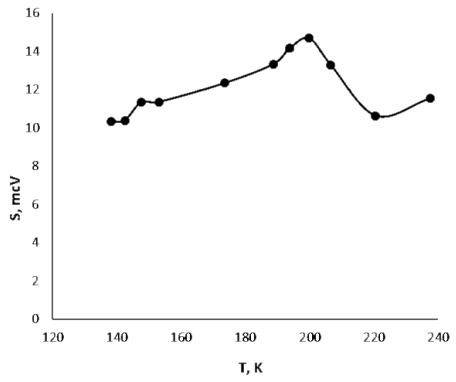

Fig. 1. Temperature dependency of thermopower of $Nd_{0.7}Sr_{0.3}MnO_3$

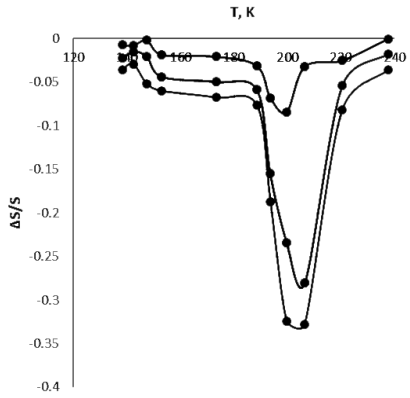

Fig. 2. Temperature dependency of magnetothermopower of $Nd_{0.7}Sr_{0.3}MnO_3$

THE MATHEMATICAL MODELING OF THE DYNAMIC MAGNETIC RESPONSE OF INTERACTING FERROPARTICLES IN MAGNETIC FLUID: PARALLEL GEOMETRY FIELDS

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In this article dynamic response of ferrofluid is studied by analytic methods, set in constant and feeble linearly-polarized alternating magnetic fields. The ferrofluid is modeled by a system of solid single-domain spheres suspended in an elongated cylindrical vessel which larger axis coincides with the direction of the static and alternating magnetic fields. The study of dynamic properties is based on the Fokker-Planck-Brown equation. An additional term, suggested in this work, is introduced in the Fokker-Planck-Brown equation in order to account for interparticle correlations in the simulated system [1]. This term allows to take into account dipole-dipole interactions at the level of the modified mean-field model of the first order (MMFM-1). The Fokker-Planck-Brown equation describing interparticle interactions and the simultaneous effect of constant and small magnetic fields, has been solved analytically. The orientation probability density of a randomly chosen particle is the solution of the equation.

The obtained orientation probability was used to determine the dynamic susceptibility. The spectrum of dynamic susceptibility depending on the magnetic field strength is investigated in this work. An increase in the intensity of a constant magnetic field that leads to a decrease in the value of the imaginary maximum part is shown. Also, a shift of the maximum of the imaginary part to the field of high frequencies is observed. So, the system relaxation time is reduced. In the field of low frequencies, the real part of the susceptibility decreases with the increasing of the magnetic field constant.

The obtained results were confirmed by computer simulation (Dr Philip J. Camp, University of Edinburgh).

[1] A.O. Ivanov, *Soft Matter* **15**, 3507 (2016).

THE EFFECT OF MILLING TIME ON THE MAGNETIC PROPERTIES OF NiFe-BASED COMPOSITES

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The structure and magnetic properties of composites made of NiFe powder with various concentrations and shapes of particles were investigated. Frequency dependencies of permittivity and permeability of the composites have been measured and discussed. The powder particles of various shapes were prepared by high-energy milling of permalloy (81 vol.% Ni, 19 vol.% Fe) powder in organic media. NiFe microparticles were dispersed in paraffin wax, in different volume fractions. The permittivity and permeability of the composites were measured by the Nicolson-Ross-Weir technique in a 7/3 coaxial line in the frequency range of 0.13 to 10 GHz. The measured frequency dependencies of the material parameters were compared with known mixing rules.

It is shown that the shape of the particles changes from sphere to platelet with increase of milling time. The change leads to a shift of the ferromagnetic resonance (FMR) frequency and magnetic loss peak to higher frequencies. With increase of the concentration of the permalloy particles in composite, the magnetic loss peak shifts to lower frequencies. It is shown that larger damping of the FMR is characteristic for the larger particles due to the change of the magnetic structure.

THE ELECTRONIC STRUCTURE OF MAGNETIC D-IONS IN MANGANESE DOPED COPPER METABORATE $Cu_{0.98}Mn_{0.02}B_2O_4$

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Magnetic materials with complex crystal and magnetic structure have attracted much attention because of their interesting properties and features. One of the brightest representatives of such compounds is a copper metaborate CuB_2O_4. The compound demonstrates a unique combination of magnetic, magnetoelectric, linear and nonlinear optical properties.

The copper metaborate CuB_2O_4 has a complex crystal structure (SG *I42d*, *Z*=12). Magnetic Cu^{2+} ions (S=1/2) in the unit cell occupy two different crystallographic positions, *4b* and *8d*. In both positions, copper atoms are square-coordinated, the same as in high-temperature superconductors. Cu(*4b*) and Cu(*8d*) magnetic sublattices order at different temperatures, 21 K and ~ 8 K, respectively. Multiple frustrated and nonfrustrated antisymmetric exchange interactions within and between the *4b* and *8d* magnetic sublattices result in a rich complex magnetic phase diagram.

CuB_2O_4 exhibits unusual optical properties. Recent studies of electronic absorption spectra of CuB_2O_4 revealed narrow zero-phonon lines (ZPL) for all transitions between the crystal-field-split *3d*-states of Cu^{2+} ions [1]. Recently we have found a large sublattice-sensitive optical linear dichroism (LD) in the crystallographically isotropic *ab*-plane of copper metaborate. LD is observed on ZP exciton lines connected with the Cu(*4b*) magnetic subsystem, it arises below the temperature of the antiferromagnetic ordering of this subsystem [2]. We elucidated the nature of the LD attributing it to the magnetic Davydov splitting.

The present work is devoted to the study of magnetic phase transitions in manganese-doped copper metaborate $Cu_{1-x}Mn_xB_2O_4$ (x=0.02). It was expected that a doping with manganese could lead to interesting new magnetic effects. Measurements were carried out both with and without an applied external magnetic field. A study of the absorption spectra allowed us to establish the Neel temperature of compound (T_N = 19 K) and make a comparison of the electronic structures of pure and doped metaborates. Linear antiferromagnetic dichroism associated with magnetic Davydov splitting has been observed in $Cu_{0.98}Mn_{0.02}B_2O_4$ the same as in CuB_2O_4, but the character of the magnetic transitions is different from that for undoped metaborate. According to the temperature dependence of the LMD signals of these compounds (see. Fig. 1) we can see that the LMD signal of $Cu_{1-x}Mn_xB_2O_4$ is about 10 times less than in pure metaborate. The LMD sign of $Cu_{0.98}Mn_{0.02}B_2O_4$ undergoes changes at temperature T^* = 7.0 K, moreover in contrast to the pure metaborate there is no splitting of T^* transition.

The results are interesting in the context of development of new rapid magneto-optical and spintronics devices.

Support of the Russian Foundation for Basic Research (Grant No 15-02-07451a) and the President of the Russian Federation (Grant MK-3577.2017.2) is acknowledged.

[1] R.V. Pisarev, A.M. Kalashnikova, O. Schöps, L.N. Bezmaternykh, *Phys. Rev. B* **84**, 075160 (2011).
[2] K.N. Boldyrev, R.V. Pisarev, L.N. Bezmaternykh, M.N. Popova *Phys. Rev. Lett.* **114**, 247210 (2015).

STRICTION OF HYBRID MAGNETOACTIVE ELASTIC COMPOSITES

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Our study focuses on the striction effect in magnetic elastic hybrid materials, i.e. materials that are composed of an elastic matrix (e.g. silicone rubber) and magnetic particles embedded in this matrix. Both magnetically hard and soft particles can be used as a filler, as well as a mixture of the two [1-3]. The properties of such composites are controllable by means of externally applied magnetic fields. The presence of a magnetically hard component allows to tune an initial state of the composite, changing its remanence magnetization [4]. Moreover, by applying a magnetic field during composite polymerization, a specific microstructural anisotropy of the material can be achieved. This results in an alternate material behavior. One of the most application-oriented parameters of the hybrid magnetoactive elastic composites is their controllable striction, which provides the possibility to use them as actuating elements [5].

In this study we experimentally examine strictional (magnetodeformational) effects in magnetic elastic hybrid composites based on magnetically hard powder of various morphologies under the influence of an externally applied magnetic field. The effect of powder concentration, initial elasticity of the matrix, magnetization of the samples, as well as initial microstructural anisotropy on the induced mechanical stress and on the elongation of the composites is evaluated. Results are compared with the behavior of conventional magnetorheological elastomers [6,7] based on carbonyl iron powder. Detailed results of our investigations and their discussion will be presented at the conference.

Financial support by Deutsche Forschungsgemeinschaft (DFG) under Grant Bo 3343/1-1 and Od18/24-1 within PAK 907 providing the basis for our investigations is gratefully acknowledged. G.S. would like to acknowledge the support of RFBR under Grant 16-53-12009.

[1] G.V. Stepanov et al., *Polym. Sci. Ser. A* **56**, 603–13 (2014).
[2] G.V. Stepanov, D.Yu. Borin, A.V. Bakhtiiarov, P.A Storozhenko, *Smart Mater. Struct.* **26**, 035060 (2017).
[2] J.M. Linke, D.Y. Borin, S.Odenbach, *RSC Adv.* **6**, 100407–16 (2016).
[4] D. Yu. Borin,G.V. Stepanov, S. Odenbach, *J. Phys.: Conf. Ser*. **412**, 012040 (2013).
[5] J.H. Koo, A. Dawson, H.-J. Jung, *J. Intell. Mater. Syst. Struct.* **23**, 1049-54 (2012).
[6] A.V. Chertovich et al., *Macromol. Mater. Eng*. **295**, 336–341 (2010).
[7] G.Y. Zhou, Z.Y. Jiang, *Smart Mater. Struct.* **13**, 309 (2004).

SYNTHESIS, AND CHARACTERIZATION OF $Ca(OH)_2$ NANOPARTICLES DOPED WITH ALKALI METALS

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The calcium hydroxide ($Ca(OH)_2$) nanoparticles were synthesized doped with alkali metals such as Potassium (K), Lithium (Li) and Barium (Ba) using simple precipitation method, and characterized the structure by powder X-ray diffraction pattern. FT-IR spectra were recorded in visible (400-4000cm^{-1}) range to find the functional groups presented in the sample. Exothermal reactions were analyzed by TG-DSC spectrometry and studied the phase transitions (Peaks obtained at 467.09°C, 498.5°C, 460.8°C and 460.8°C) due to alkali metal impurities. The particle size and surface morphology of $Ca(OH)_2$ nanomaterials were examined by Focused Ion beam-scanning electron microscope (FIB-SEM), and studied the changes in size and shape of the particles by means of alkali metals. The average particle size has obtained about 85-200nm, and it possesses fine hexagonal shape with considerable thickness. Patel flower and hexagon like a shape of nanoparticles have appeared in K doped nanomaterial, and lots of fine hexagonal shaped particles have presented in Li doped nanoparticles and Ba doped nanoparticles showing as multi-layers of hexagon one above the other. The band gap of $Ca(OH)_2$ nanoparticles were investigated to understand the reactivity of $Ca(OH)_2$ with alkali metals using UV-Visible spectra. Finally, the Density Functional Theory (DFT) and the Time dependent-Density functional Theory (TD-DFT) calculations have also been done to confirm the shape and band gap of title material.

CHEMICAL COMPOSITION MEASUREMENT OF MULTILAYER STRUCTURES OR COVERINGS

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The chemical composition of the samples to be studied significantly affect the sample's properties. When using pure materials for sputtering, the composition is not a question, but in the other cases, there is a need to confirm the desired composition. The depth profile and the layers densities are also of high importance.

Traditionally, SEM+EDX or FIB+SEM+EDX, XRF or TXRF spectroscopy, XRD and In-plane geometry XRD, and GDS are used to evaluate the composition and geometrical properties of layers.

SEM can measure layers from the edge cut of a sample, but the resolution can be insufficient, also the light elements in low content are not easy to analyze. FIB+SEM capable of evaluating the interfaces between the layers, and can be used during the sample production, but is rather expensive.

XRF is a nondestructive and general-purpose method, but it is limited by absorption of the sample, and the thickness evaluation is a kind of inverse problem, so to get the thickness, one should be sure of composition, and make the thickness calibration.

Total reflection X-ray fluorescence (TXRF) spectrometer can provide depth profile information by manipulating grazing angle (GI-XRF), but the results are hard to interpret and also requires the inverse problem solution.

Conventional XRD is capable of measuring multi-layer structures interference properties (according To Bragg's law thus allowing precision layer thickness determination); In-plane geometry XRD [2] provides also crystalline sizes of interfaces, and crystalline form of the layers information, but is also limited by X-Ray transparency of the samples. The samples are often not polycrystalline, thus limiting a use of XRD.

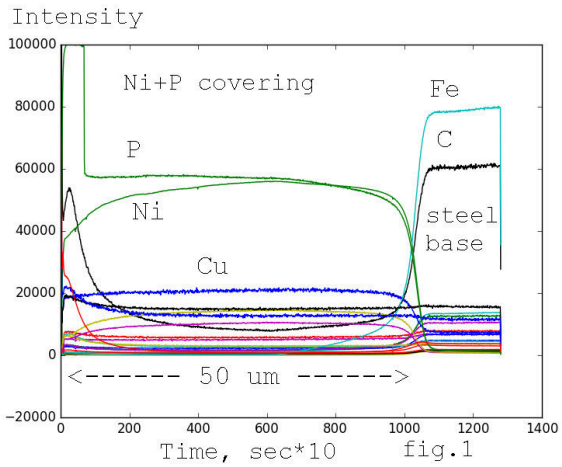

fig.1

Glow Discharge Spectroscopy[2] is a destructive method and is used to materials analysis since the 1930s, and well suited to multi-layer structures measurements or if a flat witness sample is available. Modern commercially available devices can have interferometer to measure thickness directly, can process conductive and non-conductive (ceramic or organic) samples (require RF-source); measure non-metallic elements like C, H, O, Cl, N, S, P in low contents, and convenient to use.

Our setup is based on an old LECO GDS-400a spectrometer and has modified data acquisition system to allow higher resolution simultaneous measurement and multi-layer samples analysis. Our experience includes measuring Permendur, Permalloy, NiP-on-steel (see fig.1) samples, transformer steels and several targets for sputtering.

[1] http://www.rigaku.com/newsletters/mabu/feb2016/RigakuJournal_XRD.pdf
[2] L. Lobo et al., *J. Anal. At. Spectrom.* **32**, 920-930 (2017).

AN ORIGIN OF ASYMMETRY OF GIANT MAGNETORESISTANCE LOOPS IN SPIN VALVES

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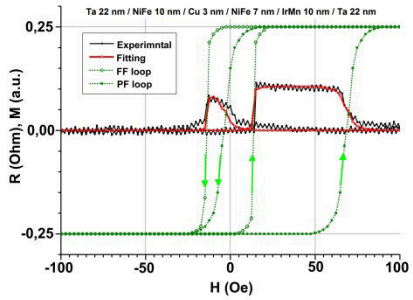
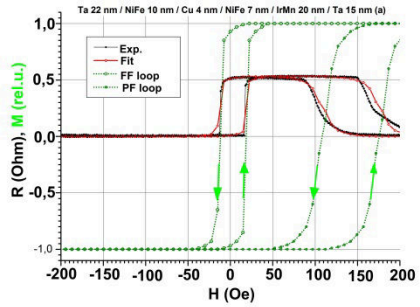


a)



b)

Fig.1 Experimental MR *R(H)* curves (black) with fitting (red) and derived hysteresis loops for FF and PF layers (green) for cases of 10nm- (a) and 20nm-thick (b) AF layer. Insufficient exchange bias (a) leads to superposition of hysteresis loops thus to GMR decrease.

The regular shape of the magnetoresistance as a function of applied magnetic field, $R(H)$, is important for numerous spin valves applications. Nevertheless, in many practical studies the shape of the $R(H)$ curve is unpredictably complicated. The observed $R(H)$ features can be of different nature. Here, a simple technique is proposed which allows interpreting the $R(H)$ features and calculating $R(H)$ curves from known magnetisation hysteresis $M(H)$ loops of ferromagnetic layers, composing spin valves. And vice versa, the shape of the hysteresis $M(H)$ loops of the composing ferromagnetic layers can be obtained from $R(H)$ curves, as shown in Fig.1. The method does not give an insight into the origins of the factors determining the shape of hysteresis loops, but it is suitable for prompt selection of promising spin valve stacks. A series of spin valve structures was prepared and their magnetoresistance curves were measured. Two examples are illustrated in Fig.1, (a) for the case of small exchange bias comparable with coercive fields of the free (FF) and pinned (PF) layers, i.e., when the *M(H)* loops overlap, and (b) for the case when the exchange bias is large enough, compared with coercive fields, thus the *M(H)* loops for FF and PF layers are separated. Both cases are often observed in practice and are widely illustrated in the report. The analysis of the experimental data demonstrates the capacity of the proposed method.

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ANOMALOUS HALL EFFECT IN POLYCRYSTALLINE Mn_xSi_{1-x} ($x \approx 0.51$-0.52) FILMS

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The structural and magnetotransport properties of polycrystalline nonstoichiometric Mn_xSi_{1-x} ($x \approx 0.51$–0.52) films grown by the pulsed laser deposition (PLD) technique onto $Al_2O_3(0001)$ single crystal substrates at $T = 340$◦C have been studied. A highlight of used PLD method is the non-conventional "shadow" geometry (SG) with Kr as a scattering gas during the sample growth. The magnetization of these films is determined by two ferromagnetic phases; the high-temperature phase with the Curie temperature $T_C \approx 370$ K and the low-temperature one with $T_C \approx 46$ K [1].

We reveal the change in the sign of the anomalous Hall effect (AHE) in Mn_xSi_{1-x} films, in which at $x \approx 0.51$–0.52 we earlier observed the high-temperature ferromagnetism accompanied by the positive AHE becoming more pronounced with the decrease in temperature [2]. The films studied in [2] were grown by the PLD technique using the ordinary ("direct") geometry (DG). We find that SG films, as well as the DG films [2], exhibit a positive AHE at high temperature (> 100 K). On cooling, however, the AHE changes its sign in SG films at $T \approx 30$–50 K; the specific value of this temperature depends on the thickness of the Mn_xSi_{1-x} film.

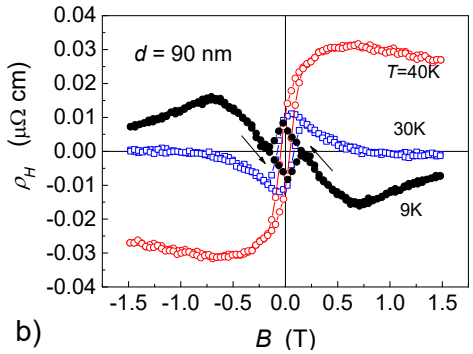

Fig. 1. Magnetic-field dependence of the Hall resistivity $\rho_H(B)$ for the sample with film thickness 90 nm measured at different temperatures.

The results can be interpreted in terms of the structural self-organization related to the formation of two layers in the course of film growth. These layers have nearly the same chemical composition but significantly differ in the shapes and sizes of crystallites. This leads to a drastic difference in the values of T_C and in the value and the sign of the AHE for such layers. As a result the AHE in SG films includes the contributions of both positive and negative components (Fig. 1). The role of the latter grows with the film thickness and lowering temperature, especially at temperatures below 50 K. In particular, this manifests itself in the negative sign of the Hall effect at low temperatures ($T \leq 30$ K) and at the applied magnetic field $B \geq 1$ T(Fig. 1).

The work was supported by the RFBR (grant № 16-07-00798, 16-07-00657, 15-07-01160).

[1] S.N. Nikolaev, *AIP Adv.* **6**, 015020 (2016).
[2] V.V. Rylkov, *JETP Lett.* **96**, 255 (2012).

MAGNETOCRYSTALLINE ANISOTROPY AND CRYSTAL FIELD EFFECTS IN LOW SYMMETRY Nd-BASED COMPOUNDS

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The true sets of crystal field (CF) parameters have been obtained for the first time for a few Nd-based intermetallic systems with low local symmetries at the positions of the Nd ions. The magnetic excitation spectra have been measured by the inelastic neutron scattering technique on both single crystals and powder samples, namely intermetallics of Nd, 3d metals and the main groups elements. The measurements were performed on the triple-axis and time-of-flight neutron instruments. In addition, experimental information on the specific heat and the anisotropic static magnetic susceptibility was taken into account. The method of paramagnetic impurity in a nonmagnetic host matrix was used in a few cases.

The new approach focused on a global search in the CF parameters space (many independent parameters in the low symmetry case) was developed. The true solutions to the CF problem provide good fits of the neutron spectra measured of powder and single crystals as well as the macroscopic data measured in a wide temperature range. The approach developed in the current work is better suited for low symmetry magnetic systems with localized magnetic moments than the widely used phenomenological method based on a local minimization procedure which provides in many cases only a plausible solution to the CF problem.

QUANTUM SPIN LADDER COMPOUND $Cu(CF_3COO)_2$

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The experimental realisation of compounds with a ladder-like structure has contributed to the intense interest in low-dimensional quantum systems. The existence of a spin gap, magnetisation plateaus, quantum critical points and superconductivity under hole doping are examples of key physical properties observed in the ladder compounds. From the standpoint of quantum mechanics the polymeric chain in the structure of copper trifluoroacetate $Cu(CF_3COO)_2$ is a zigzag half-integer spin ladder. Here, we present the results of both experimental and theoretical study of this compound.

The crystal structure of $Cu(CF_3COO)_2$ consists of the magnetic monolayers coupled by weak van – der – Vaals interaction. The coordination environment of the Cu atom is trigonal bipyramide with Cu-O distances of 1.909-2.441 Å in edge-sharing dimeric structural units. The dimers are bridged into zig-zag ladders by O – C – O links. The ladders are separated by isolated CF_6 units [1].

The physical properties of $Cu(CF_3COO)_2$ were studied in measurements of magnetization M and electron spin resonance (ESR). The temperature dependence of magnetic susceptibility $\chi = M/B$ has been taken at $B = 0.1$ T. At lowering temperature, the signal passes through broad maximum and rises again at lowest temperatures. This behavior is typical for the spin-gap system with defects/impurities. The estimation of defects/impurities concentration n ~ 0.45% has been obtained from M vs. B measurements at low temperatures. The fits of χ(T) curve in isolated dimers, coupled dimers and alternating chain models are shown in Fig. 1.

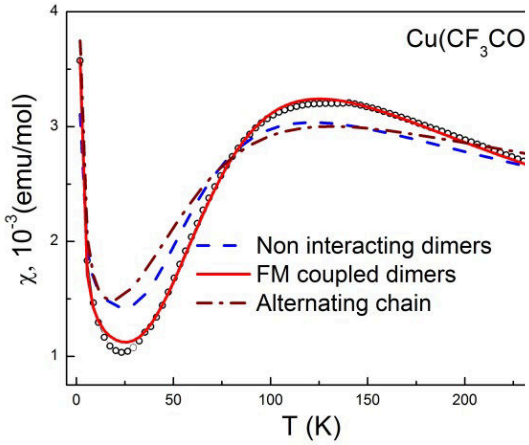

Fig. 1. The fitting of experimental data χ(T) in various models.

The temperature evolution of ESR spectra in $Cu(CF_3COO)_2$ is dominated by rather intense isotropic single line L_1 of Lorenzian lineshape indicative of exchange narrowing at high temperatures. This line is characterized by effective g-factor $g = 2.15$ and could be ascribed to Cu^{2+}(S=1/2) ions in pyramidal coordination. The integral ESR intensity χ_{ESR} compares favorably with the static magnetic susceptibility χ data.

The electronic and magnetic properties of $Cu(CF_3COO)_2$ were calculated using Vienna ab-initio simulation package. For the calculation of the exchange couplings J we calculated total energies of four magnetic configurations, from which one may find three exchange constants J = 278 K, J_2 = 12.7 K, J_3 = - 3.6 K. The largest is the exchange coupling between nearest neighbors forming dimers.

[1] E.V. Karpova, A.I. Boltalin, Y.M. Korenev, S.I. Troyanov, *Russ. J. Coord. Chem.* **26**, 361 (2000).

COOLING RATE UPON IN AIR HEAT TREATMENT AND MAGNETIC PROPERTIES OF AMORPHOUS SOFT MAGNETIC ALLOYS

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Amorphous magnetic alloys are used in various devices as magnetic cores and magnetic shielding. Protection of biological objects from electromagnetic fields is one of the important functions of magnetic shielding. The heat treatment (HT) in air is a standard method of improving the magnetic properties of amorphous soft magnetic alloys. A high level of magnetic characteristics cannot be obtained without optimizing the parameters of heat treatment.

Influence of cooling rate upon in air heat treatment (v_{cool}) on magnetic properties and magnetization distribution in ribbons of amorphous soft magnetic iron- and cobalt-based alloys with different sign of saturation magnetostriction has been investigated in this work. Samples of the amorphous soft magnetic alloys of Fe-Ni-Si-B and Co-Fe-Ni-Cr-Si-B were used. The samples had the form of strips with dimensions 120 x 10 x 0,020 mm. The distribution of magnetization: relative volumes of domains with orthogonal ($V_\perp$) and planar magnetization oriented along (V_{180}) and transversely (V_{90}) to the ribbon axis was determined using the author's method [1] with an error of about 5%. Errors in the determination of magnetic permeability are about 3%. The sign of the magnetostriction saturation was determined through the influence of ribbon surface treatment by water on the magnetization distribution. The main results are presented in the Table 1.

Table 1

The ribbon state	v_{cool}, °C/min	μ_{max}	$V_\perp$, %	V_{180}, %	V_{90}, %	η
Fe-Ni-Si-B, HT 410 °C, 5 minutes, λs>0	15	30000	15.0	64	21	3.1
	40	42000	13.0	76	11	6.9
Co-Fe-Ni-Cr-Si-B, HT 380 °C, 10 minutes, λs<0	15	440000	6,0	76	18	4,2
	40	415000	7,2	55	38	1,5

It is seen that the maximum magnetic permeability (μ_{max}) increases with increase in cooling rate for λs>0, while it decreases for λs<0. This behavior μ_{max} is associated with the redistribution of magnetization in the ribbon. The increase in cooling rate helps to reduce $V_\perp$ for the alloy Fe-Ni-Si-B and increasing the magnetic anisotropy in the ribbon plane $\eta = V_{180}/V_{90}$; increase $V_\perp$ and decrease η for alloy Co-Fe-Ni-Cr-Si-B. Increasing the cooling rate contributes to the preservation of a greater concentration of atoms of hydrogen and oxygen, embedded in the ribbon surface during annealing in its interaction with atmospheric water vapor. In this case, mostly flat tensile stresses are induced. The formation of a high concentration of atoms which embedded across the axis in the ribbon plane under cooling induces in this direction, the pseudo uniaxial stretching. The magnetization is reoriented in the direction of the tensile stress at λs>0 and perpendicular to this direction, if λs<0.

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[1] N.A. Skulkina et al., *Izvestiya Akademii Nauk. Ser. Fizicheskaya* **65**, 10, 1483 (2001).
[2] N.A. Skulkina et al., *The Physics of Metals and Metallography* **117**, 10, 982 (2016).

TEMPERATURE INFLUENCE ON MAGNETIC STRUCTURE OF THE AMORPHOUS $Co_{66}Fe_4Ta_{2.5}Si_{12.5}B_{15}$ WIRE

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It is known that amorphous soft magnetic wires have non-uniform magnetic structure conditioned by the fast quenching technology of its producing. These nonuniformities arise due to heterogeneous residual quenching stresses in the core and outer shell of the wire. These stresses condition a type of magnetic anisotropy which depend on the magnetostriction constant sign of the material. A magnetoimpedance spectroscopy method is a high effective method for study of the magnetic structure features.

A dependence of the imaginary impedance component on the frequency was investigated for the amorphous soft magnetic $Co_{66}Fe_4Ta_{2.5}Si_{12.5}B_{15}$ wires under different values of tensile force influence. The samples' length and diameter were 30 mm and 130 μm, respectively. Investigations were carried out at the automatized measuring complex of the magnetoimpedance spectroscopy in the ac frequencies interval of (0.1 — 100) MHz and temperature range of (120 — 300) K. The maximal value of the mechanical stresses σ created by tensile force and directed along the sample's length was 443 MPa.

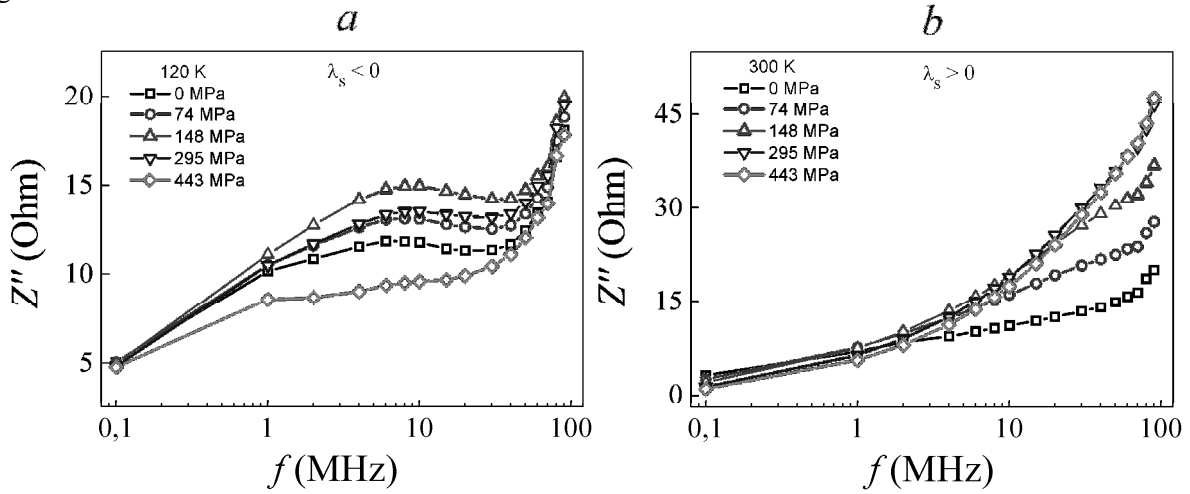

Fig. 1. Frequency dependences of the impedance imaginary component of the $Co_{66}Fe_4Ta_{2.5}Si_{12.5}B_{15}$ wires. The dependences were obtained under elastic tensile stresses: 0, 74, 148, 295 and 443 MPa and temperatures: 120 K – *a* and 300 K – *b*.

At the dependences of $Z''(f)$ a section with $dZ''/df \leq 0$ was detected in the temperature range T = (120 – 160) K (fig. 1, *a*). With the elastic tensile stresses σ increase the $Z''(f)$ dependence becomes monotone increasing. In the temperature range of T = (180 – 300) K the frequency increase leads to the monotone increase of the Z'' for all σ values (fig. 1, *b*). These regularities are explained by change of quenching stresses influence on forming magnetic anisotropy. This change is occurred as result of constant magnetostriction sign change at the temperature T_λ = 170 K.

This work was supported by a project part of Government Assignment for Scientific Research from the Ministry of Education and Science, Russia (№ 3.1941.2017).

MAGNETIC FLUCTUATIONS SORTED BY MAGNETIC FIELD IN MNSB CLUSTERS EMBEDDED IN GaMnSb THIN FILMS

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Dynamics of magnetization reversal of the MnSb clusters embedded in GaMnSb thin films has been studied [1]. The lognormal distribution of ferromagnetic MnSb cluster sizes f(D) has been extracted from the field and temperature dependences of magnetic viscosity S(T,H) in GaMnSb thin films. An average cluster diameter D=55 nm is in agreement with the magnetic force microscopy data. Magnetic anisotropy constant $3.2 \cdot 10^4$ erg/cm^3 has been determined. The fluctuation field H_F=7 Oe and the activation volume $V_A=1.7 \cdot 10^{16}$ cm^3 have been calculated from the magnetic viscosity data. Stepped sweeping of the magnetic field expands the windows of experimentally detectable fluctuations. The change in the reversal magnetic field provides the scanning of the MnSb clusters sorting them by fluctuation time (or frequency).

The generality of the processes of spontaneous and induced magnetization reversal of MnSb clusters embedded in GaMnSb thin films was found. Kinship of thermally activated and field-induced processes of magnetization reversal reflected in the fact that the maximum magnetic field dependence of the viscosity of S(H) coincides with the coercive field H_C of sample. The analysis of this experimental fact has allowed to obtain a formula that establishes a connection of the H_C with parameters of model describing the S(H) dependence. This formula is identical to the well-known Kneller law determined the temperature dependence $H_C(T)$ of non-interacting superparamagnetic nanoparticles [2].

The work was supported by the Grant of President of Russian Federation, Project No. MK-5754.2016.3.

[1] A.I. Dmitriev et al., *JAP* **119**, 073905 (2016).
[2] E.F. Kneller, F.E. Luborsky, *JAP* **34**, 656 (1963).

ELECTROPHYSICAL AND GALVANOMAGNETIC PROPERTIES IN $LiNbO_3$/CoFeB NANOCOMPOSITE FILMS

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Memristive devices are the key contenders for the development of multilevel nonvolatile analog memories and parallel neuromorphic computing architectures [1]. In particular, metal oxide memristors have emerged as promising candidates for hardware implementation of artificial synapses in spiking networks due to their excellent scaling prospects [2]. Memristors with fast switching speed, high endurance and long retention time have been reported in various oxides. Among metal oxides the $LiNbO_3$ based system has emerged as a promising candidate for the functional oxide layer in memristive devices [3]. In the present work we study structural and electrophysical properties of $(Co_{41}Fe_{39}B_{20})_x(LiNbO_3)_{100-x}$ nanocomposite (LNO NC) films and their possible application in spiking neuromorphic networks.

The LNO NC films of thickness 3 μm were synthesized by ion-beam sputtering of a composite target, allowing in a single cycle formation of $Co_{41}Fe_{39}B_{20}$ nanoparticles in the $LiNbO_3$ matrix with oxygen vacancies. The factor x was varied in a range of 5 – 48 at. %. For the film with x ~ 10 at. % resistive switching (RS) effect was observed. RS is weakly dependent on the contacts material (Cu, Cr) and the thickness of the LNO NC layer. The number of switching cycles (endurance) exceeds $N_{max} > 10^5$, and the high-resistance to low-resistance state ratio was $R_{off}/R_{on} = 65$. The obtained value of N_{max} is comparable with those got in HfO_2-based memristors in which, nevertheless, R_{off}/R_{on} ratio is significantly smaller, ~ 6. The influence of magnetic field on the RS effect was demonstrated.

Observed RS effect is described by the significant influence of oxygen vacancies on tunneling conductivity of chains of metal nanoclusters, determining the electrical resistance of structures below the percolation threshold. The ability of LNO NC memristive devices to support the spike-time-dependent plasticity was demonstrated. These results give every hope for stable operation of future large neuromorphic networks based on LNO NC memristive devices.

The work was partially supported by the Russian Science Foundation (16-19-10233) and performed on the Resource Center facility (Kurchatov Institute).

[1] A. V. Emelyanov, D. A. Lapkin, V. A. Demin, et al., *AIP Advances* **6**, 111301 (2016).
[2] M. Prezioso, F. Merrikh Bayat, B. Hoskins et al., *Sci. Rep*. **6**, 21331 (2016).
[3] X. Pan, Y. Shuai, C. Wu et al., *Appl. Phys. Lett*. **108**, 032904 (2016).

THE HIGH-RESOLUTION RECIPROCAL-SPACE MAPPING BY REFRACTIVE X-RAY OPTICS

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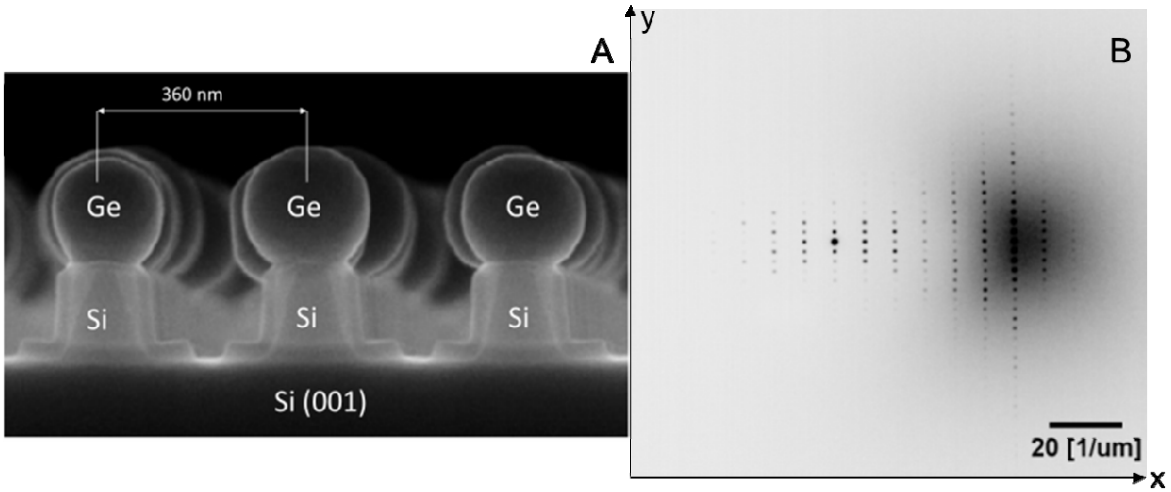
The third-generation synchrotron together with refractive optics have opened up new possibilities in the study of microscopic objects. Apart from the excellent microfocusing and imaging applications, one of the most notable and useful properties of compound refractive lenses(CRL) [1] is it's intrinsic ability to perform one or two dimensional Fourier transforms. These properties in the case of hard X-rays has been demonstrated theoretically [2] and experimentally [3]. Recently it has been shown that the small angle diffraction setup with CRL as a Fourier analyser has the microradian angular resolution. In the present work we propose refractive optics as a Fourier transformer of high resolution x-ray crystal diffraction. In this case the wave transmitted through the object transforms into spatial intensity distribution at the observation plane according to the Fourier relations. CRL are well suited for the Fourier transform analysis in the hard X-ray energy range from 2 to 100 keV.



Pic.1 SEM image of Si-Ge nano-heterostructure(A) and their Fourier pattern performed by CRL(B).

Further development of Fourier transform diffraction techniques based on refractive optics will complement a triple-crystal diffractometry results. This technique could be used to design an X-ray diffraction microscope similar to electron microscope where diffraction pattern can be switched to full-field image.

[1] A.Snigirev, V.Kohn, I.Snigireva and B.Lengeler, *Nature* **384**, 49-51 (1996).
[2] V.Kohn, I.Snigireva, A.Snigirev, *Optics Communications* **216**, 247-260 (2003).
[3] M.Drakopoulos, A.Snigirev, I.Snigireva, J.Schilling, *Applied Physics Letters* **86**, 014102 (2005).

A TRIMORPHIC MAGNETOELECTRIC TRANSDUCER FOR ENERGY HARVESTING DEVICES

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Advancements in manufacturing processes have enabled the development of miniaturized microelectronic devices with reduced power consumption for applications such as biomedical devices and portable electronics [1, 2]. One of the most problem in this scope remains a limited lifetime and power of the batteries.

A promising solution to overcome this challenge is development of devices, which can convert ambient energy into electric energy and storage it for supplying low-power electronics (energy harvesting devices). Nowadays, some different types of devices are used for energy harvesting. Among them, magneto-electric effect based devices can generate relatively larger output voltages under low magnetic fields.

In this paper a magnetoelectric energy harvester based on a three-layer planar structure is presented. A piezoelectric (PE) layer was placed between two ferromagnetic layers (FM) with different signs of magnetostriction. A cantilever beam based on this structure was made. One end of the beam was fixed on the massive base and another end was free (figure 1).

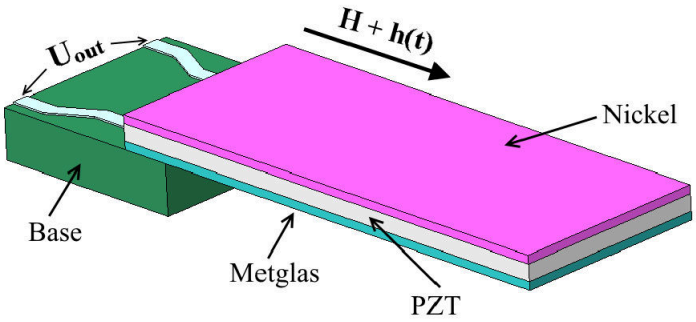

Figure 1. A trimorphic magnetoelectric energy harvester.

PZT-19 piezoceramics with dimensions of 32 mm * 12 mm * 0.6 mm was used as a PE layer. Metglas 2605S3A Magnetic Alloy with dimensions of 32 mm * 12 mm * 0.075 mm was used as a FM material with positive magnetostriction and Nickel with dimensions of 32 mm * 12 mm * 0.075 mm was used as a FM material with negative magnetostriction. All layers were bonded by means of cyanoacrylate glue.

During investigation the harvester was placed into alternating magnetic field *h(t)* and constant bias magnetic field *H* which were applied along the structure. Magnetostriction of the FM layers resulted in its mechanical deformation. These deformations transferred to the PE layer and an electrical voltage U_{out} was appeared across the layer.

Due to different signs of magnetostriction there is a possibility of increasing bending moment of the structure and thereby enhancing several times of output voltage.

The research was supported by Russian Foundation for Basic Research grant № 15-32-70006.

[1] A.P. Chandrakasan, N. Verma, D.C. Daly, *Biomed. Eng*. **10**, 247-274 (2008).
[2] R. Roman, C. Alcaraza, J. Lopez, N. Sklavos, *Computers & Electrical Engineering* **37**, 2, 147–159 (2011).

E-FIELD CONTROL OF ME EFFECT CHARACTERISTICS IN LAYERED COMPOSITE STRUCTURES

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Investigation of the magnetoelectric effect in composite structures have received great attention in recent years due to the prospects of their application in highly sensitive sensors, memory devices, etc. [1]. Magnetoelectric effect in layered composite structures is a result of combination of magnetostriction of magnetic layer and piezoeffect of piezoelectric layer. Large number of magnetic materials with different magnetostriction constants are used for composite structures fabrication therefore most of the works was devoted to the study of the influence of magnetic fields on ME characteristics. However, recently several new types of piezoelectric materials: piezoelectric single crystals (Langatate), piezoelectric polymers (PVDF) and piezoelectric semiconductors were proposed for ME composites production. Therefore, there is great interest in study of the influence of electric field on ME characteristics.

In this paper, we studied influence of the electric field on the characteristics of the ME effect in a composite structure based on a piezoelectric langatate ($La_3Ga_{5.5}Ta_{0.5}O_{14}$ «Fomos-Materials» [2]) for the first time. The experiments were carried out on a two-layered langatate-amorphous magnetic alloy (FeSiCB «Metglas Inc. ») structure. High voltage power supply model 320 was used to apply constant electric voltage to the structure. Figure 1 shows the dependencies of the ME voltage, resonance frequency and resonance Q-factor on electric voltage. Measurements were carried out at resonance frequency of planar acoustic oscillations f_{res} = 117,170 kHz. The shift in the resonance frequency and Q factor can be explained by the dependence of the dielectric constant and Young's modulus on the electric field.

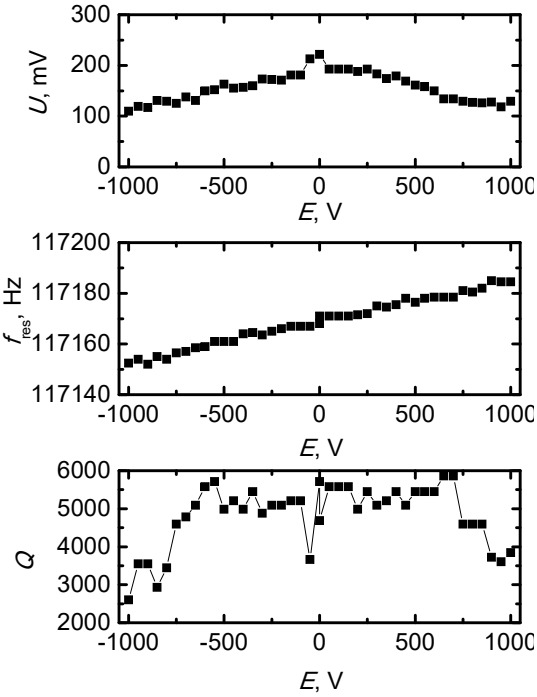

Figure 1. Magnetoelectric voltage, resonance frequency and quality factor shift under applied electric field E.

The research was supported by Russian Scientific Foundation grant № 17-12-01435.

[1] Van Suchtelen, *Philips Res. Rep*. **27**, 28–37 **(**1972).
[2] G. Sreenivasulu, L.Y. Fetisov, Y.K. Fetisov, G. Srinivasan, *Appl. Phys. Lett.* **100**, 052901 (2012).

MAGNETO-OPTICAL PROPERTIES OF NANOCOMPOSITES FERROMAGNETIC-CARBON

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Current work is dedicated to studying the magneto-optical results of nanostructures based on transition materials with carbon. Films of carbonaceous heterogeneous systems were obtained using ion-beam sputtering of composite target on ceramic substrates. There were three systems synthesized with wide range of metallic phase concentrations - $(Co_{41}Fe_{39}B_{20})_X(C)_{100-X}$ (system 1), $(Co_{45}Fe_{45}Zr_{10})_X(C)_{100-X}$ (system 2) and $(Co)_X(C)_{100-X}$ (system 3). Precipitation of the composites has been conducted for both argon environment, and for mixed argon environment with admixture of hydrogen. The elemental composition information of the films was provided using energy-dispersion x-ray Oxford INCA Energy 250 device on the JEOL JSM-6380 LV scanning electronic microscope. Research of the composite structures revealed that all the composites were 3-phase heterogeneous structures and besides the quantity and type of the carbonaceous phase depended not only on C concentration, but also on metallic granule elemental composition.

Magneto-optical properties were studied in the energy range of 0.5 – 4.2 eV in the Transversal Kerr Effect (TKE) geometry at magnetic fields of up to 3 кOe.

TKE field dependences analyze shown that unlike previously studied "ferromagnetic(FM)-dielectric" composites [1] the current composites demonstrate the percolation thresholds (PT), which were determined by appearing of FM-order, that do not correlate with PT's determined using transport measurements [2]. FM-order appeared in systems 1, 2 and 3 at $x \geq 35.4$, 32 and 54.5at% respectively. Adding hydrogen to sputtering environment led to TKE increase and to shift of the percolation threshold towards higher values of x. Shapes of system 1 TKE spectra weakly depended on x. The evolution of system 3 TKE spectra during the concentration changes indicate a transition from amorphous CoC granules to a cristallic Co granules in a carbon matrix, which is in a good agreement with structural measurements.

This research was supported by the Russian Foundation for Basic Researches №15-02-02077

[1] Gan'shina E.A., Vashuk M.V., Vinogradov A.N. et al., *Journal of Experimental and Theoretical Physic* **98** (5), 1027 (2004).
[2] A.A. Aleshnikov, Yu.E. Kalinin, et.al., *Vestnik Voronezh State University* **2** (11), 83 (2012).

MAGNETIC AND TRANSPORT PROPERTIES OF Mn_2FeGa

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Recently, there has been growing interest in the development of novel materials for spintronic applications. Heusler alloys, specifically so-called inverse Heusler alloys [1] and equiatomic quaternary Heusler alloys [2] have been suggested as a potential candidate in this respect. First principles theoretical calculations have suggested [3] that Mn_2FeZ (Z = Al, Ga, Si, Ge, Sb) Heusler alloys can be of interest for experimental studies due to their potential half-metallic properties. Experimental studies of the Heusler alloy with Z = Ga, Mn_2FeGa, have shown that crystal structure and magnetic properties of Mn_2FeGa strongly depend on annealing conditions [4,5].

To further explore physical properties of this alloy, we have prepared Mn_2FeGa in the form of polycrystalline bulk samples by arc-melting method and in the form of melt-spun ribbons by a melt spinning technique and performed a comparative study of the bulk and melt-spun samples by X-ray diffraction (XRD), magnetic and transport measurements.

Room-temperature XRD diffraction revealed that the as-spun ribbons have a primitive cubic structure while the bulk samples consist of the main phase and an impurity phase. The main phase crystallizes in a cubic Heusler structure. Magnetic properties of the melt-spun ribbons turned out to resemble properties of antiferromagnetic compounds while ferromagnetism was evident in the bulk samples. Measurement of electrical resistivity revealed that transport properties of melt-spun and bulk samples of Mn_2FeGa are also different in a temperature interval 80 – 360 K. While the melt-spun ribbons demonstrate behaviour of electrical resistivity typical for semiconductors, the bulk samples exhibit metallic behaviour of the resistivity in the measured temperature interval.

This work was supported by Russian Science Foundation (grant No. 16-42-02035).

[1] X. Wang, Z. Cheng, J. Wang, X.-L. Wang, G. Liu, J. *Mater. Chem. C* **4**, 7176 (2016).
[2] L. Bainsla, K.G. Suresh, *Appl. Phys. Rev.* **3**, 031101 (2016).
[3] H.Z. Luo, H.W. Zhang, Z.Y. Zhu, L. Ma, S.F. Xu, G.H. Wu, X.X. Zhu, C.B. Jiang, H.B. Xu, *J. Appl. Phys.* **103**, 083908 (2008).
[4] T. Gasi, A.K. Nayak, J. Winterlik, V. Ksenofontov, P. Adler, M. Nicklas, C. Felser, *Appl. Phys. Lett.* **102**, 202402 (2013).
[5] Z.H. Liu, Y.J. Zhang, H.G. Zhang, X.J. Zhang, X.Q. Ma, *Appl. Phys. Lett.* **109**, 032408 (2016).

MAGNETIC PROPERTIES OF HETEROGENEOUS MATERIALS BASED ON MANGANITES

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Here we present the investigation of microstructural and magnetic properties of (80-x)%($La_{0.7}Sr_{0.3}MnO_3$)+20%GeO_2+x%NaF (LSMO/GeO/NaF) composite materials for x = 0-0.20. Synthesis technology and magnetoresistive properties of composites based on lanthanum-strontium manganite without sodium fluoride are described in [1]. For the preparation of fluorinated compounds 5-20 weight percent of NaF was added in the stoichiometric mixture of La_2O_3, $SrCO_3$, Mn_2O_3, GeO_2 at the percolation threshold. Composites containing NaF mainly consist of hexahedral hollow tubes and demonstrate more regular microstructure than composites with x=0 and (Fig. 1). The addition NaF to composite also leads to the increasing of the absolute value of the magnetization in five times (Fig. 2). We suggest that the replacement of the manganese ions of fluorine leads to the change in the parameters of the double exchange and improves the ferromagnetic properties.

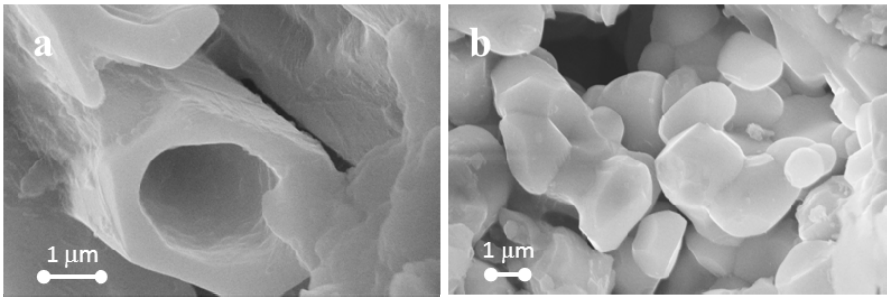

Fig. 1. SEM images of LSMO/GeO/NaF composites: (a) x=0.1, (b) x=0.

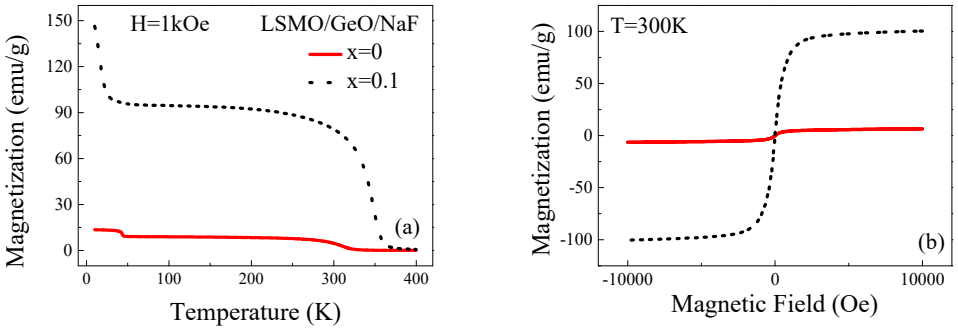

Fig.2. (a) Temperature dependence, (b) field dependence of magnetization in LSMO/GeO/NaF

[1] Kabirov Yu.V. et al., *Technical Physics Letters* **42**, 278 (2016).

SYNTHESIS AND MAGNETIC PROPERTIES OF COPPER-BASED LUDWIGITES

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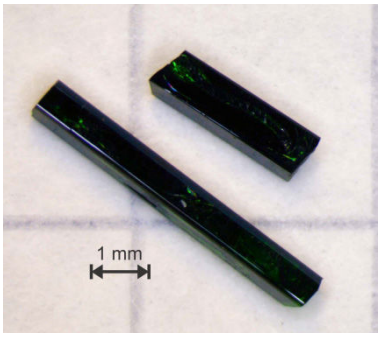

Fig.1. Optical image of Cu_2GaBO_5 crystals

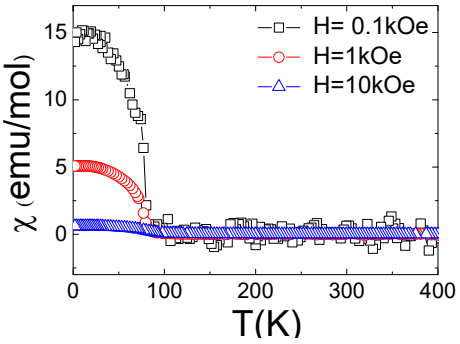

Fig.2. Temperature dependencies of magnetic susceptibility of $Cu_{2.5}Mn_{0.5}BO_5$.

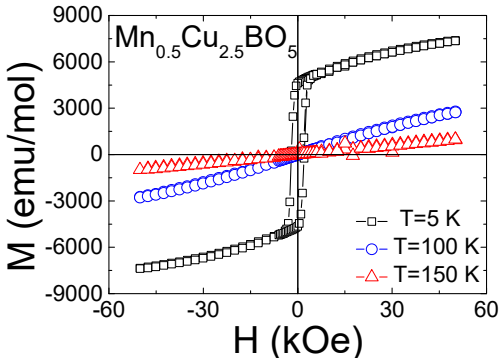

Fig.3. Field dependence of the magnetization of the Cu_2MnBO_5 (H||c).

Here we present the investigations of structural and magnetic properties of Cu-based compounds of the ludwigite family: Cu_2GaBO_5 and $Cu_{2.5}Mn_{0.5}BO_5$. The Cu_2GaBO_5 and $Cu_{2.5}Mn_{0.5}BO_5$ single crystals were synthesized by the flux method in the form of orthogonal prisms (Fig. 1). The synthesized samples have a monoclinic symmetry and belong to the $P2_1/c$ space group. The important peculiarity of $Cu_{2.5}Mn_{0.5}BO_5$ compared Cu_2GaBO_5 is the presence of two Jahn-Teller cations in the structure. Because of the strong distortions of the nearest surroundings of Mn and Cu ions the original magnetic structure is expected. The typical feature of these compounds is a presence of quasi-low dimensional elements - ribbons, ladders, zigzag walls. Moreover, metal ions form triangular groups in most compounds, which originates geometric prerequisite for frustrations rising in the system. In these quasi-low dimensional compounds, a whole range of interesting effects is observed, e.g. charge ordering and two magnetic subsystems existence, which order at different temperatures. Temperature dependencies of magnetic susceptibility of $Cu_{2.5}Mn_{0.5}BO_5$ are presented in Fig. 2. Field-thermal dependencies of the magnetization measurements revealed the paramagnetic-ferrimagnetic phase transition at $T_c \approx 80$ K. The behavior of magnetization is paramagnetic at temperatures T=100 K and 150 K, while the narrow hysteresis loop is observed at 5K due to the presence of the ferromagnetism in the sample (Fig.3).

This work was supported by the RFBR no 17-02-00953.

INCOMMENSURATE MAGNETIC ORDER IN CoO NANOPARTICLES REVEALED BY NEUTRON DIFFRACTION

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CoO nanoparticles can exist with a crystal structure of wurtzite and zinc blende, unlike a rock-salt structure, which is characteristic for the bulk. However, the magnetic structures of wurtzite and zinc blende phases remain unknown. The neutron diffraction studies were performed in CoO nanoparticles with wurtzite (~ 30 nm) and zinc blende (~ 15 nm) crystal structures to unravel magnetic order and its temperature evolution. The magnetic structure in wurtzite nanoparticles turned out to be complex with two perpendicular components. One component is incommensurate, Longitudinal Spin Wave type with the moments aligned within the *ab*-plane. In the perpendicular direction, along with the hexagonal axis, this magnetic order is uncorrelated forming pronounced quasi-two-dimensional magnetic layers. Another component of the magnetic moment, along with the hexagonal axis, is commensurate and corresponds to the antiferromagnetic order known as the 2-the type of wurtzite structure. The temperature dependencies confirm such arrangement.

In contrast to wurtzite nanoparticles, the magnetic order in the zinc blende nanoparticles appeared to be commensurate, antiferromagnetic, corresponding to the 3-th type of magnetic ordering in the fcc lattice similar to the bulk. Magnetic moments were found to be aligned along a cube edge.

The incommensurate magnetic structure in nanoparticles is an unusual phenomenon and in the case of wurtzite CoO, it is probably caused by the "stacking faults" type defects in the anisotropic crystal structure of wurtzite at the nanoscale.

METHODS OF POLYCRYSTALLINE Ni-Mn-BASED HEUSLER ALLOYS THIN FILMS FORMATION BY PULSED LASER DEPOSITION TECHNIQUE

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The Ni-Mn-based Heusler alloys with the structural formula X_2YZ belong to the most studied intermetallic compounds due to a variety of interesting physical effects inherent to them, including the shape memory effect, magnetocaloric effect and field-induced structural phase transition [1, 2]. These effects are mainly based on the martensitic transformations, i.e. a first-order structural transition from high-temperature cubic austenitic phase to a low temperature martensitic phase (orthorhombic, monoclinic etc). Temperature and dynamics of the martensitic transition are very sensitive to the concentration of the elements in this type of alloys [3, 4].

We report the results of investigation of polycrystalline Ni-Mn-In and Ni-Mn-Ga thin films with thicknesses about 50 nm, grown by pulsed laser deposition. Three different approaches of formation were examined with ablation from: i) Ni-Mn-In (or Ni-Mn-Ga) alloy target with certain concentrations; ii) three independent targets of pure metals (Ni, Mn and In or Ga) using two lasers; iii) Ni-Mn-In (or Ni-Mn-Ga) target with one laser and co-deposition of Mn by second laser.

All listed methods of thin films fabrication are suitable for formation of Ni-Mn based Heusler alloys thin films with martensitic transformation, but careful selection of growth parameters is required to avoid droplets. Dependences of stoichiometry transfer coefficients from deposition parameters were observed.

The martensitic transition features were investigated using magnetic (Physical Property Measurement System - PPMS, vibrating sample magnetometer - VSM), structural (X-Ray diffraction - XRD) and electronic (Hard X-ray Photoelectron Spectroscopy - HAXPES) techniques. It was shown, that magnetic attributes of martensitic transition, observed by PPMS, are in a wider temperature range (about 200 K), than structural ones, studied by X-ray diffraction (about 90 K). Broad temperature range of transition (about 200 K) was observed for electronic structure investigation of the valence band, provided by HAXPES on P09 beamline at PETRA III synchrotron source.

It was shown that co-deposition of alloy and Mn target is more acceptable in the context of concentrations variation and droplet density.

[1] J.Liu, T. Gottschall, K.P.Skokov, J.D.Moore, O.Gutfleisch, *Nature Materials* **11**, 620–626 (2012).
[2] P. Klaer, H. C. Herper, P. Entel, R. Niemann, L. Schultz, S. Fähler, H. J. Elmers, *Phys. Rev. B* **88**, 174414 (2013).
[3] Thorsten Krenke, Mehmet Acet, and Eberhard F. Wassermann, Xavier Moya, Lluís Mañosa, and Antoni Planes, Ferromagnetism in the austenitic and martensitic states of Ni-Mn-In alloys, Phys. Rev. B 73,174413 (2006).
[4] T. Graf, C. Felser, S.S.P. Parkin, *Progress in Solid State Chemistry* **39**, 1-50 (2011).

SELF-ASSEMBLY OF DESIGNED MAGNETIC FILAMENTS OF DIFFERENT TOPOLOGY

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Newly developed experimental techniques allowed combining magnetic particles and polymers. These techniques make it possible to create a certain aggregated structures with finely controllable mechanical, magnetic and other properties. Here, we investigate magnetic filaments with different topologies made out of ferromagnetic spherical and ellipsoidal nanoparticles - simple open chains and closed rings which are the ground states of dipolar hard particles [1,2] Using Langevin dynamics simulations, we analyse different properties of single filament of different conformations, length and temperature (the end-to-end distance, radius of gyration, total magnetic moment). On Fig. 1 two types of filaments are presented. To describe particles shape anisotropy we use parameter X_0 (semiaxis ratio for ellipsoid). Different orientation of magnetic moment inside the particles for filaments made out ellipsoids is also investigated. Thus, we show that shape of particles, the size of their magnetic moment, temperature and filament's length can significantly change conformation and properties of a single filament. These results will form the basis for developing theoretical models and provide recommendations for the design of novel magnetoresponsive systems.

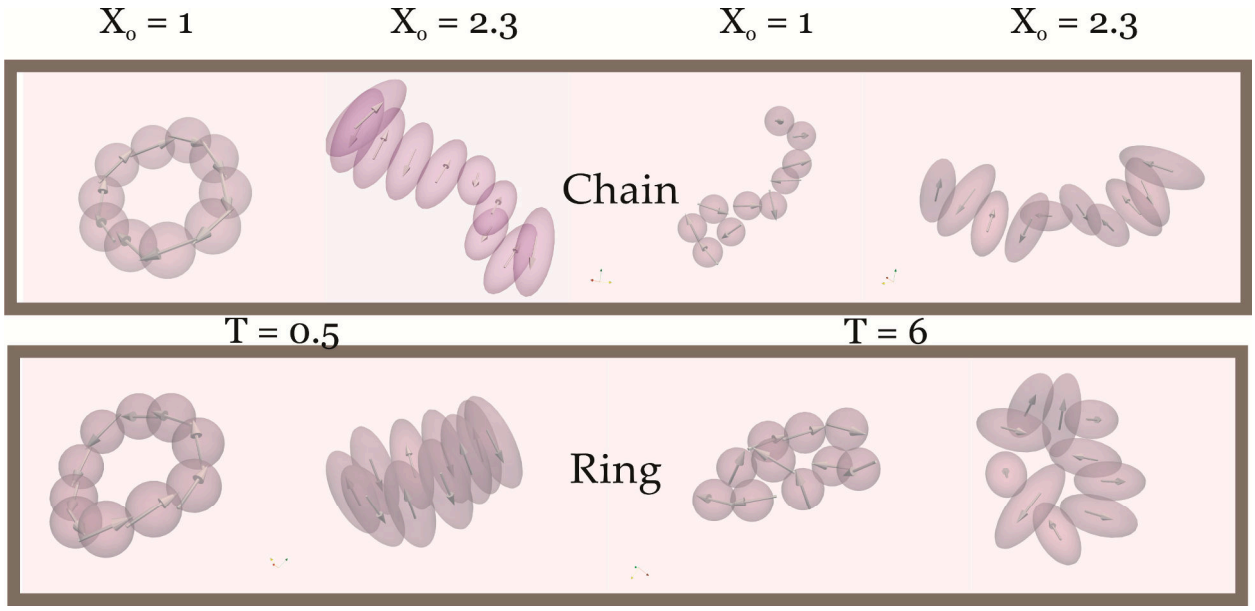

Fig. 1. Examples of filaments. The length of filaments equal to 10 and square of particles magnetic moment is equal to 8.

[1] Prokop'eva, *JETP* **113**, 435 (2011).
[2] Kantorovich, *Soft Matter* **9**, 6594 (2013).

STRUCTURAL PROPERTIES OF PARTIALLY SUBSTITUTED BARIUM HEXAFERRITE

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The magnetic industry pays the attention to the hexaferrites due to their high chemical and temperature stability and magnetocrystalline anisotropy. Barium hexaferrite is well-known material for the memory devices. But nowadays $BaFe_{12}O_{19}$ is interested for the microwave application because of the substitution ability. This paper devotes barium hexaferrites structural properties investigation includes the thermal stability characteristics. Barium hexaferrite tablets prepared by the sintering method and single crystals obtained by flux technique were chosen for the research. Iron oxide Fe_2O_3 and barium carbonate $BaCO_3$ were used as initial components with batch composition of 82.92 wt. % Fe_2O_3 and 17.08 wt. % $BaCO_3$. Samples were calcinated in platinum crucibles in a horizontal SiC tube furnace with maximum temperature 1450 °C. Both components were mixed and grinded in an agate mortar during 1 hour. The resulted powder was regrounded and pressed into pellets. Single crystals were performed from lead and iron oxides and barium carbonate by the flux growth technique. The mixture was ground in an agate mortar and filled in a 30 ml platinum crucible. The crucible was placed in an oven equipped with a resistive heater. To homogenize the educts, the furnace was maintained at 1260 °C for 3 h. The flux was cooled down to 900 °C with a rate of 4.5 K/h, followed by a more rapid cooling by turning off the furnace. The crystals were separated from the solidified melt by leaching in hot nitric acid.

The chemical composition of the samples were determined by energy dispersive spectrometer Oxford INCA X-max 80 attached to a scanning electron microscope Jeol JSM7001F. The crystal structure was define by the a powder diffractometer Rigaku Ultima IV in the angular range from 10 to 90 °2θ with the speed of 2 °2θ/min with filtered CuKα radiation. The Curie temperatures were measured using a differential scanning calorimeter (DSC) Netzsch STA 449C Jupiter and also with the use of dilatometer Netzsch DIL 402C in the range from 200ºC to 800ºCby the analysis of the dependence thermal expansion of the heating temperature.

All the samples reveal the structure of $BaFe_{12}O_{19}$. The differentiation curve of thermal expansion dependence of heating temperature shows the maximum at 455 ºC that is consistent with the Curie temperature measured by DSC for single and poly crystals.

The coefficient of thermal expansion for pellets does not depend on the axis and equals to $11{,}239 \times 10^{-6}$ 1/K. For the single crystal the coefficient of thermal expansion measured along the c axis exceeds more than twice the value of the coefficient of thermal expansion measured along the a axis and equals $16{,}414 \times 10^{-6}$ 1/K. Also, for single crystals, the effect of thermal compression was observed with an increase in the heating temperature. For the isotropic pellets the compression effect is not noticed.

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MAGNETO-OPTICAL TOPOGRAPHY OF THE PLANAR COMPONENT OF AN INHOMOGENEOUS FIELD

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The application of ferrite-garnet films with planar anisotropy to visualise magnetic fluxes created by currents in superconducting materials is an effective research method [1]. In [2] by the dependence of the normal component of the field determined from magneto-optical measurements, by means of the inverse Fourier transform, the possibility of determining the magnetisation pattern in the field source was shown.

In our work, the possibility of topography of the planar component of an inhomogeneous field from the magneto-optical images (MOI) of this field in magnetic metal films with planar anisotropy is shown. The method of topography is based on fixing the coordinates in the xy plane of the positions of the singular points of the MOI when an external uniform magnetic field is applied.

For the observation of the MOI, the meridional Kerr method was used with record the normal and planar magnetization components in the indicator film. In the experiment, miniature magnets were used as the source of the inhomogeneous field, the magnetic moments of which were oriented perpendicularly **(M ‖ n)** and parallel **(M∞ n)** to the plane of the indicator film. Here **n** is the normal to the plane of the indicator film.

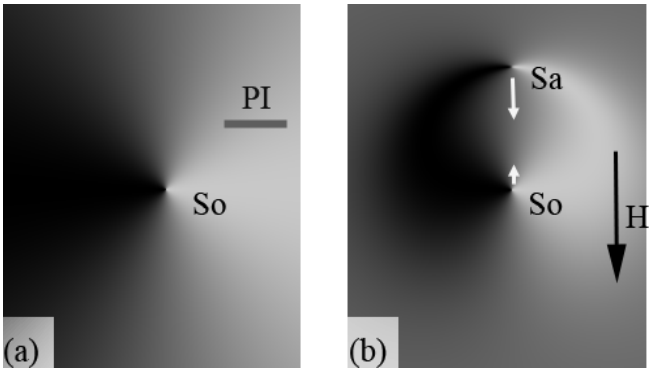

Figure 1. MO imagings of a plane component of the stray field of a single magnet (a) in the absence of a field and (b) in an external homogeneous field.

In the absence of an external field, MOI contain one (figure 1a, if **M ‖ n**) or two **(**if **M∞n)** singular points of source or sink type [3]. The application of a homogeneous external field parallel to the plane of the indicator film induces the appearance of singular points of the "saddle" type (figure 1b) . At singular points, the total field $\mathbf{H_R}=\mathbf{H_{in}}+\mathbf{H_{ex}}=0$**,** or componentwise $H_{inx}=H_x$, $H_{iny}=H_y$**.** The increase of the field leads to the convergence of saddle-shaped points and the of "source", "sink" and their mutual collapse. Using this motion, we obtain the dependence X, Y **($\mathbf{H_{ex}}$),** which we then transform into the coordinate dependence of the inhomogeneous field **H**(x, y**).**

[1] L.A. Dorosinskii, M.V. Indenbom, V.I.Nikitenko, Y.A.Ossip'yan, A.A.Polyanskii, V.K Vlasko-Vlasov, *Physica C* **203**, 149 (1992).
[2] S. Dreyer, J. Norpoth, C. Jooss, S. Sievers, U**.** Siegner, V. Neu, T. H. Johansen, *J. Appl. Phys.* **101**, 0839051 (2007).
[3] Ivanov V. E. *Journ. Magn. Magn. Mater*. **401**, 200 (2016).

CURRENT MAGNETIC TWEEZERS AS CELL BIOCHIPS: PERSPECTIVES AND PROBLEMS

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Physiologic conditions of cell viability are generated *in vitro* by a microenvironment design including hydrodynamics (cell bioreactors, microfluidics), gas transport, chemical composition and topography of extracellular matrix [1], surface free energy and wettability [2], and electromagnetic field [3]. New microfluidics technology "lab-on-a-chip" [4], and "cells-on-a-chip" [5] were developed for cell culturing and manipulation. Currently, electromagnetic tweezers design [6] has been currently recognized as novel prospective direction of cell behavior control. The investigation was carried out to estimate stromal stem cells reaction on electromagnetic field with state-of-the-art application of knowledge for designing of new generation of electromagnetic tweezers.

Firstly, mini-device "Autonomous electrostimulator of gastrointestinal tract" (AES GIT) permitted for clinical application was used for mouse bone marrow colony forming units of fibroblasts (CFU-Fs) *in vitro* processing. It generates pulse current with pulse duration 5-7 ms, current intensity (I) 9-15 mA, and 16 pulse packets duration 320-450 ms. Calculated total energy density of electromagnetic (EM) field with interelectrode voltage (U) 4.5 V in cell culture medium varied in the range of W=0.1-3.6 J/cm^3 depending on time deposition of 5-180 min. CFU-Fs growth was estimated in semisolid culture medium as described earlier [7].

Secondly, current magnetic tweezers (CMT) with I=0.3 A, U=0.25 V, and strength of a magnetic field on surface of wire 17.6 mT was tested in short-term liquid culture of human adipose–derived multipotent mesenchymal stromal cells (hAMMSCs) for 120 min.

Table 1 - AES GIT dose-dependent influence bone marrow mesenchymal stromal cells, X

Time of deposition, min	0	5	10	20	30	60	120	180
CFU-Fs number, %	100	1200*	1900*	1600*	1000*	5600*	400	0*

Note: *) – significant differences with point 0 according to Mann-Whitney test.

Results of AES GIT in vitro usage are shown in Table 1. Both positive and negative impact on stem cells was revealed. However, marked corrosion of steel electrodes of mini-device proposed the dopants uncontrolled effect on cell culture. So, CTM-based "cell biochip" with cuprum wires isolated by silicon dioxide was constructed and had no toxic action on hAMMSCs adhesion to glass substrate and viability. Thus, novel generations of tweezers need to keep in mind ambivalent nature of cell reaction on electromagnetic field.

[1] N. Sniadecki et al., *Ann Biomed Eng* **34**, 59 (2006).
[2] L. Ponsonnet et al., *Mater SciEng C* **23**, 551 (2003).
[3] J. Ferrier et al., *J Cell Physiol* **129**, 283 (1986).
[4] R. Khamsi, *Nature* **435**, 12 (2005).
[5] J. El-Ali et al., *Nature* **442**, 403 (2006).
[6] V. Bessalova et al., *JMMM* **415**, 66–71, (2016).
[7] I. Khlusov et al., *Bull Exp Biol Med* **128**, 1162 (1999).

ANOMALOUS HARD X-RAY FOCUSING BY NICKEL REFRACTIVE LENS

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Despite the successful use of X-ray refractive optics at synchrotron X-ray sources [1], questions related to the spectral features of beam focusing as a promising direction in the development of analytical methods of research have not yet been considered. In particular, this applies to issues related to anomalous dispersion absorption discontinuities in materials. Usually the dependence of the refractive index on the wavelength is monotonous (a monotonous function, which, if it changes with increasing value of the argument, then only in one direction). However, discontinuous change is observed in anomalous refraction because of the resonance nature of the interaction of X-rays with specific (defined) chemical elements.

The lack of interest in such type of research is due to the extremely limited set of instrumentation for studying the effects associated with refraction. In order to fill this gap, we investigated the focusing properties of a nickel refractive lens, depending on the energy in the region of K-edge absorption of nickel, which is 8.3328 keV according to [2].The measurements were carried out at the Micro Optics Test bench at the ESRF ID06 beamline. The desired energy was selected by cryogenically cooled Si (111) double crystal monochromator, which provides the energy resolution 0.5 eV. Single Ni lens with a 50-μm radius of curvature and a thickness of 1 mm was used. Experimentally was observed the abrupt change of the focal length in the order of 30% near the nickel absorption K-edge. The lens parameters such as the lens effective aperture and the size of the focal spot was changed discontinuously. According to the calculations, this change in the focal length correlates with the nature of the change in the refractive index and the associated form factor, which makes it possible to obtain the parameters of the material under study by direct refraction measurements. A possibility of determining these parameters for different alloys and multiphase materials will be discussed.

[1] A. Snigirev, V. Kohn, I. Snigireva, B. Lengeler, *Nature* **384**, 49 – 51 (1996).
[2] K. Sevier, Atomic electron binding energies. *At. Data Nucl. Data Tables* **24**, 323–371.(1979).

EQUILIBRIUM PROPERTIES OF MAGNETIC FILAMENT SUSPENSION

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Magnetic filament is a chain of magnetic micro- or nanoparticles, which are permanently connected with polymer linkers. The suspension of nanosized filaments in a non-magnetic carrier liquid is a perspective smart material, which is potentially able to combine sedimentation stability of standard ferrofluids and substantially larger magnetic susceptibility. In the present work, some equilibrium properties of magnetic filament suspension are investigated via Langevin dynamics simulation. Initial magnetic susceptibility of suspension is calculated for different values of magnetic phase concentration, particles' magnetic moment, and filaments' length. It is shown that manifold increase in susceptibility can be achieved through the increase in filament length. However, for moderately concentrated systems susceptibility growth is limited and the usage of filaments, which contain more than ten particles, seems to be superfluous. Sedimentation of filaments in a strong gravitational (centrifugal) field is simulated. It is shown that equilibrium vertical distribution of magnetic phase in filament suspension is close to the distribution of unlinked magnetic nanoparticles with large magnetic moments.

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DOMAIN WALL NUCLEATION IN BISTABLE AMORPHOUS FERROMAGNETIC MICROWIRES

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Bistable ferromagnetic microwires are of high interest for applications in a variety of magnetoelastic sensors [1]. Aim of this work is to study domain wall nucleation process in ferromagnetic microwires with the emphasis on connection between local nucleation field and anisotropy distribution within the crossection of the wire.

The theoretical foundation of the process description based on the three-dimensional Heisenberg model. A key part of the research is extraction of analytic correlations between the local nucleation field, material parameters and anisotropy distribution by means of scaling procedures supplemented by numerical simulations of the domain nucleation process. Assumed anisotropy distribution is based on theoretical calculations of Chiriac et al. [2].

The main result is that the local nucleation field strongly depends on the rate of anisotropy change and not on its maximum or average value in the bulk. The numerical simulations clearly show that the nucleation process of a domain wall starts at the point, where the anisotropy changes from axial to radial near the surface of the metallic core of the wire.

The results clearly show that the behaviour of bistable ferromagnetic microwires can be properly understood only if we take into account an accurate anisotropy distribution within the wire. Additionally, the simulations of domain wall nucleation within the wire may also bring new insight into the remagnetisation process and help in explaining the unusual, elongated shape of a moving domain wall [3] as well as extremely high propagation speeds [4].

[1] A. Zhukov, *JMMM* **242–245**, 216–223 (2002).
[2] H. Chiriac, T. A. Óvári, Gh. Pop, *PRB* **52**, 14, 10104 (1995).
[3] L.V. Panina, M. Ipatov, V. Zhukova, A. Zhukov, *Physica B* **407**, 14421445 (2012).
[4] A. Zhukov, J.M. Blanco, M. Ipatov, A. Chizhik and V. Zhukova, *Nanoscale Research Letters* **7**, 223 (2012).

IRON OXIDE NANOPARTICLES DRIVE DIFFERENT MECHANISMS OF CELLULAR DEATH DEPENDING ON THEIR SHAPE AND SURFACE

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Introduction. Specifically designed and surface functionalized nanoparticles hold great promise for biomedical applications. Currently, the applicability of nanoparticles is greatly predetermined by their surface functionalization. At the moment, nanomaterials are widely tested for both diagnostics and targeted treatment of cancer. However, for the development of efficient and safe nanoparticle-based treatments, diagnostics and therapy, it is crucial to establish systematic investigations of adverse effects of nanomaterials.

Methods. The aim of this study was to investigate how 4 types of magnetic nanoparticles with Fe3O4 core (Table 1) affect cell survival and death signaling. Taking in count that iron oxide nanoparticles predominantly accumulate in the liver after i.v. administration, we chose human hepatocellular carcinoma HuH7 cell line as a model for assessment of nanoparticle induced liver toxicity. Cytotoxicity was assessed by WST-1 assay. Immunoblotting was utilized to identify the signalling pathways affected by nanoparticle treatment.

Results. We found that all types of nanoparticles induced cell death in time and concentration dependent manner. Indeed, different types of nanoparticles induced distinct cell death pathways. NP1 displayed higher amount of necroptosis marker RIP3 in comparison to untreated cells and cells treated with the other nanoparticles. NP2 as well as NP3 nanoparticles induced apoptosis via caspase 3 activation. NP3 but not the other tested nanoparticles also activated conversion of LC3I to LC3II increasing Caspase 3 cleavage and suggesting lysosomal leakage. Surprisingly, NP4 nanoparticles did not show marked cell death mechanism at 6 hours.

Discussion. These data suggest that molecular mechanisms of cell death strongly depend on the nanoparticle type. Our research provides fundamental knowledge which can be effectively used in developing safe and efficient novel nanoparticle-based therapies.

	NP1	**NP2**	**NP3**	**NP4**
Composition:	Fe3O4-Au	Fe3O4	Fe3O4	Fe3O4
Size:	20-23 nm	8-10 nm	30 nm	clusters
Shape	circular	circular	rectangular	rectangular
Covering	modified lipid + PEG	without cover	Nitrodophamin-PEG	Nitrodophamin-PEG

Table 1. Types of nanoparticles

MAGNETIC PROPERTIES OF FERRITE-GARNET MAGNETOOPTICAL THIN FILMS GROWN BY LIQUID-PHASE EPITAXY

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These investigations are applied for using of $(R, Bi)_3(Fe, M)_5O_{12}$ thin films in development of method of magneto-optical eddy current introscopy, where they are used as eddy current magnetic field sensors. The problem is to select the optimal sensor, i.e. to choose the range of a number of magnetic parameters of film to make the visualization of defects be less energy-intensive, more contrastive and more sensitive and high resolving. Magneto-optical eddy current defectoscopy is an unconventional, but effective method of nondestructive testing of metal objects. A great advantage of the method is the possibility of obtaining visual images of defects in testing objects [1-2]. Meanwhile, in most known experiments, sufficient attention was not paid to the analysis of the properties of the garnet film.

This work is devoted to investigation of magnetic properties of magneto-optical ferrite-garnet films. Single-crystal epitaxial films based on substituted bismuth ferrite-garnet with the general formula $(R, Bi)_3(Fe, M)_5O_{12}$ with the type of magnetic crystallographic anisotropy "easy axis". Crystallographic orientation of all samples was (111). These films were grown by liquid-phase epitaxy method on gadolinium-gallium garnet substrates. The series consists of nine films of thickness varied in the range from 1.9 to 7.2 μm.

Previously, we measured some parameters that allowed us to select samples with different values: the anisotropy field from 500 to 3000 Oe, the period of the domain structure from 5.5 to 32 μm, and the saturation field from 22 to 77 Oe.

Magnetic properties of thin films were investigated with vibrating sample magnetometry by Lake Shore. Hysteresis loops were obtained at different angles between magnetic field and normal vector of film from out-of-plane geometry to in-plane in increments of 10 degrees. Then there were obtained angle dependences of saturation field and coercivity.

These studies helped to obtain saturation magnetization values, which were used to calculate the uniaxial anisotropy constant. After the experiments on the magneto-optical defectoscope of the eddy current and the processing of a series of MO images, the correlation was made with all the obtained magneto-optical parameters.

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[1] Z. Zeng, X. Liu, A Y. Deng, L. Udpa, L. Xuan, W. Shih, G. Fitzpatrick, *IEEE transactions on magnetics* **42/11**, 113737-3744 (2006).

[2] V. Uchanin, *Technical Diagnostics and ND testing* **2**, 3-12 (2006).

X-RAY OPTICAL PROPERTIES OF BULK AND HIGHLY POROUS BERYLLIUM

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X-ray refractive lenses are widely used as beam transport and beam conditioning optics at the new generation synchrotron radiation sources [1-3]. In order to extend their use for microscopy applications the significant improvements of the optical properties in terms of shape quality and bulk homogeneity are needed. It turned out that beryllium, as a low-Z element, is the most suitable for lens manufacturing. However, beryllium being a sintered material has an internal grain structure with a relatively high content of the beryllium oxide, which create a strong small- and ultra-small angular scattering [4].

Recently we successfully reported about new special device called a ‘speckle suppressor’ for X-ray applications, which contains a highly porous beryllium [5]. Highly porous beryllium is new and promising material for X-ray optical applications. Due to its low density and high porosity this material allows manipulation of the spatial coherence length, thus changing the effective source size and removing the undesirable speckle structure in X-ray imaging experiments almost without beam attenuation. The absorption of the highly porous plate is below 1% for 1 mm thickness at 12 keV.

In this work we present experimental results of study X-ray optical properties of different beryllium types and grades. We are confident that these new beryllium materials are very promising for X-ray imaging techniques and will also allow to use the full potential of novel X-ray sources.

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[1] A. Snigirev, V. Kohn, I. Snigireva, B. Lengeler., *Nature* **384**, 49-51 (1996).
[2] A. Snigirev, V. Kohn, I. Snigireva and etc., *Appl. Opt.* **37**, 653-662 (1998).
[3] A. Snigirev, I. Snigireva, Springer Series in Optical Sciences **137**, 255 285 (2008).
[4] I.I. Lyatun, A.Yu. Goikhman, P.A. Ershov, I.I. Snigireva, A.A. Snigirev, *Journal of Surface Investigation. X-ray, Synchrotron and Neutron Techniques* **9** (3), 446–450 (2015).
[5] A. Goikhman, I. Lyatun, P. Ershov, I. Snigireva, P. Wojda, V. Gorlevsky A. Snigirev et. al., *Journal of Synchrotron Radiation* **22**, 796–800 (2015).

NEW MULTIFUNCTIONAL MATERIALS CONSISTING OF POLYMER, FERROMAGNETIC AND FERROELECTRIC PARTICLES

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The multiferroic materials are multifunctional materials which combine elastic, magnetic and electric properties. The layered multiferroics are one of the most investigated materials; the magnetoelectric effect in such materials is the result of combination of magnetostriction and piezoelectric effect. In magnetorheological elastomers the so-called magnetostriction effect was also found. In contrast to magnetostriction in metals, the magnetic deformation in elastomers is several orders of magnitude larger and can exceed 100 percent. Therefore, a new multiferroics material on the basis of magnetorheological elastomer can be created. In this work a new three phase material, possessing not only magnetodeformational properties, but also electric ones, was obtained by adding ferroelectric PZT particles into the magnetic elastomer with NdFeB particles. Properties of this material were investigated.

Firstly, properties of each component of three-phase material were investigated with Differential Scanning Calorimeter NETZSCH 204 F1 Phoenix. The phase transition temperatures (Curie temperatures Tc) were found for the bulk and powder materials. Curie temperature did not depend on the size of the NdFeB particles in micro range. Curie temperature of PZT-19 powder depended on the size of the particles and decreased from 321.1 C for 5 μm particles to 309.4 C for bulk crystal. The mixture of NdFeB and PZT-19 powder revealed the displacements of the Curie temperatures of each component, namely, Tc of NdFeB increased by 10 C, Tc of PZT-19 decreased by 6 C. At the other side Tc of barium ferrite (BF) and PZT particles were not changed for the mixture in reference to T_cs of separate powders. Probably, this fact indicates the interaction between ferroelectric PZT particles and ferromagnetic conducting NdFeB particles. This interaction should be taken into account in the modeling.

The polymer material SIEL which was used as a matrix was also investigated in DSC and revealed the glass transition temperature at the -36 C. This glass transition also influences magnetic properties of elastomer based on SIEL polymer. Magnetic moment of elastomer with NdFeB particles significantly increased when the temperature passed the transition temperature.

The three-phase composite materials consisted of polymer matrix and ferromagnetic and ferroelectric filling particles, demonstrated magnetoelectric effect. Magnetic parameters of elastomer in the crossed electric and magnetic fields differed from those without electric field. So the external electric field can affect the forces of magnetic particles interaction or interaction of particle with magnetic field, and can also affect the elastic force acting on a particle in matrix by shifting the ferroelectric particles and thus creating additional stresses in elastic matrix. This assumption was confirmed by modeling in the software Comsol Multiphysics 3.5a. The model takes into account the following points: 1) the dipole interaction between ferromagnetic particles, 2) the dipole interaction between ferroelectric particles, 3) the elastic interaction between particles and matrix, 4) the interaction between ferroelectric and conducting ferromagnetic particles. The interaction forces between ferromagnetic particles have been studied in different conditions.

IMPACT OF VANADIUM SUBSTITUTION ON STRUCTURAL, MAGNETIC AND MAGNETOCALORIC PROPERTIES OF $La_{0.7}Sr_{0.2}(Ca\ Li)_{0.05}Mn_{1-x}V_xO_3$ [$x = 0$ and $x = 0.05$] MANGANITE

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The $La_{0.7}Sr_{0.2}(Ca\ Li)_{0.05}Mn_{1-x}V_xO_3$ [S_1*(x = 0) and* S_2*(x = 0.05)*] polycrystalline compounds ,prepared by solid state reaction method, are found to exhibit a Ferromagnetic - Paramagnetic transition (FM-PM) when temperature increases with a decrease of Curie temperature T_C when substituting Mn with V from T_C = 271 K to T_C = 266 K. The arrot plots near Curie temperature show positive slopes under an applied magnetic field varying from 0 to 5 T indicating the second order transitions for our samples. Basing on the magnetic-field dependences of magnetization measured around T_C, maximum magnetic-entropy changes $\left|\Delta S_M^{\max}\right|$, under the applied field of 5 T, are about 211.46 J kg^{-1} and 195.46 J kg^{-1} for S_1 and S_2 respectively. The study of the universal curves show that the rescaled magnetic entropy change curves for different applied fields collapse onto a same curve confirming the second order transition for S_1 and S_2.

THE NEW X-RAY INTERFERENCE TECHNIQUE FOR THE THIN FILMS STUDYING

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X-ray reflectometry (XRR) is one of the classical techniques for thin-films and multilayer systems studying. XRR has a number of serious limitations despite the long-standing developing of the method: low lateral resolution and time resolution, high sensitivity (requirements) to sample surface quality (roughness), relatively large sample surface area and etc [1]. The appearance of new optics for X-ray synchrotron and laboratory sources increased opportunities for the development of X-ray investigation techniques, including reflectometry. In this work, we demonstrate a new X-ray reflecto-interferometry method based on compound refractive optics (CRL) for thin-films structures studying.

Today, X-ray refractive optics is the most dynamically developing kind of X-ray optical elements [2-3]. Compound refractive lenses quickly gained popularity among synchrotron sources users due to their ease of operation and the possibility of application in a wide range of energies [4-5].

The possibilities of the new X-ray reflecto-interferometry technique based on CRL were demonstrated at the ID06 beamline, at the European Synchrotron Radiation Facility (Grenoble, France). A series of interference patterns for test thin-film membranes with different thicknesses from 200 nm to 1000 nm thick was experimentally obtained.

The new reflecto-interferometry technique opens a wide horizons for both rapid thin-film and multilayer systems analysis, studying of the processes dynamics at the surface and in sample depth, and for complex structured and biological samples studying.

The work is supported by Ministry of Education and Science of the Russian Federation (contract № 14.Y26.31.0002 and 5-100 Project).

[1] M. Yasaka, *The Rigaku Journal* **26**(2), 1-9 (2010).
[2] A.Snigirev, V. Kohn, I. Snigireva and B. Lengeler, *Nature* **384**, 49-51 (1996).
[3] A.Snigirev, I. Snigireva, *Springer Series in Optical Sciences* **137**, 255-285 (2008).
[4] A.Snigirev, V. Kohn, I. Snigireva, and etc., *Appl. Opt.* **37**, 653-662 (1998).
[5] Bosak, I. Snigireva, K. S. Napolskii, A. Snigirev, *Adv.Mater.* **22**, 3256–3259 (2010).

STROMAL STEM CELLS MANIPULATION IN VITRO BY COMPOSITE MATERIAL WITH INTRINSIC ELECTRIC CHARGE

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Natural microenvironment of stem cells might be reproduced *ex vivo* with the help of its 3-dimensional (3D) reconstruction with the help of artificial bioinspired matrices. Multipotent mesenchymal stem cells (MMSCs) and osteoblasts are known to respond to artificial surface charge [1] by means of cellular ion channels and zeta potential [2]. Titanium and calcium phosphate (CP) materials have own electrical charge [3]. This work focuses on the CP coating *in vitro* effect on MMSCs culture behavior related with CP electrostatic potential (EP).

Micro-arc CP bilateral coating on commercially pure titanium plates ($10 \times 10 \times 1$ mm^3) has been obtained as described previously [4]. The method of the lifting electrode (the Eguchi method) was used to measure the EP on CP surface at the macroscale [5]. CP surface electric charge at the nanoscale was estimated according to [6]. Human adipose–derived MMSCs (hAMMSCs) were incubated in the culture medium without osteogenic supplements. Cell behavior and fate were detected on plastics with or without CP specimens.

Results showed an absence of CP toxic effect on the hAMMSCs viability and motility (7-day culture). Vice versa, bland stimulation of 11 genes expression and osteocalcin secretion (crucial protein of osteoblasts) in 14-day culturing and sharp osteoblasts and chondroblasts formation in 21-day culturing were determined around the CP samples. Indirect influence of dielectric CP surface could be caused by calcium and phosphate ions output and/or their intrinsic negative charge. Macroscale EP magnitude was 40-120 mV. Unequal distribution of nanoscale CP with physiological magnitude ±80 mV was revealed on CP surface topography. As result, weak electromagnetic field in 3D culture with moving charged ions and cells could not be excluded. It has to be well recognized in conditions of bioinspired multiphase and composite materials [7], "lab-on-a-chip" [8], and "cells-on-a-chip" [9] design for stem cells application.

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[1] E. Thian et al., *Acta Biomater* **6**, 750 (2010).
[2] G. Li, X. Deng, *World J Stem Cells* **3**, 19 (2011).
[3] D. Aronov et al., *Appl Phys Lett* **88**, 163902 (2006).
[4] Yu. Sharkeev et al., *COMPOS INTERFACE* **16**, 535 (2009).
[5] E. Gostischev, *Russian Federation Patent* 2223511, (2004).
[6] Yu. Dekhtyar et al., *IFMBE Proceedings* **38**, 182 (2013).
[7] I. Khlusov et al., *IFMBE Proceedings* **38**, 99 (2013).
[8] R. Khamsi, *Nature* **435**, 12 (2005).
[9] J. El-Ali et al., *Nature* **442**, 403 (2006).

THE RESEARCH OF VISCOELASTIC PROPERTIES OF MAGNETIZABLE ELASTOMERS

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Viscoelastic properties of the magnetizable elastomers (ME), which are composite materials consisting of elastomer and ferromagnetic particles, and the influence of a magnetic field on these properties practically had not been studied. In work [1] the method for determining the shear properties of viscoelastic materials in the absence of the field is considered theoretically. In this work the method for experimental determining the viscoelastic properties of ME in a uniform magnetic field is proposed.

In the experiment a cylindrical sample of ME is suspended along the axis of the Helmholtz coils (Figure 1). The free lower end of the body is attached to the center of the rod (with the moment of inertia J) which is twisted at the initial angle φ_0. Further, the video recording of the damped oscillations of the rod is made with the subsequent storyboard and plotting of the dependence $\varphi(t)$. An example of this dependence is shown in Figure 2.

A mathematical model, which is a generalization of the Kelvin-Voigt model, is built. This model takes into account some internal dry friction in ME caused by the magnetic interaction of the ferromagnetic particles in the field. From the comparison of theory and experiment, the coefficients of elasticity and viscosity are found in this model. It is shown these coefficients depend on the magnetic field.

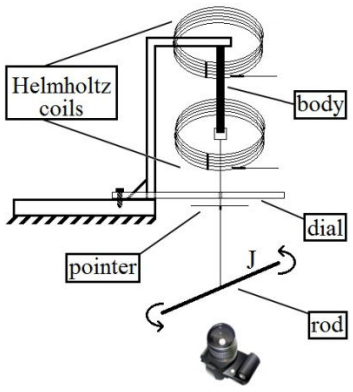

Figure 1. Experimental setup

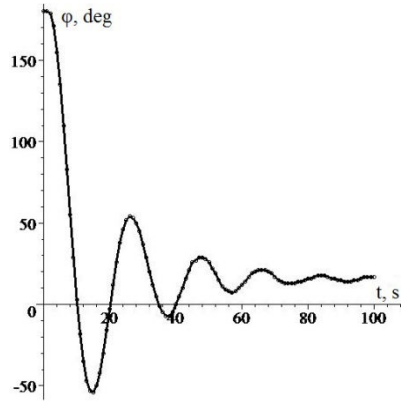

Figure 2. Dependence of φ on t

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[1] E.D. Martynova, A.V. Muravlev, *In the collection: Lomonosov readings – 2016, the series of Section "Mechanics", Moscow: Moscow University press* (in Russian), 122-123 (2016).

SPIN EXCITATIONS IN COMPLEX MAGNETIC $Ni_3(BO_3)_2$

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Nickel orthoborate $Ni_3(BO_3)_2$ has a complex orthorhombic structure (sp. gr. *Pnnm* (# 58)) of kotoite mineral. The Ni^{2+} ions occupying two different octahedral crystallographic positions, *2a* and *4f*, form two magnetic subsystems which order antiferromagnetically at the temperature T_N = 46 K [1]. In our recent study of the lattice dynamics of $Ni_3(BO_3)_2$ [2], we showed that, at T_N, also a structural phase transition takes place, associated with a doubling of the crystal cell and a corresponding "folding" of the Brillouin zone.

The present work devoted to investigation of magnetic structure and magnetic features of nickel orthoborate by optical spectroscopy methods. Several excitations have been observed below T_N at the terahertz range of transmission spectra in a zero magnetic field. The frequency range and the temperature behavior of the detected modes allowed us to assume that they relate to magnetic excitations. The field dependence of the frequencies of these excitations has a distinct nonlinear character (see Figure 1). This may indicate to an interaction of the magnetic modes with each other (spin-spin interaction). In addition, the behavior of magnetic modes indicating "spin-flop" phase transition has been observed in strong magnetic fields (> 10 T).

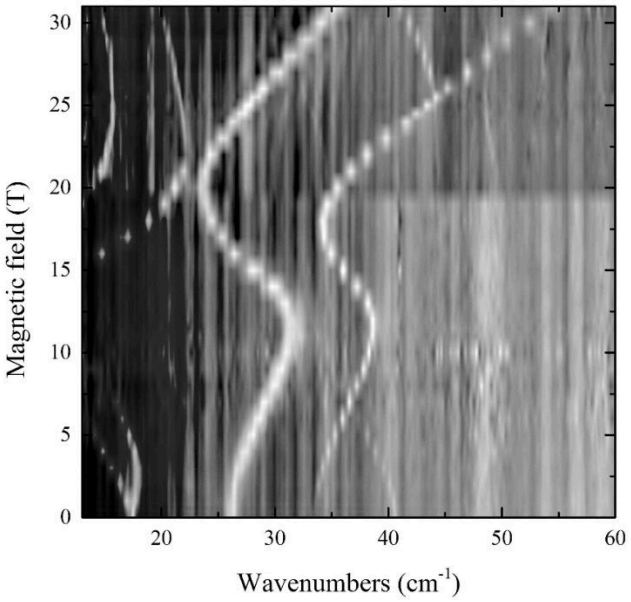

Figure 1. The field dependence of the THz transmission spectrum of the $Ni_3(BO_3)_2$ single crystal at temperature T = 1.5 K.

This work was supported by the Russian Foundation for Basic Research (Grant No 15-02-07451a.) and the President of the Russian Federation (Grant MK-3577.2017.2).

[1] L.N. Bezmaternykh et al., *Phys. Stat. Solidi B.* **249**, 1628 (2012).
[2] R.V. Pisarev et al., *Phys. Rev. B.* **93**, 134306 (2016).

MAGNETIC METALLOPOLYMER NANOCOMPOSITE MATERIALS BASED ON UNSATURATED COBALT (II), NICKEL (II) AND IRON (II,III) DICARBOXYLATES: SYNTHESIS AND INVESTIGATION

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In this work the actual problem of simultaneous synthesis and stabilization of the obtained magnetic nanocomposites of cobalt, nickel, and iron by distribution of nanoparticles (NPs) in a polymer matrix and the formation of a protective polymeric shell of «core-shell» structure is solved by the method of controlled thermolysis of unsaturated carboxylates of this metalls. Cobalt, nickel and iron carboxylates of a number of unsaturated dicarbonic acids were synthesized: maleic, itaconic, citraconic, acetylenedicarboxylic, allylmalonic, glutaconic and cis, cis-muconic ones. As follows from the synthesis the acidic cobalt (II) and nickel (II) carboxylates (ACC and ACN), mixture of acidic and/or medium iron (II, III) carboxylates (AIC and MIC) were obtained. The controlled thermolysis of synthesized cobalt, nickel and iron carboxylates was carried out. Synthesized magntic metallopolymeric nanocomposites, obtained by thermal decomposition of carboxylates under an argon atmosphere, are powders consisting of two structural elements: in organic polymer matrix the spherical NP Co_3O_4/CoO, NiO/ß-Ni or γ-Fe_2O_3 in a polymeric shell of «core-shell» structure are embedded, in accordance with the data of XRD and Mössbauer spectroscopy (for iron). It was established that by thermolysis of acid itaconate nickel the carbon nanotubes are formed. The enthalpies (ΔH_r^0) of formation reaction of ACC, ACN, AIC and MIC were calculated. The average NPs diameter (d_{avg}) of obtained cobalt, nickel and iron nanocomposites are within the range of 4-9 nm. Relation between d_{avg} and H^o_r of reaction of ACC and ACN formation is established. The microstructure and magnetic characteristics of the synthesized nanocomposites were determined. The highest coercive force is observed for the nanocomposites obtained by the thermolysis of acidic cobalt maleate (756 Oe), acidic nickel allylmalonate (131 Oe) and mixture of acidic iron itaconate (119 Oe). The highest maximum magnetization was found for the nanocomposites whose precursors were cobalt (15.1 emu/g) and nickel (23.0 emu/g) glutaconate and iron citraconate (37.8 emu/g). In the case of nickel composites, a direct proportional dependence of the growth of the saturation magnetization from the increase of the percent content of the ferromagnetic phase with decreasing superparamagnetic one is observed. The critical value of the NP diameter for cobalt, which is associated with the transition from multidomain to single-domain particles, is found to be 3.8 nm. Possible applications of the obtained magnetic nanocomposite materials of cobalt, nickel and iron are as gas and magnetic sensors, catalysts, magnetic carriers of high density information, as well as the use of magnetic iron nanocomposites in medicine and diagnostics. At present, research is being conducted on the use of synthesized nanocomposites in some of the areas represented.

This work was supported by the Russian Foundation for Basic Research, projects 13-03-00342, 16-03-00148.

STRUCTURE, MAGNETIC PROPERTIES AND R2-RELAXIVITY OF MAGNETITE-GOLD NANODUMBBELLS

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At the present time dumbbell-like magnetite-gold nanoparticles (NPs) are of great interest for biomedical application due to their physical-chemical properties. The feature of magnetite-gold nanodumbbells is the presence of two types of surfaces, which allows their double functionalization, for example, covering magnetite NPs with a biocompatible polymer shell and introduction of vector molecules on the surface of gold NPs, and usage for magnetic resonance imaging (MRI) as tumor-selective contrast agents.

It has been established in literature that the growth of magnetite-gold nanodumbbells proceeds through the mechanism of heterogeneous nucleation of magnetite NPs on gold NPs [1], which occurs during the thermal decomposition of iron pentacarbonyl in high-boiling solvents. The properties of the obtained NPs can be controlled by adjusting of synthetic parameters.

In this work we obtained magnetite-gold nanodumbbells with the size: 1) 9±2 / 4±1 nm, 2) 12±3 / 4±1 nm, 3) 25±3 / 9±2 nm (magnetite / gold), according to the transmission electron microscopy data. In all samples two phases were detected by X-ray analysis: monocrystalline magnetite and gold. The saturation magnetization, normalized to the weight of magnetite, and the coercive force, measured in magnetic field 30 kOe, enhanced with increase of the magnetite NPs size and were equal to 46, 62, 86 emu/g and 6, 13, 60 Oe for samples 1, 2 and 3, respectively.

All samples were covered with a biocompatible polymer coating (the derivative of polyethylene glycol and phospholipid) transferring them to the aqueous phase before the MRI-relaxivity measurement. The values of the R2-relaxivity 202, 167, and 385 $mmol^{-1} \cdot s^{-1}$ were obtained for samples 1, 2 and 3, respectively.

Therefore, non-monotonous dependence of the R2-relaxivity on the saturation magnetization (and the size) of NPs was found. This can be related to the possible contribution of gold to the magnetic properties of the sample, which is more significant for the larger gold-to-magnetite mass ratio in case of sample 1. The observed trend undoubtedly requires further study because of the existing literature data on the origin of magnetic properties in gold NPs in contact with magnetite [2].

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[1] C. Wang, C. Xu, H. Zeng, S. Sun, *Adv. Mater*. **21**, 3045–3052 (2009).
[2] F. Pineider, C. Fernández, V. Videtta, et al., *ACS Nano.* **7(1)**, 857-866 (2013).

RADIOGRAPHY AND TOMOGRAPHY BASED ON MICROFOCUS SOURCE FOR X-RAY REFRACTIVE LENSES DIAGNOSTICS

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One of the most advanced optical components for focusing of X-ray beams at the synchrotrons worldwide is compound refractive lens (CRL) with parabolic profile. Main applications of CRLs are micro- and nano-focusing [1] and X-ray microscopy [2]. Fabrication technique, as well as the quality of the materials significantly affect the CRL imaging properties. In order to improve a technology of X-ray optics fabrication it is urgent to develop an effective approach of precise nondestructive CRL diagnostics.

At this work, we report the assessment of the efficiency of non-destructive inspection techniques: x-ray radiography and x-ray tomography. This technique allows to realize non-destructive testing irregularities, the presence of voids, inclusions in lenses material and at the same time to analyze the shape and geometric parameters: the coaxiality, the distance between the refracting surfaces and shape of refractive surfaces.

X-ray radiography and X-ray tomography was performed using the X-ray inspection system YXLON designed for generating high-quality X-ray images with the 1 μm resolution. We present the CT imaging results of lenses made of high-purity aluminum with the parabola apex radii of 50 μm.

Comparing the obtained images with specified requirements of the geometrical characteristics of the lenses, the quality of the refractive surface and internal size of defects allows us to estimate the lens manufacturing quality.

[1] Snigireva I., Vaughan G.B.M., Snigirev A., *AIP Conf. Proc.* **1365**, 188 (2011)
[2] A. Snigirev, I. Snigireva, G. Vaughan, J. Wright, M. Rossat, A. Bytchkov, C. Curfs, *J. Phys.: Conf. Ser. 186 012073*, 1 (2009).

THE DYNAMIC MAGNETIC RESPONSE OF THE FERROFLUID TO AC AND DC MAGNETIC FIELDS PERPENDICULAR TO EACH OTHER

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The dynamic magnetic response of ferrofluids to a weak linearly polarized AC field is studied in an external static magnetic field. In this investigation interparticle interaction is taken into account.

The ferrofluids are modeled by the system of uniformly magnetized hard spherical particles, suspended in a long cylindrical tube, whose long axis coincides with Oz-axis of the coordinate system. The alternating magnetic field is perpendicular to the Oz-axis, whereas the static uniform magnetic field is applied along Oz-axis: $\mathbf{H} = \left(0, \alpha_a e^{i\omega t}, \alpha_s\right)$ (t – denote time; α_a and α_S are Langevin parameters described the intensity of the dipole-field interactions in the static and alternating magnetic fields correspondently; ω is the oscillating frequency). The probability density of the orientation of the magnetic moment of a randomly chosen particle $W(t,\theta,\varphi)$ is the solution of the Fokker-Planck equation in which the action of a uniform static field is taken into account.

$$2\tau \frac{\partial W}{\partial t} = \nabla^2 W + \nabla \cdot (W \nabla U_e)$$

where τ is the Debye relaxation time. In Ref. [1] it was shown that the effective interaction U_e between a single particle and the effective AC magnetic field at the first level over concentration n is

$$U_e = U_h + n\langle W(t,\theta_1,\varphi_1)\bar{W}(t,\theta_2,\varphi_2)U_{dd}(1,2)\rangle_2,$$

$$U_{dd}(i,j) = \frac{1}{kT}\left[\frac{3(\mathbf{m}_i,\mathbf{r}_{ij})(\mathbf{m}_j,\mathbf{r}_{ij})}{r_{ij}^5} - \frac{(\mathbf{m}_i,\mathbf{m}_j)}{r_{ij}^3}\right]$$

The first term $U_h = -(\boldsymbol{\mu}_1,\mathbf{H})/kT$ describes the interaction of the randomly chosen first particle with AC and DC fields and has the form of Zeeman energy related to the thermal energy kT. The second term in Ue is take into account interparticle correlations and it is weight-averaged dipole-dipole interaction ($Udd(12)$) between particles 1 and 2 over all possible orientations and positions of the randomly chosen particle 2. It is assumed that the relaxation of the magnetic moment of the particles occurs according to the Brownian mechanism. The solution of the Fokker-Planck equation is expressed as a series in terms of the spherical functions. An analytical solution of the Fokker-Planck equation is used to determine the dynamic susceptibility. The behavior of the real and imaginary parts of the dynamic susceptibility as a function of the intensity of the external magnetic field is analyzed: increase of intensity of the alternating magnetic field in the system leads to decrease of real part of the dynamic susceptibility and shift of imaginary part of the dynamic susceptibility. From these facts follows that this system becomes more stable.

The comparison of theoretical and simulation results of dynamic susceptibility shows good agreement.

[1] A.O. Ivanov, *Soft Matter* **15**, 3507 (2016).

EFFECT OF IRON OLEATE COMPLEX STRUCTURE ON THE SHAPE OF IRON OXIDE NANOPARTICLES

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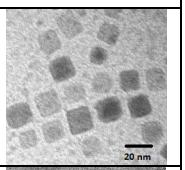
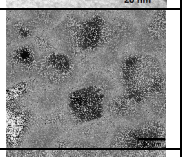
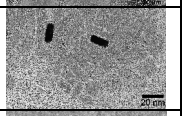
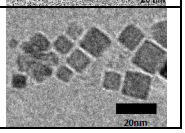
Magnetic nanoparticles (MNPs) play an important role in various branches of biomedicine, such as targeted drug delivery, MRI and magnetic hyperthermia. MNPs shape and size determine their physical and chemical properties (relaxivity, magnetization and hyperthermic properties). It means that the shape control is important in case of MNPs synthesis.

In this research the shape of MNPs was controlled by using different types of ferric oleate complexes (FOC). The complexes were synthesized in ethanol/water or methanolic media by mixing $FeCl_3$ with sodium oleate. Then the cubic and octahedron MNPs were obtained from ethanolic FOC according to protocol [1]. When the ethanolic FOC was substituted by methanolic, the nanoplates formation was detected instead of nanocubes and the nanocubes instead of octahedron MNPs. The effect probably caused by structural differences between FOC from methanolic and ethanolic media [2, 3]. The MNPs were characterized via various methods:

Solvent	Shape	Size (nm)	Magnetization Hc, кA/m (Oe)	MRI T_2-relaxivity, $mM^{-1} \cdot s^{-1}$	SAR (W/g)	TEM
Ethanol Water	Cubes	18	6,34 (79,7)	262,0	1,42	
	Octahedrons	19	2,65 (33,3)	236,5	3,23	
Methanol	Plates	20*5	4,1(517)	1,3	2.39	
	Cubes	18	-	-	2.31	

The nature of medium where iron oleate complex was synthesized had a great influence on the shape of MNPs that, in turn, determines their structural and magnetic properties.

[1] Z. Zhou et al., *Chem. Mater.* **27** (9), 3505–3515 (2015).
[2] L. Bronstein and etc., *Chem. Mater.* **19**, 3624 (2007).
[3] X. Ding and etc., *RSC adv.* **4**, 9314-9320 (2014).

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THEORETICAL STUDY OF HYDROGEN-TERMINATED FINITE GERMANIUM NANOWIRES OF VARIOUS SIZES

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Germanium is a potentially attractive alternate of silicon for nanoscale electronic applications due to its higher electron, hole mobility and larger exciton Bohr radius. Based on the magnetic, electrical, and electrochemical properties, GeNWs have numerous potential applications such as spintronics, solar cells with enhanced efficiency, Li-ion batteries, photodetectors in the visible range, flexible chemical sensors. Taking into account for theoretical design of more complex systems, involving several nanoscale components for well-specified operations, using all-electron *ab initio* or density functional theory (DFT) calculations has a prohibitively high computational cost [1]. Compared to silicon this problem is more acute for germanium because of the larger number of electrons, which make GeNWs calculations much more computationally demanding for DFT calculations, even with minimal basis sets. We have put considerable effort to overcome this difficulty, by implementation of suitable effective core potentials and application of appropriate semiempirical model chemistry, with no (significant) compromise on accuracy and quality of results. To this end, we have evaluated the performance of several semiempirical methods, before our final choice of adopting a "mixed" scheme of DFT and semiempirical calculations. Some results have been shown below for hydrogen passivated GeNWs of various morphologies and sizes.

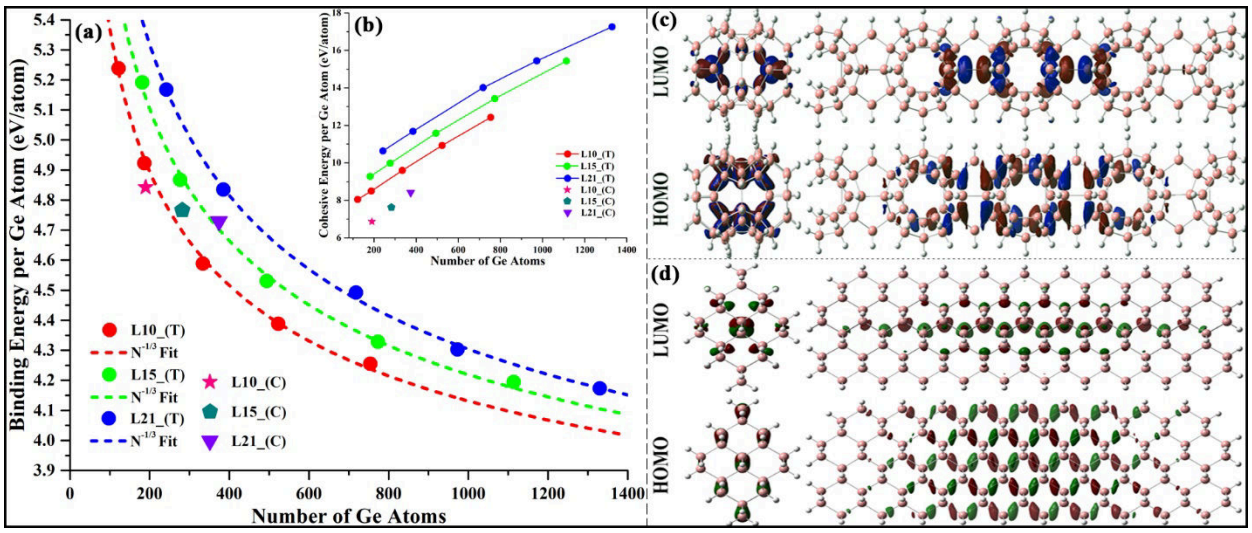

Figure 1: (a) Representation of binding energy (b) and cohesive energy per germanium atom with respect to the increasing number of germanium atoms for all three different lengths of H-GeNWs. Red, green and blue dots represent tetrahedral 'T' whereas pink, cyan and violet dots represent clathrate 'C' type nanowires. The doted lines show $N^{-1/3}$ linear dependence of QC fitting to our DFT results (c-d) graphical representation of frontier molecular orbitals (FMOs) for hydrogen passivated clathrate and tetrahedral type germanium nanowire at isovalue = 0.015.

[1] Shanawer Niaz *et al*., *Sensors & Transducers* **189**, 162 (2015).
[2] Shanawer Niaz and Aristides D. Zdetsis, *J. Phys. Chem. C* **120**, 11288 (2016).

ONE-POT METHOD FOR PRODUCING MAGNETIC NANOCRYSTAL CLUSTERS

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The development of nanoparticle-based systems for diagnostic and therapeutic purposes is one of the emerged areas in modern biomedicine. From the number of different nanomaterials, magnetic nanoparticles in particular magnetite nanoparticles (MNPs) are certainly the most promising material for biomedical applications, including magnetic-resonance imaging (MRI), hyperthermia, cell-labeling and others [1]. Shape- and size-controlled synthesis of nanoparticles has become a recent focus, because different shapes of particles can introduce novel magnetic and electric properties, which affect the parameters required for biomedical applications, such as MRI and hyperthermia. MNPs with strongly marked anisotropy represent a special interest for biomedical applications. In particular colloidal clusters with controlled size and shape have been an area of great interest for researchers coming from a wide range of disciplines [2]. The controlled assembly of initial small magnetic nanoparticles into cluster structures with defined shape and size opens horizons for materials which combines properties of individual nanocrystals as well as collective properties due to interactions between the single units.

In this work one-pot method for producing magnetic nanocrystal clusters was used. All samples were obtained by thermal decomposition of iron precursor in high-boiling organic solvents in the presence of different organic acids (cyclopropanecarboxylic acid, cyclobutanecarboxylic acid, cyclopentanecarboxylic acid, cyclohexanecarboxylic acid, benzoic acid, 4-formilbenzoic acid, 3-clorbenzoic acid, 1-indanecarboxylic acid, biphenyl-4-carboxylic acid and 4,4'-biphenyldicarboxylic acid). The results show that the organic acids can directly affect the final shape and size of nanoclusters through specific absorbance onto surface of magnetite nanocrystals. Thus, nanoclusters with spherical, cubic and flower-like shape were obtained. To confirm structure of obtained nanoclusters physicochemical investigations such as transmission electron microscopy, X-ray diffraction analysis, Mössbauer spectroscopy, magnetic measurements, thermogravimetric analysis, magnetic resonance imaging and others were performed. For determination of T_2-relaxivity values as well as *in vitro* and *in vivo* testing nanoclusters were modified by polyethylene glycol derivative. All obtained magnetite nanoclusters have very high magnetic saturation and T_2-relaxivity values. Moreover they can be promising nanomaterials for MRI and hyperthermia.

This work has been financially supported by Ministry of Education and Science of the Russian Federation (14.607.21.0132, RFMEFI60715X0132).

[1] L.H. Reddy et.al. *Chem. Rev.* **112**, 5818 – 5878 (2012).
[2] A. Kostopoulou, *Nanotechnol. Rev*. **4(6)**, 595–624 (2015).

MAGNETOCALORIC EFFECT IN GdTX (T = Sc, Ti, Mn, Fe, Co, X = Si, Ge) COMPOUNDS

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The direct measurements of the magnetocaloric effect (MCE) and the magnetic entropy change calculations have been carried out for CeFeSi-type (*P4/nmm*) $GdMn_{1-x}T_xSi$ (T = Ti, Fe, Co) compounds and for CeScSi-type (*I4/mmm*) $GdSc_{1-x}Ti_xGe$ compounds. The compounds possess high magnetic moments and order ferro- or ferrimagnetically in the wide temperature interval from 120 K to 390 K.

The RMnSi compounds are the natural layered magnetics with two sublattices: rare earth (R) and Mn. Gd has a localized magnetic moment while the value of the magnetic moment of the 3d sublattice depends on the overlap of Mn 3d band with 4p Si band [1,2]. An appreciable correlation of magnetic ordering temperatures with d electrons concentration has been observed and it has been proved that the decrease of d electrons concentration leads to increase in density of states on Fermi level and hence to the increase of magnetic ordering temperatures [3]. The Curie temperature T_C decreases monotonously with 3d electron concentration for $GdTi_{1-x}Mn_xSi$, $GdMn_{1-x}Fe_xSi$ and $GdMn_{1-x}Co_xSi$ series.

The maximum value of MCE (1.09 K at 12kOe) has been observed for ferromagnetic GdFeSi compound in which the overlap of the Fe and Si layers leads to a filling of 3d band. The increase in Mn content leads to the appearance of the magnetic moment in 3d sublattice, the establishment of the ferrimagnetic ordering and decreases the value of MCE effect. The change in interatomic Mn-Mn distances in compounds with high Mn concentration leads to decrease in R-Mn interactions. Thus, two peaks have been observed on the temperature dependence of MCE in GdMnSi compound due to the separated order-disorder transitions in Gd and Mn sublattices. The Ti substitution decreases the partial filling of 3d band of Mn with Si electrons and the magnetic moment of 3d-sublattice the values of T_C and MCE increases.

In $GdSc_{1-x}Ti_xGe$ compounds the spin polarization of Sc or Ti d band electrons, strongly hybridized with spin polarized 5d band electrons of Gd enables a high long range interaction between 4f moments. Thus, these compounds possess the highest magnetic ordering temperatures. T_C and MCE values increase almost linear with Ti concentration.

Analysis of the magnetocaloric properties of the series of isostructural compounds investigated in this work shows that both Curie temperatures and MCE strongly depend on 3d electrons concentration injected into the crystal lattice by substitution of Mn by Fe, Co, Ti or Sc by Ti which have a different number of 3d electrons.

The work has been supported by RFBR grant N 16-02-00472 A.

[1] I. Ijjaali, R. Welter, G. Venturini, B. Malaman, E. Ressouche., *J. Alloys Compds* 270, 63 (1998).
[2] S.A. Nikitin, T. I. Ivanova, Yu. A. Ovchenkova, M. V. Maslennikova, G.S. Burkhanov, O.D. Chistyakov., *Physics of the Solid State,* 44 (2), 308–311 (2002).
[3] S.A. Nikitin, I.A. Tskhadadze, A.V. Morozkin, Yu.D. Seropegin., *Journal of Magnetism and Magnetic Materials* **196 – 197**, 632 – 633 (1999).

EFFECT OF THE NANOPARTILCLE SHAPE ON THE CANCER TREATMENT IN VITRO AND IN VIVO: THE CASE OF PLURONIC F127 STABILIZED AND DOXORUBICIN LOADED MAGNETITE NANOCUBES AND NANOSPHERES

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Magnetic nanoparticles (MNP) are extensively prepared for the potential use in various fields of nanomedicine such as MRI and drug delivery. Among those fields the ones of the most promising objects are magneto-niosomes – MNP, stabilized by non-ionic surfactants. They are examples of theranostic agents combining therapy (drug delivery) and diagnostics (MRI contrast agents) in one agent. The other poorly studied aspect is effect of MNP shape on toxicity, drug delivery and relaxivity. The following work is dedicated to synthesizing of MNP with different core shapes (spherical and cubic) and its effect on MRI contrast, toxicity toward prostate cancer PC3 and LNCaP cell lines and mice in *in vivo* studies.

MNP were synthesized by thermal decomposition of iron (III) oleate complex in 1-octedecene medium. Shape control was reached by different molar ratio of stabilizers in reaction medium. According to TEM and DLS average size of the obtained MNP is 20±5 nm. The synthesized MNP were transferred into water medium through organosol mixing with non-ionic surfactant (Pluronic F127) solution. DLS data shows that average size of nanoparticles rose up to 90±10 nm due to formation of niosomes with non-ionic surfactant shell. Then the hydrophilized MNP were loaded with doxorubicin (Dox) by addition of its solution into hydrosol and 24 hours stirring. Dox excess was taken away by centrifugation and supernatant removing. Spectrophotometry was used to determine the Dox concentration in supernatant at λ = 495 nm and, consequently, the Dox loading in the nanoparticles (50 μg/ml Dox in the 0,32 mg/ml magnetite colloid solution). The average loading is 13,5% of the Dox in nanoparticles. Dox loaded niosomes cytotoxicity was measured on PC3 and LNCaP cell cultures by MTT assay and compared to cytotoxicity of unloaded nanoparticles and free Dox after 48 hour of incubation. In vivo efficiency was evaluated on mice allogenic by 4T1 model of mice mammary carcinoma cell line. The samples were injected three times with 4 days interval and 2 mg/kg Dox dosage.

The obtained data demonstrate lower cytotoxicity of Dox loaded MNP compared to free Dox at the same total Dox concentrations in cell culture medium. This happens due to slow Dox releasing from Pluronic shell of MNP which are play a role of drug carrier. Also niosomes with nanocubes core (CbD) showed a bit higher cytotoxicity compared analogous nanospheres based agents (SpD). It caused by four times higher uptake of nanocubes versus nanospheres. Both cubic and spherical niosomes demonstrated relatively high T_2-relaxivity (240 $mM^{-1}*c^{-1}$ and 262 $mM^{-1}*c^{-1}$ respectively). According to *in vivo* studies the highest median survival was in the case of mice group with CbD, and the lowest is for SpD.

The authors gratefully acknowledge the support of the Ministry of Education and Science of the Russian Federation (grant № 14.578.21.0201 (RFMEFI57816X0201)).

INFLUENCE OF LIQUID ENVIRONMENT AND LASER PARAMETERS ON THE MAGNETIC PROPERTIES OF NANOPARTICLES SYNTHESIZED BY LASER ABLATION

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Nowadays a study of synthesis methods and magnetic nanoparticles properties become one of most promising scientific field. Specifically prepared and functionalized nanoparticles can be useful in many different applications such as biomedicine, catalysis, energy storage etc. [1] Laser ablation is a method which can offer to synthesize many different types of particles out of same initial substance, for example core/shell nanoparticles or non-spherical shape nanoparticles [1]. Laser ablation is a complex physical and chemical processes – a removal (ablation) of the substance from the surface or volume of the solid target using a laser beam. In contrast to the chemical ways of synthesis, nanoparticles prepared by laser ablation consist only from the material of target and the liquid (without impurities).

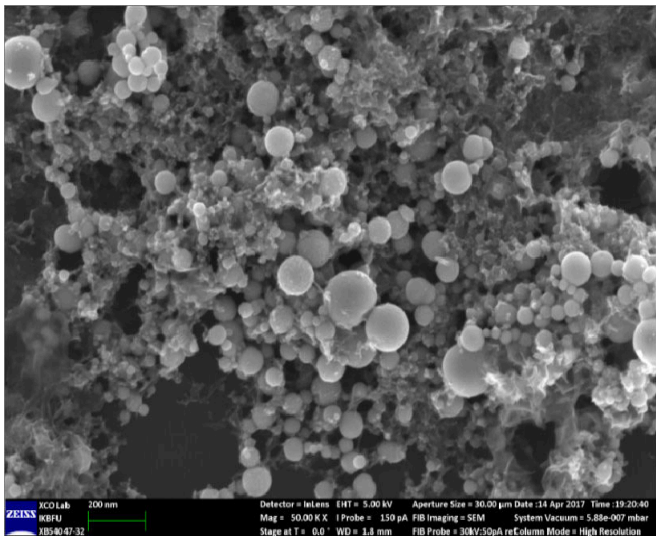

Figure 1. SEM Image of prepared samples.

In present work, we prepared the magnetic nanoparticles by laser ablation of a α-Fe target in an aqueous medium and in the isopropyl solution, using two different types of lasers (nanosecond and femtosecond) and different power of laser beam (15, 25 and 250 mJ). Pictures of fabricated samples were taking by SEM of FIB Carl ZEISS Crossbeam 540 (Fig.1.). The obtained nanoparticles have a spherical shape and a mean diameter of less than 100 nm, which is close to size indicates superparamagnetic state for Fe_xO_y. Magnetic measurements carried out by vibrating sample magnetometer 7404 System by LakeShore. For analysis of the magnetic properties, the hysteresis loops of each sample at room temperature, the low temperature dependence of magnetization in zero-field cooled and field cooled (ZFC/FC) protocols were measured. All samples show the ferromagnetic behavior, high saturation magnetization values (up to 39 emu/g) and enchanted coercivity (100-545 Oe) in comparison with bulk value.

[1] K.Y. Niu, J. Yang, S.A. Kulinich, J. Sun, H. Li, X.W. Du, *J. Am. Chem. Soc.* **132,** 9814 (2010).

FROM Mn_3O_4/MnO CORE-SHELL NANOPARTICLES TO HOLLOW Mn_3O_4: EVOLUTION OF MAGNETIC PROPERTIES

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Manganese oxide nanoparticles (MNOPs) [1], when dispersed in a water solution, show a magnetic behavior that drastically changes after an aging process. In this work, the variation in the magnetic properties has been correlated with the structural evolution of the nanoparticles: in particular, the as prepared Mn_3O_4/MnO core/shell system manifests a low temperature magnetization reversal that is strongly affected by the presence of the MnO shell and, in particular, by the existence of a frustrated interfacial region playing a key role in determining the low temperature irreversibility, the finite coercivity slightly above the Curie temperature of the Mn_3O_4 phase, and the horizontal displacement of the FC-hysteresis loop.

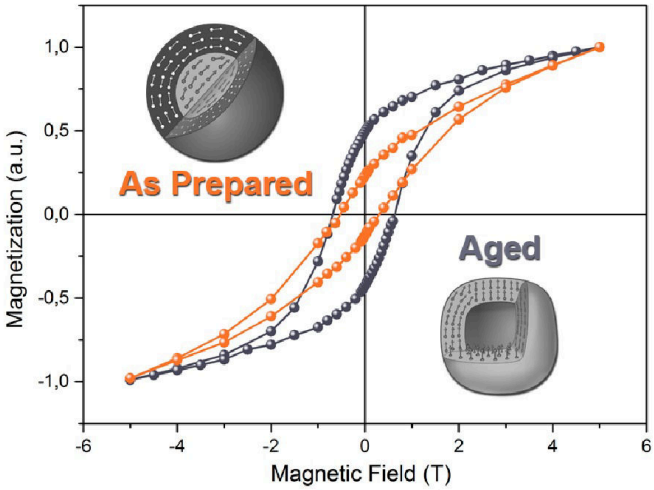

Figure 1. Field cooling (5T) hysteresis loops of the as-prepared and aged sample at 5K.

On the other hand, the magnetic behavior of the aged system results dominated by the presence of Mn_3O_4 whose highly anisotropic character (i.e. high coercivity and high magnetization remanence) is attributed to the presence of a large fraction of surface spins. Such result is consistent with the structural evolution, from core/shell to hollow nanoparticles, as shown by TEM observation.

[1] B.H. McDonagh, G. Singh, S. Hak, S. Bandyopadhyay, I.L. Augestad, D. Peddis, I. Sandvig, A. Sandvig, W.R. Glomm, *Small.* **12,** 301–306 (2016). doi:10.1002/smll.201502545.

MAGNETIC PROPERTIES OF $CoFe_2O_4$ NANOPARTICLES: MAGNETOCRYSTALLINE AND SURFACE COMPONENT OF ANISTROPY

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Spinel ferrite nanoparticles (NPs) are object of increasing interest due to their technological applications in different fields, e.g. biomedicine, magnetic recording and catalysis [1]. Nanosized cobalt ferrite in mesoporous silica matrix ($CoFe_2O_4$//SiO_2) nanocomposites with low wt% of magnetic phase (15 wt%) were synthesized by a sol-gel auto-combustion method involving metal nitrates, citric acid and tetraethoxysilane as precursors and treated afterwards at three different annealing temperatures 700, 800 and 900ºC. The growth of particle sizes with the increase of annealing temperature was observed by Transmission Electron Microscopy (TEM). Magnetic properties were studied by SQUID magnetometer, Mössbauer spectroscopy and AC susceptibility measurements. The value of effective magnetic anisotropy constant (K_{eff}) increases with the decrease of particle size, being two times higher than the bulk value for ~3 nm particles. This can be ascribed to the increase of surface component of anisotropy. Moreover, we observed a strong increase of K_{eff} for particles with same size but annealed at different temperature (Figure 1). This can be related to difference in cationic distribution, beyond the effect of particle size. In fact single ion anisotropy for Co^{2+} located tetrahedral sites ($^4A_2$ crystal field ground energy term, -79×10^{-24} J/ion) is smaller compared to Co^{2+} in octahedral sites ($+850\times10^{-24}$). This can induce an increase of magnetocrystalline anisotropy related to the orbital contribution in the $^4T_1$ ground energy term [2].

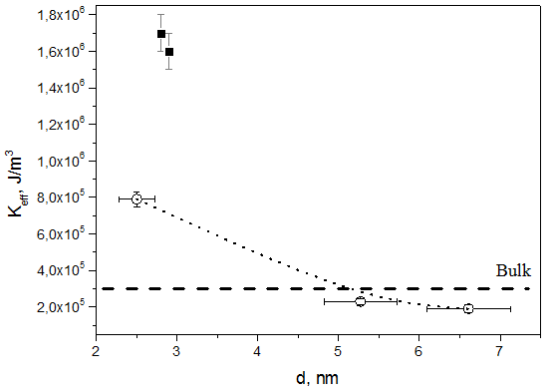

Figure 1. Size dependence of effective anisotropy constant.

[1] C. Cannas, A. Musinu, D. Peddis, G. Piccaluga, *Chem. Mater.* **18**, 3835 (2006).
[2] C. Cannas, A. Musinu, G.Piccaluga, D.Fiorani, D. Peddis, H.K. Rasmussen, S. Mørup, *J. Chem. Phys.* **125**, 164714 (2006).

THE MAGNETOCALORIC EFFECT IN THE INTERMETALIC COMPOUNDS MnZnSb

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Currently, much attention is paid to magnetothermal properties of the intermetalic materials. It is caused by practical perspectives of application of such materials in magnetic refrigeration machine, based on magnetocaloric effect (MCE). Generally, the MCE is associated with the ferromagnetic-paramagnetic phase transition temperature of the heavy rare-earth metals. However, the alloys and compounds based on heavy rare-earth elements are too expensive for domestic application. In recent years, the magnetic and magnetocaloric properties in lots of intermetallic compounds have been studied, and some of them have been found to possess not only large magnetic entropy change but also a small hysteresis loss. Large reversible MCE with a wide temperature range have been reported in several materials that undergo multiple successive magnetic phase transitions.

In this work, the equiatomic intermetallic alloy MnZnSb with tetragonal Cu_2Sb-type crystal structure (space group P4/nmm) was melted in the resistance furnace in evacuated quartz ampule. The crystalline structure was examined by the methods of X-ray diffraction, using Cu Kα radiation. The adiabatic MCE in magnetic field up to 1.2 T in wide temperature range was studied by the direct method with T-type thermocouple attached inside the sample. The field and temperature dependencies of magnetization were investigated by vibration magnetometer in magnetic field up to 14 T, and isothermal change of magnetic contribution of entropy was calculated by Maxwell relation.

The magnetic and magnetocaloric properties of MnZnSb were investigated. It was found that temperature dependence of MCE shows a sharp peak near room temperature with the maximum at Curie temperature T_C = 317 K. The maximum magnitude of MCE is 0.45K in field of 1.2 T. It was shown that there is no the temperature hysteresis of the MCE in MnZnSb, and maximum of MCE at heating and cooling is detected at the same temperature. The MCE in fields more than 2T was estimated by calculation from the magnetization curves. The maximum value of MCE in field of 14 T is 4.5 K. It was found that in fields more than 4 T the temperature dependence of MCE demonstrates a wide maximum near Curie temperature.

It was established that at temperature less than T_C (in ferromagnetic phase) the MCE depends linear on field; at the same time at temperature above T_C (in paramagnetic phase) the MCE is linear function of square magnetization. The exchange parameter was calculated in frame of mean-field approach from the dependence of MCE on the magnetization.

It was concluded that MnZnSb is the intermetallic compound with significant MCE value about 0.4 K per 1 T at temperatures close to room temperature and the MCE hysteresis is absence. It is known that small hysteresis of MCE is important for technical applications. The main magnetocaloric characteristics of the intermetallic alloy MnZnSb: isothermal variation of the magnetic entropy under the magnetic phase transition, the magnitude of the magnetocaloric effect, and the cooling capacity were determined. It was found that the alloy investigated is of interest from the point of view of practical applications (magnetic cooling).

The work is supported by RFBR grant #16-02-00472 BRFBR grant #T16P-170.

MODELING OF THE STRUCTURAL AND MAGNETIC PROPERTIES OF Fe-Rh-(Z) (Z = Mn, Pt) BY FIRST PRINCIPLES METHOD

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As for today, Fe-Rh-based alloys is a promising material showing a metamagnetic first-order phase transition above room temperature that is of great interest for future technologies such as thermally assisted magnetic recording, magnetic cooling and spintronics devices [1-3]. Fe-Rh alloys with almost equiatomic composition are ones of the best magnetocaloric materials showing a giant magnetocaloric effect close to room temperatures. For instance, the direct magnetocaloric effect measurements in $Fe_{51}Rh_{49}$ alloy [2] showed that the value of the adiabatic temperature change was found to be -13 K at the point 307 K with the magnetic field change from 0 to 2 T. In our work, we present theoretical investigations of the structural and magnetic properties $Fe_8Rh_{8-x}(Mn, Pt)_x$, (x = 0 – 3) alloys.

In the present work we used the density functional theory as implemented in the VASP package. The generalized gradient approximation for the exchange correlation functional in the formulation of Perdew, Burke and Ernzerhof (PBE) was taken into calculations. The energy calculations were performed for $L2_1$ supercell ($Fe_8Rh_{8-x}Z_x$). The ab initio calculations have been carried out by using the 16-atom supercell approach with different initial spin configurations. In the present work we calculated the total energies of the 16-atom supercells for $Fe_8Rh_{8-x}Z_x$ system calculated for different spin configurations as functions of the lattice parameter. For the parent Fe-Rh compound, the antiferromagnetic checkerboard-like spin configuration in a cubic cell is energetically favorable compared to other antiferromagnetic and ferromagnetic configurations. In this case, a total magnetic moment is found to be of 0 μ_B/f.u.

To investigate the possibility of martensitic transformation in these alloys in dependence on the third element, we performed total energy calculations for tetragonal distortion of the cubic structure along *z* axis. To accomplish this, we fixed the volume of a supercell as $V_{cubic} \approx V_{tetragonal}$ ($a_0^3 \approx a^2c$). Where a_0 is the parameter for the cubic structure, *a* and *c* are the lattice parameters for the tetragonal structure, here c is directed along *z* axis. The total energy differences between the tetragonal distorted and cubic phases for $Fe_8Rh_{8-x}(Mn, Pt)_x$, (x = 0 – 3) compositions with the energetically favorable spin configuration as functions of *c*/*a* ratio was found. We note that the calculated optimized lattice parameter for Fe-Rh alloy is in a good agreement with experimental and other theoretical values [1, 3].

This work is supported by advanced research foundation of the Chelyabinsk State University and President RF Grant MK-8480.2016.2.

[1] A. Gray, *Phys. Rev. Lett.* **108**, 257208 (2012).
[2] A. Chirkova, *Acta Mater.* **106**, 15 (2016).
[3] J. Ruigrok, *J. Appl. Phys.* **87**, 5398 (2000).

FOLATE TARGETED SPIONS FOR MRI

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Cancer is one of the most important human diseases, being the leading cause of death worldwide therefore has received significant attention focused on finding new and more sensitive nanomaterials that can improve current diagnostic imaging techniques. Among the conventional imaging modalities magnetic resonance imaging (MRI) is considered one of the most useful. To enhance the MRI quality it is crucial to choose the appropriate contrast agent, able to discriminate between diseased and healthy tissues ant to allow better visualization of anatomical details [1]. At this regard, superparamagnetic iron oxide nanoparticles (SPIONs) are the most developed negative contrast agents that can shorten the T2 relaxation time of water protons, resulting in enhanced contrast and sensitivity. In this study, a new amphiphilic inulin-based graft copolymer named INU-LA-PEG-FA was used as biocompatible coating material for 10-nm Fe_3O_4 SPIONs. Folic acid (FA) was graft to inulin backbone, using PEG as spacer, to induce active targeting to the tumor. Physicochemical characterization and in vitro biocompatibility study was then performed on the prepared magnetic nanoparticles. The improved targeting and imaging properties of the prepared FA-SPIONs were further evaluated in nude mice using 7-Tesla MRI spectrometer. FA-SPIONs exhibited the ability to act as efficient contrast agents in conventional MRI, providing a potential nanoplatform not only for tumor diagnosis but also for cancer treatment, through the delivery of anticancer drug or locoregional magnetic hyperthermia [2].

[1] Lee N. et al., *Chem. Rev.* **115**, 10637–10689 (2015).
[2] Scialabba C. et al., *Nanoresearch.,* DOI: 10.1007/s12274-017-1540-4 (2017).

MOSSBAUER STUDIES OF SPATIAL SPIN-MODULATED STRUCTURE AND HYPERFINE INTERACTIONS IN MULTIFERROIC $BiFe_{0.80}Cr_{0.20}O_3$

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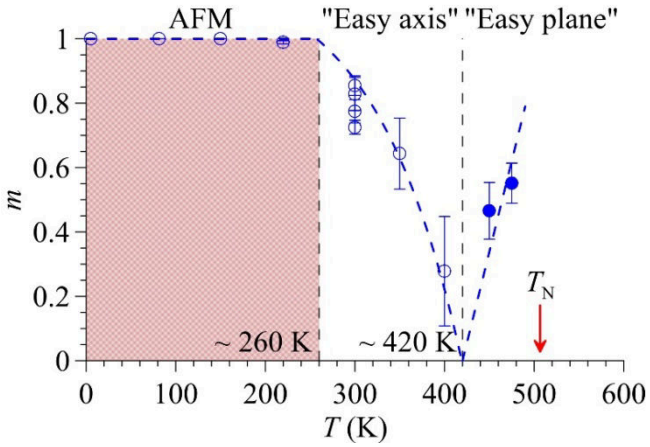
We have investigated the influence of substitution of Cr atoms for Fe atoms on the crystal structure, local magnetic and valence states of Fe atoms and parameters of the spatial spin-modulated structure (SSMS) by the ^{57}Fe Mossbauer method in bulk multiferroic $BiFe_{0.80}Cr_{0.20}O_3$ synthesized at high pressures. Measurements were carried out in the temperature range of 5–600 K. The samples had a rhombohedral structure belonging to space group R3c. A cycloid type SSMS model [1] was used in the processing and analysis of our Mossbauer spectra.

The temperature dependences of the hyperfine parameters of the ^{57}Fe Mossbauer spectrum – the isomer shift, the quadrupole shift of the spectral components, isotropic and anisotropic contributions to the hyperfine magnetic field and the anharmonicity parameter *m* of SSMS were obtained and analyzed. It was found the positions of Fe atoms in the first cation coordination sphere of which there were one, two, three and four atoms of Cr. The isotropic contribution to the hyperfine field of the iron atom is decreased when its nearest cation sphere contains chromium atoms. A magnetic phase diagram was constructed in the "anharmonicity parameter *m*" – "temperature *T*" axes, indicating the regions of the antiferromagnetic structure of the G-type, anharmonic SSMS with magnetic anisotropy of the "easy axis" and "easy plane" type (see Figure). The paramagnetic state was observed at temperaturc above the Neel point T_N = 505 K.



This work was supported by RFBR, project No. 14-02-01109 and the Ministry of Education and Science of the Russian Federation (contract № 3.5859.2017/BP).

[1] V.S. Rusakov, V.S. Pokatilov, A.S. Sigov, M.E. Matsnev, Gubaidulina., *JETP Letters* **100** (7), 463–469 (2014).

LOCAL ATOMIC AND MAGNETIC STRUCTURE OF NANOCRYSTALINE ALLOYS $Fe_{80}Cr_5B_{15}$

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Of particular interest are nanocrystalline Fe–B–T (T=d-atoms) alloys containing transition metal impurities as a functional composite materials. D-impurities allow to generate certain nanocrystals and unique magnetic and other properties in these alloys. However, the influence of d–atoms impurities on the composition, the atomic and magnetic structures of nanocrystalline phases of nanocrystalline Fe–B–T (3d–atoms) alloys was not almost studied. The aim of this work is to study the influence of impurity chromium atoms on the crystal structure, the composition, local atomic and magnetic structure of the nanocrystalline alloys $Fe_{80}Cr_5B_{15}$.

The thick ribbons of amorphous alloy $Fe_{80}Cr_5B_{15}$ were annealed in the temperature range 400–473°C. The X-ray diffraction studies of the samples were carried out on a Rigaku Geigerflex diffractometer. The local atomic and magnetic structures of the nanocrystalline $Fe_{80}Cr5_{B15}$ alloys were studied using a Mössbauer spectrometer MS1104Em at room temperature. For processing and analysis of the Mossbauer spectra was used the program SpectrRelax.

At the annealing temperature T = 440°C, nanocrystals of the α–Fe(Cr) phase (~1%) precipitate in the amorphous matrix of the alloy. The complete crystallization of the amorphous alloy occurs at T = 473°C with the formation of α–Fe(Cr) nanocrystals 26 ± 2 nm in size and nanocrystals of tetragonal boride t–$(Fe, Cr)_3B$ 47 ± 2 nm in size. It has been found that Cr atoms are located in nanocrystals of the α-Fe(Cr) and t–$(Fe, Cr)_3B$ phases. It was discovered that adding 5 at.% Cr in the amorphous alloy $Fe_{85}B_{15}$ suppress the appearance of the orthorhombic phase Fe_3B in nanocrystalline alloy $Fe_{80}Cr_5B_{15}$. At the annealing temperature 473°C, the sample contains only nanocrystals of the α – Fe(Cr) (55–60%) and *t*–$Fe, Cr)_3B$ (45–40%) phases. There are two states of Fe atoms in the α–Fe(Cr) phase and three equally probable crystallographic nonequivalent states of iron atoms in the t–$(Fe,Cr)_3B$ phase. The Cr concentration in the nanocrystalline phases is found to be ~5 at %. The substitution of chromium atoms for Fe atoms in t–$(Fe, Cr)_3B$ substantially decreases local magnetic moments of the Fe atoms compared to the values of the magnetic moments of Fe atoms in t–Fe_3B..

This work was supported by the Ministry of Education and Science of the Russian Federation (projects № 3.5859.2017/BP; № 3.5346.2017/BP; 8.50.98.2017/BP).

MAGNETOCALORIC EFFECT AND MAGNETOSTRICTIVE DEFORMATION IN Tb-Dy-Gd-Co-Al WITH LAVES PHASE STRUCTURE

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The aim of this paper was to investigate the influence of partial substitution of Co by Al atoms on the magnetic, magnetothermal and magnetoeleastic properties of multicomponent (Tb,Dy,Gd)Co_2 compounds with Laves phase structure. In this work the magnetocaloric effect (MCE) and magnetostriction of the $Tb_{0.2}Dy_{0.8-x}Gd_xCo_{1.9}Al_{0.1}$ (x = 0.3, 0.4, 0.5) compounds were investigated and compared with the results obtained previously for the original Al - free $Tb_{0.2}Dy_{0.8-x}Gd_xCo_2$ system [1]. The alloys were synthesized by arc method in helium atmosphere. The purity of Co and rare-earth metals was 99.99 and 99.9%, respectively. The alloys were remelted three times and annealed (at 900°C for one month) to obtain homogeneous samples.

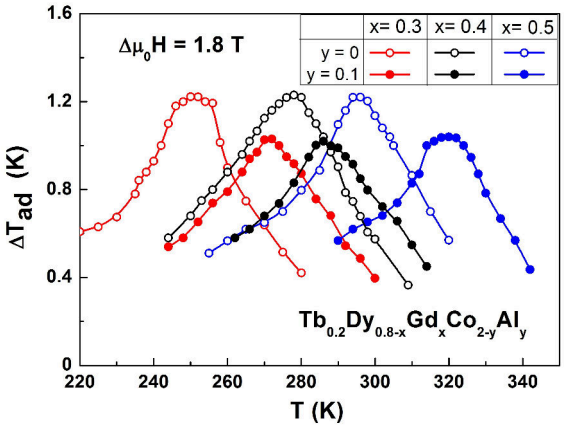

Fig. 1. Temperature dependencies of the adiabatic temperature change for $Tb_{0.2}Dy_{0.8-x}Gd_xCo_{2-y}Al_y$ (x = 0.3, 0.4, 0.5, y = 0, 0.1) obtained by direct method.

The crystal structure and lattice parameters were determined by X-ray diffraction. The thermal expansion as well as the longitudinal and transverse magnetostriction were studied in detail by the strain-gauge method in the temperature range 80-320 K in fields up to 1.2 T. The MCE was measured in fields of up to 1.8 T by direct method (MagEq MMS 901 setup). It was found that the partial substitution of Co by Al atoms leads to increases the Curie temperature on the average by 20 K, while the magnitude of the MCE (ΔT_{ad}), as shown in Fig.1, decreases not significantly (on 0.2 K).

It has been established that the MCE value remains constant over a wide temperature range, while the content of Gd and Dy is varied, in both the Al-substituted and the original Al-free compounds. This fact is important and allows promising the development of new functional materials based on the $Tb_{0.2}Dy_{0.8-x}Gd_xCo_{2-y}Al_y$ (x = 0.3, 0.4, 0.5, y = 0, 0.1) compounds.

The work is supported by the RFBR and Moscow city Government according to the research project 15-33-70040 mol_a_mos.

[1] I.S. Tereshina, J.Cwik, E.A. Tereshina, G.A. Politova *et al.*, *IEEE Trans. Magn.* 50, 11, 2504604 (2014).

SURFACE MODIFICATION OF MAGNETITE-GOLD DUMBBELL NANOPARTICLES WITH FLUORESCENT DYES AND DRUGS FOR NEW OPPORTUNITIES IN BIOMEDICAL APPLICATION

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Due to unique properties, magnetic nanomaterials are widely used in many branches of science and technology. Recent developments in nanotechnology and molecular biology have helped to translate multifunctional nanoparticles into one of the most perspective and actively developed areas - biomedical application. New possibilities in nanotechnology area are related with so called theranostics, which are defined as a material for the combination of therapy and imaging within a single platform.

Hybrid materials based on nanoparticles with different surface nature as well as different chemical properties represent particularly especial interest. Such materials can be controlled modified in various ways simultaneously, in particular with drugs and targeted molecules [1]. Surface modification of nanoparticles with fluorescence dyes opens horizons for visualization capabilities, also allows us to trace the behavior of particles in a biological environment, which is essential for their future biomedical applications [2].

In this work we developed synthetic procedure for magnetite-gold dumbbell nanoparticles modified with different copolymers containing: fluorescein and sulfo-Cy5 and investigated of the similar system with a drug (DOX) instead of the dye. Next, in vitro biodistribution of nanoparticles was studied on LNCaP cell line (PSMA-positive prostate cancer cell line). More detailed information for the synthesis, characterization and biological testing will be discussed in report.

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[1] Fang-hsin Lin and Ruey-an Doong, *J. Phys. Chem. C* **115** (14) (2011).
[2] Vladislav Verkhusha et al., *BioTechniques* **51** (5) (2011).

MICROSTRUCTURE AND EQUILIBRIUM PROPERTIES OF MAGNETIC FILAMENT SOLUTIONS

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Magnetic filaments are semiflexible polymer-like chains of magnetic nanoparticles permanently crosslinked with polymers which have been recently shown to be promising building blocks for the creation of sophisticated magnetoresponsive materials. Here, we investigate solution of magnetic filaments with different conformations and lengths made out of ferromagnetic particles of different shapes. For spherical nanoparticles simple open chains, closed rings and branched structures with “X” and “Y” junctions are investigated. For ferromagnetic ellipsoidal nanoparticles we investigate simple open chains and closed rings only. It was inspired by the recent findings on the low temperature self-assembly and ground state of dipolar hard spheres and ellipsoids. Using Langevin dynamics simulations, we focus on low-concentration solutions of filaments, analysing in detail their self-assembly and macroproperties. Extensive cluster analysis was made using graph theory. We also compare the structures formed by filament solutions to those observed in "conventional" magnetic fluids containing non-crosslinked nanoparticles of different shape. Then we investigate initial susceptibility for different concentration and different particle’s parameters (shape, value of magnetic moment). We have shown that conformation of filaments can dramatically change microstructure and macroscopical response of solution. These results will form the basis for developing theoretical models and provide recommendations for the design of novel magnetoresponsive systems.

ELECTRIC-FIELD CONTROL OF MAGNETOCALORIC EFFECT IN $Fe_{48}Rh_{52}$ –PZT MULTIFERROIC COMPOSITE

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In recent years the magnetic compounds with significant magnetocaloric effect (MCE) near room temperature are intensively studied. Recently, among the promising materials for magnetic refrigeration, a considerable interest is attracted to the materials showing magnetostructural phase transitions with giant MCE.

FeRh alloys are one of the perspective magnetocaloric materials for applications. $Fe_{48}Rh_{52}$ exhibits a giant negative MCE near room temperature, arising from a metamagnetic first-order transition near 315 K between antiferromagnetic (AFM) and ferromagnetic (FM) order. However, the broad hysteresis often associated with the transition is key drawbacks for applications. A dramatic degradation of MCE versus number of refrigeration cycles is obtained by recent direct measurements. The irreversibility of the MCE is associated with very broad or incomplete transitions. While the irreversibility and hysteresis losses in other caloric materials with first-order magnetic transitions have been reduced by doping or introducing porosity, such reductions have remained elusive in the case of FeRh.

To achieve reversibility of the MCE in FeRh materials, the simple bilayer multiferroic composite with piezoelectric and magnetostrictive components were fabricated. Magnetoelectric sandwich consists of $Fe_{48}Rh_{52}$ alloy as a magnetic component and $PbZr_{0.53}Ti_{0.47}O_3$ (PZT) piezoelectric with thicknesses about 0.2 mm. The magnetic, magnetocaloric and magnetoelectric (ME) properties of FeRh-PZT composite were performed around room temperature. M(T) curves were demonstrated typical for FeRh alloys behavior with metamagnetic transitions from AFM to FM state around T=315 K with hysteresis ~10 K.

The MCE measurements were performed in two regimes: with 25 V switching across the thickness of the sample and when the voltage was switched off. MCE in «switch off» regime is demonstrated the typical for $Fe_{48}Rh_{52}$ alloy behavior – maximum of temperature change, ΔT, is observed near temperature of AFM-FM transition ~316 K in heating and ~311.5 K in cooling. The temperature dependencies of MCE are demonstrated the hysteresis with temperature width about 4 K. The voltage switching leads to the small decrease of the MCE value and the AFM-FM transition point shifting by ~3 K toward high temperatures. The width of the hysteresis of MCE is decreased in applied electric field down to 3 K from 4.5 K.

ME output voltage exhibits the maximum near AFM-FM transition temperature in AC magnetic field with amplitude of 0.62 T and frequency of 3 Hz. The anomaly of the ME coefficient can be explained by magnetic field induced mechanical strain near AFM-FM transition temperature.

These results can be used for control of magnetic properties, MCE through the electric field and frozen of the irreversibility of the MCE effect in caloric materials.

INCOMMENSURATE ANTIFERROMAGNETISM IN THE CENTROSYMMETRIC CUBIC PHASES OF $REGe_{2.85}$ (RE = Tb, Dy)

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Polycrystalline samples of $TbGe_{2.85}$ and $DyGe_{2.85}$ were synthesized at a pressure of 8 GPa. They both have $AuCu_3$-type cubic structure with space group *Pm-3m* and lattice constants a = 4.287(5) A and 4.286(4) A, respectively [1].

The charge density wave (CDW) is formed in $TbGe_{2.85}$ below T_{CDW} = 145 K at ambient pressure. This was shown by electrical resistivity, heat capacity and magnetic susceptibility measurements. The nuclear method of time dependent perturbed angular $\gamma\gamma$-correlations (TDPAC) revealed the commensurability of CDW modulation at low temperatures.

$TbGe_{2.85}$ compound becomes antiferromagnetic below T_N = 19 K. The magnetic diffraction peaks in the neutron powder diffraction experiment have been indexed with a propagation vector $\boldsymbol{k_{ic}} = 2\pi/a(1/2, 0, 0.165)$ indicating an incommensurate helimagnetic structure (see Fig. 1).

It was supposed that this magnetic ordering closely related with CDW modulation because CDW also becomes incommensurate below the Néel temperature [2]. The similar magnetic structure was observed in a $DyGe_{2.85}$ compound in which the CDW is formed below 82 K. The Néel temperature for $DyGe_{2.85}$ is T_N = 22 K.

In addition, the neutron powder diffraction experiment at high pressure on $TbGe_{2.85}$ compound was performed. The results of this experiment demonstrates that above P = 1.2 GPa the second magnetic commensurate phase with wave vector $\boldsymbol{k_c} = 2\pi/a(1/2, 0, 0)$ is formed [3].

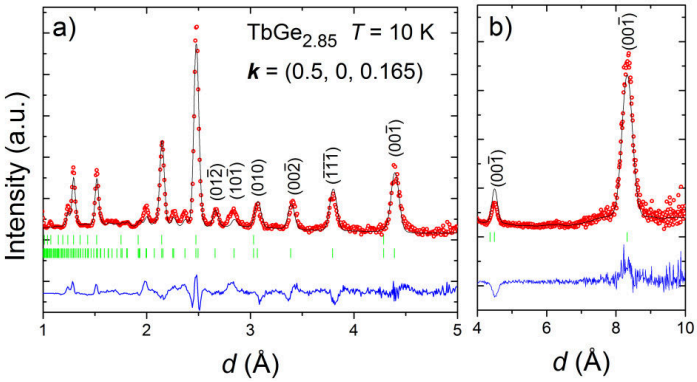

Figure. 1. Refined neutron powder diffraction pattern of $TbGe_{2.85}$ obtained at T = 10 K and P = atm. in the magnetically ordered state.

[1] A.V. Tsvyashchenko, A.I. Velichkov, et al., *JALCOM* **552**, 190 (2013).
[2] A.V. Tsvyashchenko, D.A. Salamatin, et. al., *Phys. Rev. B* **92**, 104426 (2015).
[3] D.A. Salamatin, V.A. Sidorov, et. al., *Phys. Rev. B* **94**, 214435 (2016).

SPECTRAL CHARACTERISTICS AND MAGNETIC SUSCEPTIBILITY OF A KONDO INSULATOR YbB_{12} WITH MAGNETIC AND NONMAGNETIC DEFECTS IN RARE-EARTH SUBLATTICE

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A joint analysys of the results of measuring static and dynamic magnetic susceptibility for several series of samples which based on Kondo-insulator YbB_{12} substitution by a rare-earth sublattice is presented.

For replacement of Yb has been used nonmagnetic isoelectronic ions Lu, magnetic isoelectronic ions Tm, nonmagnetic nonisoelectronic ions Y, Sc and Zr. Static susceptibility was measured on SQUID- magnetometer in weak magnetic fields, dynamic magnetic susceptibility was obtained from inelastic neutron scattering.

The simulation is performed using spectral function which has been extracted from neutron scattering experiment. A one-to-one correspondence has been established between the influence of the impurity on the neutron spectrum and the static susceptibility.

Using results of this work, we can argue about the relationship between the magnetic properties and electronic structure of systems of this class.

This work has been partially supported by RSF (grant 14-22-00098).

ON THE INDUCED ANISOTROPY OF IRON-NICKEL FILMS

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Thin magnetic iron-nickel films are widely used in microelectronics and medical technology, in particular, in magnetoresistive sensors for various purposes [1]. The magnitude of the magnetoresistive ratio and the magnetic anisotropy of the films largely determine the functional characteristics of such devices. In order to study the material with an increased (in comparison with the classical permalloy $Fe_{20}Ni_{80}$) magnetoresistive effect, we varied the composition of the films by increasing the nickel content. The magnetic anisotropy of the film is critically dependent on the technology. We applied a widely used method of producing films - magnetron sputtering. Deposition modes can vary. For example, to form an easy magnetization axis along a selected direction, an external technological field is used and the easy magnetization axis is formed parallel to the technological field. We investigated the magnetization reversal processes and the domain structure of films with a high nickel content. We observed the formation of the easy magnetization axis perpendicular to the technological field, and not along, as is the case for the $Fe_{20}Ni_{80}$ composition. This feature is most evident in the $Fe_{10}Ni_{90}$ films. To explain the observed phenomena proposed model. The model is based on the presence in the film of isotropic tensile stresses and anisotropic distribution of defects. Together with the negative magnetostriction of this composition, the model qualitatively explains the phenomenon. Experiments have been performed on the investigation of magnetoelastic properties of films, which justify the adequacy of the proposed model.

This work was supported by Ministry of Education and Science of the Russian Federation, project No. RFMEFI57815X0125.

[1] Jogschies L, Klaas, D. et al., *Sensors* **15**, 28665-28689 (2015).

INFLUENCE OF FRACTIONAL COMPOSITION OF POWDER ALLOY Fe-TM-Nd-REM-B RECEIVED BY METHOD OF GAS DISPERSION OF A MELT FOR THE PERIOD OF THE CRYSTAL LATTICE PHASE $Fe_{14}Nd_2B$

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This work is dedicated to x-ray research of the existence of a homogeneity area in the phase $Fe_{14}Nd_2B$. The method of quenching from the liquid state (MQ) allows you to extend the homogeneity area of many phases in the different alloys [*].

In our work, the compositions of the investigated multicomponent alloys on a triple diagram were chosen in such a way that the $Fe_{14}Nd_2B$ phase was in all possible regions of phase equilibriums. X-ray diffraction measurement of the periods of a lattice (**a** and **c**) the phase $Fe_{14}Nd_2B$, being in various phase equilibriums, allowed to allocate the major factors influencing its crystalline structure. Non-linear dependence **a** and **c** from composition of alloy and dispersion of MQ of the powder received by method of a gas jet dispersion of a melt a stream of noble gas (GRP) was revealed.

The values **a** and **c** calculated average atomic volume (Ω) phase $Fe_{14}Nd_2B$. The composite dependence with extremums is observed. Extreme deviations correspond to alloys $Fe_{81,66}Nd_{12,72}B_{5,62}$ and $Fe_{78,14}Nd_{12,88}B_{8,98}$, which have a maximum difference in boron content.

It was shown that depending on structure of GRP for the phase $Fe_{14}Nd_2B$ the essential dispersion of the periods of a lattice (**a** and **c**) while for average atomic volume (**Ω**) essential localization of values of dispersion takes place is observed. Such an effect can appear primarily because of the elastic stresses in the grains of the $Fe_{14}Nd_2B$ phase, whose origin is of a striction nature. The volume changes in the $Fe_{14}Nd_2B$ phase under the ferromagnetic transition can reach up to 2% [1].As a result, the alloys $Fe_{79,57}Nd_{13,97}B_{6,64}$, $Fe_{78,21}Nd_{14,81}B_{6,98}$, which represents the maximum number of magnetic phases obtained, the maximum variation of the lattice period.

In work temperature effect of annealing of GRP of various fractional composition on and, with and **Ω** the phases $Fe_{14}Nd_2B$ was experimentally studied. The analysis of the obtained data allowed to make the following generalizations: the particle size is less, the cooling rate, the higher the reached overcoolings of a melt is higher at MQ and as owing to, possible extent of supersaturation of a solid solution on the basis of the phase $Fe_{14}Nd_2B$ is higher. For GRP less than 100 microns received fractions: annealing at (863±2)K for all alloys, except $Fe_{78,21}Nd_{14,81}B_{6,98}$ (the maximal maintenance of Nd), leads to the complete removal of effect of supersaturation. It exerts the strengthening impact on magnetic properties of GRP-exemplars. At T > (973±2)K in alloy appears a liquid phase (a threefold eutectic rich Nd) in intergrain space. In such equilibrium conditions the intergrain diffusion processes (through a fluid component) providing alignment of composition of the contacting phase $Fe_{14}Nd_2B$ grains becomes more active.

The relationship between the observed effects of the dispersion and annealing of the fracturing on the Ω phase of $Fe_{14}Nd_2B$ was explained by the following assumptions: 1) the existence of the homogeneity region of the $Fe_{14}Nd_2B$ phase; 2) the temperature-concentration dependence of the solubility of the main and impurity components in the $Fe_{14}Nd_2B$ phase.

[1].A.Andreev, V.Deryagin, S.Zadvorkin. *Thermal expansion and spontaneous magnetostriction of the compounds $R_2Nd_{14}B$,* 1641-1645 (1985).

MAGNETODIELECTRIC EFFECT AND MAGNETIC STRUCTURE OF $Tb_3Fe_5O_{12}$ UNDER EXTERNAL MAGNETIC FIELD

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The $Tb_3Fe_5O_{12}$ has both of the magnetic features observed in the spiral magnets. Firstly, the $Tb_3Fe_5O_{12}$ has a canted magnetic structure [1] due to the noncollinear spin alignment of Tb^{3+}-ion moments, which form, so called, "double umbrella" ordering at low temperature (below 130 K). Along with the appearance of the "double umbrella" a lattice distortion from the cubic (space group *I*-3*ad*) to rhombohedral symmetry (*R*-3) occurs, when temperature decreases. Secondly, the $Tb_3Fe_5O_{12}$ garnet has a huge magnetostriction $\lambda_{111} = 2.4 \cdot 10^{-6}$ value (this is the largest λ_{111} for RE-garnets) at low temperature, accompanying a double umbrella magnetic ordering [2].

The aim of this work is getting a more clear understanding on the magnetodielectic effect in the $Tb_3Fe_5O_{12}$ by carrying out a study on evolutions of lattice distortions along with a reorientation of canted magnetic spins at the external field $\mu_0 H = 0.8$ T by means of neutron diffraction over the temperature range from 8.8 K up to 103 K. An increasing temperature up to 65 K results in strong decreasing of values of μ_{Tb1} and μ_{Tb2} and also strong decreasing of their canting angles with *c*-axis ($\theta_1 = 5°$ and $\theta_2 = 16°$), whereas the Fe-ion moments don't decrease.

A magnetic field causes a decreasing of unit cell volume by (0.4-2.0) $Å^3$. Application of $\mu_0 H$ field at 103 K reduces the rhombohedral distortions almost totally that the $Tb_3Fe_5O_{12}$ returns to a cubic structure. A magnetic field tends to align "double umbrella" magnetic ordering of Tb-ion moments parallel-wise along *c*-axis, i.e. a magnetic field induces a reorientation of Tb-ion magnetic moments to *c*-axis. By magnetic field application ($\mu_0 H = 0.8$ T) at 8.8 K the total magnetic moments of Tb^{3+} ions increase up to 9.3(2) μ_B for Tb1 and 9.7(2) μ_B for Tb2. The magnetodielectric effect $\Delta\varepsilon/\varepsilon$ in $Tb_3Fe_5O_{12}$ caused by this sample dimension change is expected $\approx 1.0 \cdot 10^{-4}$.

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[1] F. Sayetat, *J. Magn. Magn. Mater*. **58**, 334 (1986).
[2] M. Lahoubi, M. Guillot, et al., *IEEE Trans. Magn*. **20**, 1518 (1984).

ANALYSIS OF ANOMALOUS NEGATIVE MAGNETIC CONTRIBUTION TO THERMAL EXPANSION IN $Sm_{0.8}B_6$ AND PSEUDOBINARY COMPOUNDS $Sm_{1-x}La_xB_6$ (x=0, 0.1, 0.22, 0.5)

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Among materials with unique thermodynamic properties systems that demonstrate negative thermal expansion are of particular interest. Samarium hexaboride is an archetype of such systems. SmB_6 is the system with partial delocalization of the 4f-electrons leading to valence fluctuations between Sm^{2+} with the $4f^6$ configuration (J=0, nonmagnetic) and Sm^{3+} with the $4f^5$ configuration (J=5/2, magnetic) with characteristic time scale 10^{-15} – 10^{-13} s [1]. As a result these fluctuations form many particle non-magnetic singlet ground state (Kondo mechanism). At finite temperatures in terms of magnetism the system is an enhanced Pauli-like paramagnetic system. It's believed that the anomalous negative contribution to TEC of SmB_6 has an electronic/magnetic character and is directly connected to the valence fluctuations.

In this work the anomalous negative magnetic contribution to TEC of SmB_6 is studied using the two-level Weiss model that has been successfully applied to the ferromagnetic Fe-Ni invar alloys earlier [2]. We use our own experimental data on the lattice spacing in samarium and lanthanum based hexaborides collected by the X-ray diffraction technique in the temperature range 10 K to 320 K. The model assumes that the anomalous expansion results from two different magnetic atomic states of metal ion separated by an energy gap and that these states are characterized by different atomic volumes. If the higher-energy state has lower volume, then thermal excitation of this level leads to smaller of the atomic volume. The model was successfully applied to the systems: $Sm_{0.8}B_6$, $Sm_{1-x}La_xB_6$ (x=0, 0.1, 0.22, 0.5). Good enough agreement was found between experimental and modelled data.

This work was supported by the Program of improving the competitiveness of I. Kant BFU "5-100".

[1] Alekseev P.A. et al., *Solid State Physics* **30**, 2024 (1988).
[2] Weiss R.J., *Proc. Phys. Soc.* **82**, 291 (1963).

MAGNETIC AND TRANSPORT PROPERTIES OF Mn_2CoGa

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Recently, there has been growing interest in the development of novel materials for spintronic applications. Heusler alloys, specifically so-called inverse Heusler alloys [1] and equiatomic quaternary Heusler alloys [2] have been suggested as a potential candidate in this respect. Growing interest to Mn_2CoZ (Z = Al, Ga, Si, Ge, Sb) Heusler alloys has been conditioned by recent theoretical and experimental work which showed that Mn_2CoAl is a spin gapless semiconductor [3]. Considering a Mn_2CoZ system with Z = Ga, Mn_2CoGa, a number of experimental works performed on bulk samples [4] and thin films [5] have revealed that Mn_2CoGa has a high Curie temperature T_C = 740 K and magnetic properties which depend on stoichiometry.

To the best of our knowledge, Mn_2CoGa in the form of melt-spun ribbons has not been studied so far. Also, contrary to the magnetic properties, transport properties of this compound has not been systematically studied. This motivated us to prepare Mn_2CoGa in the form of polycrystalline bulk samples by arc-melting method and in the form of melt-spun ribbons by a melt spinning technique and performed a comparative study of the bulk and melt-spun samples by X-ray diffraction (XRD), magnetic and transport measurements.

Room-temperature XRD diffraction revealed that both the as-spun ribbons and annealed bulk samplea have a cubic Heusler structure. Magnetic properties of the melt-spun ribbons turned out to typical for a soft ferromagnet. Measurements of transport properties revealed that both melt-spun ribbons and bulk samples exhibit metallic behaviour of the r electrical resistivity in a temperature interval from 80 to 360 K.

This work was supported by Russian Science Foundation (grant No. 16-42-02035).

[1] X. Wang, Z. Cheng, J. Wang, X.-L. Wang, G. Liu, *J. Mater. Chem. C* **4**, 7176 (2016).
[2] L. Bainsla, K.G. Suresh, *Appl. Phys. Rev.* **3**, 031101 (2016).
[3] S. Ouardi, G.H. Fecher, C. Felser, J. Kübler, *Phys. Rev. Lett.* **110**, 100401 (2013).
[4] V. Alijani, J. Winterlik, G.H. Fecher, C. Felser, *Appl. Phys. Lett.* **99**, 222510 (2011).
[5] S. Ouardi, T. Kubota, G.H. Fecher, R. Stinshoff, S. Mizukami, T. Miyazaki, E. Ikenaga, C. Felser, *Appl. Phys. Lett*. **101**, 242406 (2012).

MARTENSITIC TRANSFORMATION BEHAVIOUR Of $Ni_{2.44}Mn_{0.48}Ga_{1.08}$ THIN GLASS-COATED MICROWIRES

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Ni-Mn-Ga based Heusler alloys show a first-order reversible martensitic transformation (MT) from the high temperature cubic $L2_1$ phase (austenite) to the low temperature phase (martensite) with a lower symmetry, which can be induced by single or multiple effect of heating, stress or magnetic field.

Here we report on MT in thin glass-coated Ni-Mn-Ga Heusler-type microwire prepared by Taylor-Ulitovsky technique. Microwires were annealed at 833 and 1000 K during 1 hour in vacuum with heating rate of 10 K/min, followed by furnace cooling. To separate the influence of glass coating (GC) on properties of the microwire it was etched in water diluted HF acid (25%).

SEM images and X-Ray diffraction measurements reveal the presence of a small amount of martensitic phase in the core of the both annealed microwires together with the cubic $L2_1$ austenite (Fig. 1a-b). MT has been observed below the room temperature in the microwires annealed at 1000 K during 1 hour. No signs of MT were found in the microwires annealed at lower temperature of 833 K (Fig. 1c). Curie temperature showed strong dependence on annealing temperature and the presence of the GC. In addition, circular multi-domain structure, typical for amorphous GC microwires, was observed along the axis of the microwire, disappearing after GC removal (Fig. 1d).

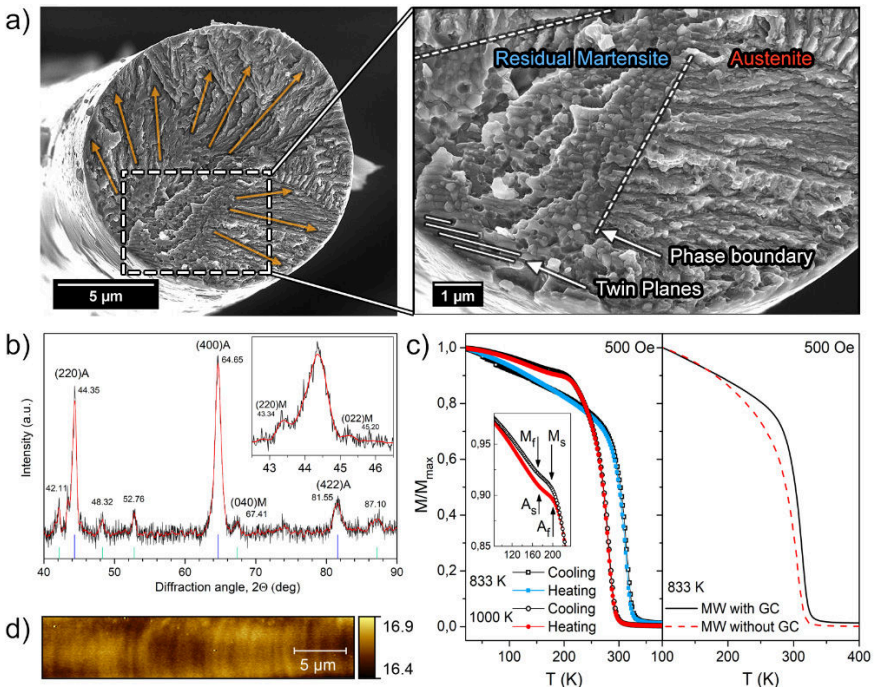

Figure 1. a) SEM image of annealed microwire cross-section;
b) XRD made at room temperature;
c) M(T) dependences for GC microwires annealed at 833 and 1000 K (left) and for microwires with and without GC (right) with magnetic field of 500 Oe applied along the microwire axis;
d) MFM scan made at room temperature showing circular magnetic domain structure on the surface of GC microwire annealed at 833 K.

MEASUREMENTS OF FREQUENCY DEPENDENCE OF MICROWAVE PERMEABILITY IN EXTERNAL MAGNETIC FIELD

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One of the methods of microwave measurements of magnetic materials is to measure the frequency dependence of the complex permeability μ under an external magnetic field [1]. The permeability is conventionally measured with high accuracy in a coaxial line in the frequency range of 0.1 to 20 GHz. This measurement geometry allows for achieving large fields and makes the sample close to the saturation. However, the samples of coaxial shape are nonuniformly magnetized. The demagnetization factors in the direction along coaxial axis are calculated in [2].

The measured frequency dependence of the real permeability for different values of external magnetic field and thickness of samples is shown at Fig. 1. The sample is a roll made of a thin Fe-N film deposited on a flexible mylar substrate. The demagnetization leads to difference in resonant frequencies for samples of different thickness. This difference decreases with increasing external magnetic field. Measurement results agree with calculated values.

Also, the frequency dependence of permeability of composite materials containing sendust powder is measured in external magnetic field, see Fig. 2. The effect of filler concentration and particle shape on the microwave magnetic properties of the composites is studied. The field inside the composite sample is calculated with account for the demagnetization coefficient and the magnetic susceptibility of the sample. The anisotropy field and magnetization of saturation of sendust particles are calculated.

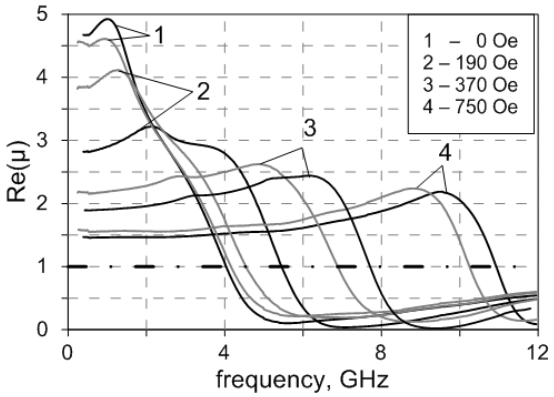

Figure 1. The measured real part of permeability of thick Fe-N film in external magnetic field (black lines correspond to 5.4 mm sample thick, gray lines to 2.5 mm)

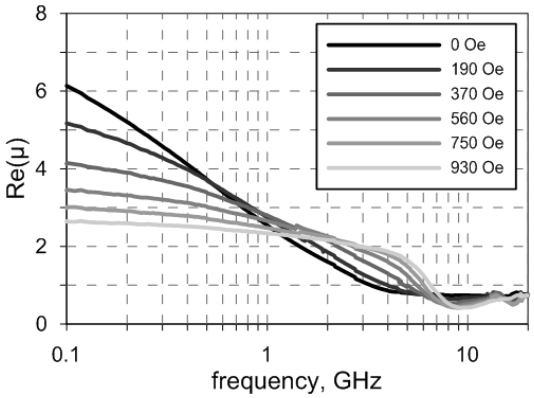

Figure 2. The measured real part of permeability of composite material filled with sendust powder in external magnetic field

[1] S.N. Starostenko, K.N. Rozanov, *PIER C* **8**, 43–55 (2009).
[2] M. Beleggia et al, *J. Magn. Magn. Mater.* **321** (9), 1306−1315 (2009).

OPTICAL PROPERTIES AND ELECTRONIC STRUCTURE OF Mn_2CoAl HEUSLER ALLOY

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Recently, Mn-based Heulser alloys (inverse full-Heuslers) with a chemical formula of Mn_2YZ have been attracted attention in the field of spintronics because many of them are reported to be half-metallic ferro- or ferri-magnets. Especially, Mn_2CoAl has been reported to have spin gapless semiconductor-type density of states [1, 2]. The physical properties associated with such a type of the electronic structure are expected to have applications for spintronics. In this work we present the results of optical properties investigations of Mn_2CoAl by the ellipsometric Beattie technique in the spectrum range λ=(0.3–13) μm at room temperature. The electronic structure calculations were performed to explain experimental results.

Figure 1 shows the dispersion curves of the real ε_1 and imaginary ε_2 part of permittivity. The alloy has a monotonous increase ε_2 with increasing the wavelength of the incident light. We see also that ε_1 remains positive up to the long wavelength boundary of the frequency interval studied. This behavior of the real part of the permittivity is abnormal for metal alloys and compounds. This indicates a substantial weakening of the metal properties.

The theoretical calculations of the electronic structure were performed within local spin density approximation for the experimental $L2_1$ [2] crystal structure parameters of the samples. The calculated total magnetic moment of Mn_2CoAl was found to be 2 μ_B in good agreement with previous results [1]. Our calculations confirmed the spin-gapless character of the electronic structure with the Fermi level located inside the semiconductor gap in both spin subband (Fig. 2). The calculated electronic structure is found to give the qualitative explanation of the observed anomalies optical properties (Fig. 1).

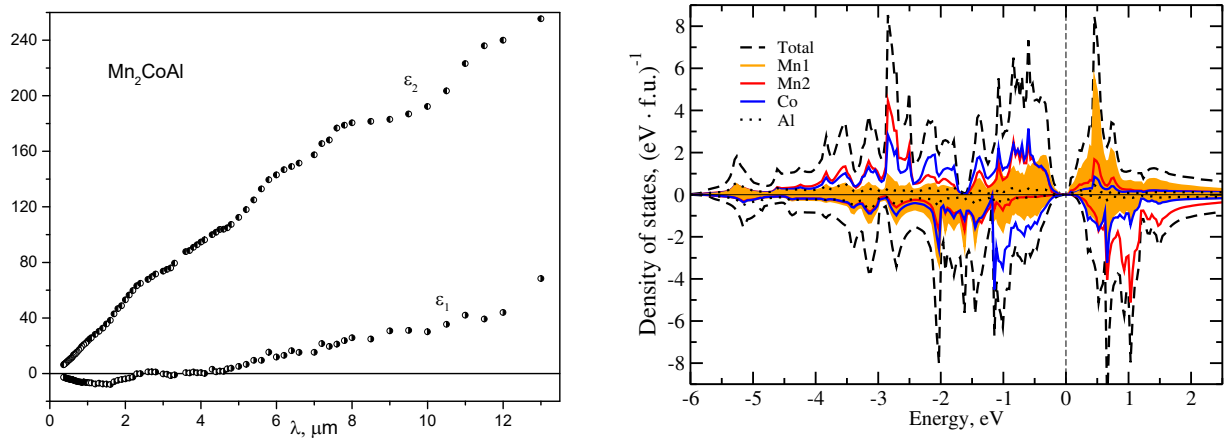

Fig.1. Dispersion of the permittivity.

This work was partly supported by the RFB

[1] S. Ouardi et al., *Phys. Rev. Lett.* **110**, 100401 (
[2] G. D. Liu et al., *Phys. Rev. B* **77**, 014424 (200

GIANT MAGNETOCALORIC EFFECT DETECTED IN $La_{0.7}Pb_{0.05}Na_{0.25}MnO_3$ MANGANITES

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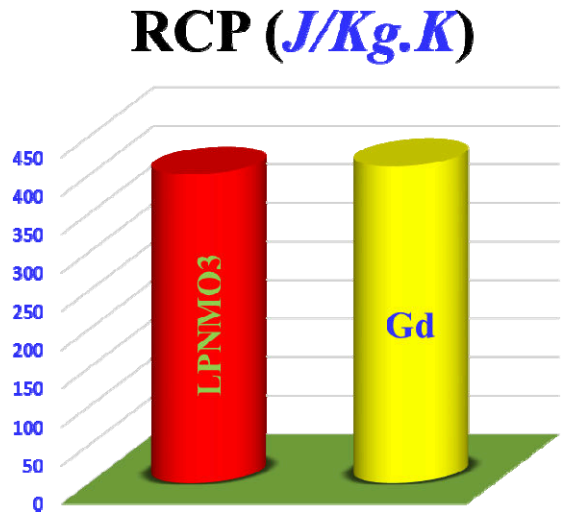
$La_{0.7}Pb_{0.05}Na_{0.25}MnO_3$ compound is prepared by the sol-gel method, at annealed at 950 °C. Structural and magnetic measurements were performed to examine the physical properties. X-ray diffraction and scanning electron microscopy shown the existence of a secondary phase attributed to the unreacted Mn3O4 oxide.

Magnetization versus temperature study has shown that all samples exhibit a magnetic transition from ferromagnetic to paramagnetic phase when increasing temperature. Critical behavior in La0.7Pb0.05Na0.25MnO3 has been investigated by dc magnetization measurements. Estimates of critical exponents yield $\delta = 4.80 \pm 0.01$, $\gamma = 1.296 \pm 0.002$ and $\beta = 0.344 \pm 0.007$ (consistent with both the predictions for the three-dimensional-Heisenberg model and with those reported for materials when the FM transition is ascribed to the double exchange (DE) mechanism as a major origin) with TC = 334.54±0.08.

Near room temperature giant magnetocaloric entropy change 7.92 J/kg.K for 50 kOe magnetic field change have been observed around the second order transition. Near room temperature, a giant magnetocaloric entropy change of 7.92 J/kg-K under 50 kOe of applied magnetic field has been observed around the second order transition. This result was affirmed via a comparison to the well known magnetic refrigerant Gd which is considered as a reference for magnetic refregeration as seen in Figure.



JAHN−TELLER EFFECT AND MAGNETIC PROPERTIES OF $FeGa_2O_4/FeGaO_3$ NANOPARTICLES

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The iron gallate $FeGa_2O_4$ nanoparticles arouse special and outstanding interest among the vast variety of materials considered to be potentially applicable in the field of biomedicine. It can possess the inverse spinel structure inherited from magnetite Fe_3O_4, and the magnetic properties of $FeGa_2O_4$ are tunable so that at the stage of synthesis the future nanoparticles can be surely adjusted for certain purposes, such as magnetic drug delivery or hyperthermia. Moreover, the magneto-optical and cathodoluminiscent features of the FeGa2O4 nanoparticles make it possible to use them as cathodoluminescent agents and magnetic-resonance (MR) contrast materials.[1] There are two important crucial parameters for such contrast materials: the spin−lattice (T_1) and spin−spin (T_2) relaxation times which also depend on the type of cations in the spinel structure. Adding different ions allows tuning these parameters to improve the local contrast in the MRI method.[1]

Complex iron−gallium oxide nanoparticles $FeGa_2O_4/FeGaO_3$ with a cubic spinel structure and the size of about 30 nm were synthesized by the combustion method. In the process of the synthesis, a new phase γ-$FeGaO_3$ created at the surface of the $FeGa_2O_4$ core adopts the spinel structure of the core. In the pure $FeGa_2O_4$ compound, the cation distribution obtained from the Mössbauer data is $(Fe^{2+}_{0.76}Ga^{3+}_{0.24})_{tet}$ $[Fe^{2+}_{0.24}Ga^{3+}_{1.76}]_{oct}$ O_4 at room temperature. With decreasing temperature, the Jahn−Teller distortions of tetrahedral A-sites initiate the charge transfer transition at 140 − 90 K leading to the redistribution of Fe^{2+} and Ga^{3+} cations over the A- and B-sites. A fine correlation and connection between the critical temperature and critical concentration of the J-T ions associated with transition from the dynamic to cooperative J-T effect was observed.[2]

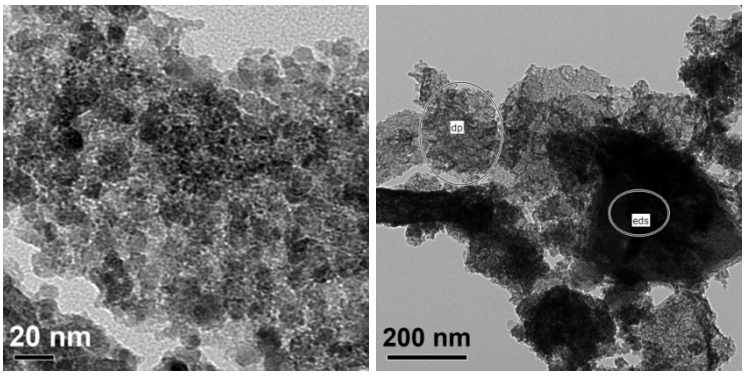

Fig.1. TEM images of $FeGa_2O_4/FeGaO_3$ nanoparticles

Support by the Russian Scientific Foundation (Project #14-12-00848) is acknowledged.

[1] C.-C.Huang,C.-H. Su,M.-Y. Liao andC.-S. Yeh, *Phys. Chem.* **11**, 6331 (2009).
[2] I.S. Lyubutin, S.S. Starchikov, N.E.Gervits, Chun-Rong Lin, Yaw-Teng Tseng, Kun-Yauh Shih, Jiann-Shing Lee, Yu.L. Ogarkova, A.O.Baskakov and K.V. Frolov, *J. Phys. Chem.* C **120** (44), 25596–25603 (2016).

ASYMMETRY OF THE HYSTERESIS LOOP OF MAGNETOACTIVE ELASTOMER

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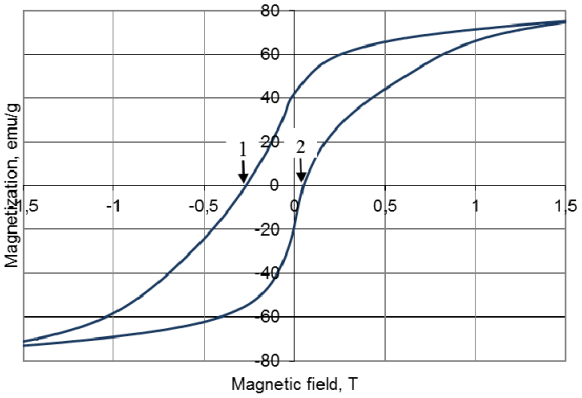
Magnetoactive elastomers (MAE) are composite materials of a new type, which belong to the so-called "smart materials" family. Exhibiting the capability of varying their properties under the influence of magnetic fields, they are interesting from the position of being used in controllable damping units, magnetic-field and acceleration sensors or as magnetic mini-dressings in medicine. Employment of MAE with magnetically hard fillers in damping devices is a promising area. After magnetizing, the loss tangent of such a composite increases during its deformation. Studies of the magnetic properties of this type of MAE unveiled anomalous and non-standard features of its hysteresis loop.



The samples were prepared by mixing thin powders of a magnetically hard filler being FeNdB with liquid silicone resin. The mixtures were then poured into molds and subjected to polymerizing at 100^0C for 1 hour. All the flowing magnetic measurements were performed using a Lake Shore 7404 vibrating sample magnetometer at a constant temperature of 20^0 C. Owing to them anomalous features of the hysteresis loop were discovered. As can be seen from Fig. 1, the shape of the dependence of the magnetization of the sample on magnetic field strength demonstrates pronounced asymmetry (compare points 1 and 2). At the same time, the loop observed for the pure FeNdB powder has a regular symmetric configuration. It is worth mentioning that the coercivities on the forward and backward return lines of the loop yielded by the MAE specimen were found to be 0.27 and 0.05 T, respectively, and that they were noticeably lower than that observed for the pure filler equal to 0.8 T. This type of anomalous behavior is connected with shifting and rotating of the magnetized particles inside the elastic polymer matrix of the composite. After the first magnetizing, the particles turn and partly line up along the force lines of the external magnetic field, as a result of which they get magnetized. When the direction of the filed changes, the particles can re-magnetize or they can turn over. In sufficiently elastic polymer matrices the turning over is preferable. Changing the field orientation back to the initial direction will cause the particles to regain their primary condition under the influence of the elastic forces of the polymer. In this case the coercivity value is minimal (arrow 2). The asymmetric configuration of the hysteresis loop points to the fact that the magnetizing and re-magnetizing of the novel composite material occur according to a previously unknown mechanism.

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ROTATIONAL EFFECT IN A FERROFLUID DOPED BY NON-MAGNETIC ANISOTROPIC PARTICLES

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The dynamics of the rotational motion of complex liquids under the action of external magnetic fields is very important for its potential applications in magneto-mechanical and magneto-optical devices, and fundamental insights in structures of such fluids and their internal dynamic mechanisms. The phenomenon that nanostructured magnetic fluids follow a rotating magnetic field is known as the rotational effect [1, 2]. Here, we study the rotational effect in binary mixtures of ferrofluids and colloidal suspension of plate-shaped pigment particles by exploring the dependence of the rotational effect on the concentration of magnetic nanoparticles in a ferrofluid as well as on the rheological properties of the carrier medium.

The detailed description of the experimental setup is presented previously [3]. A spherical glass container is completely filled with the liquid sample fixed on a thin glass string and placed inside a system of Helmholtz coils creating a rotating magnetic field. The advantage of the spherical container is the uniformity of the demagnetizing field. We measure torque density T which is found from the torsion of the glass string in dependence on the applied external magnetic field strength B and frequency f for suspensions with a constant concentration of magnetic particles and varying concentration of the plate-shaped pigment particles.

We demonstrate that the frequency dependence of the magnetic torque strongly depends on the rheological character of the carrier fluid. Magnetic torque increases monotonically with increasing frequency of the rotating field reaching a saturation at high frequencies for samples with a low concentration of the pigment particles. The suspensions with a high concentration of the pigment particles, having higher viscosity and exhibiting a strong non-Newtonian behavior, have a smaller slope of the torque $T(f)$ at low frequencies. The saturation of the torque $T(f)$ also shifts to the higher frequency range. Characteristic response time, which scales the frequency, decreases with increasing concentration of the plate-shaped pigment particles. This behavior reflects an intricate interaction between the flow induced by the rotating MNPs and the plate-shaped pigments. Detailed theoretical study is required to understand this behavior.

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[1] A.F. Pshenichnikov, et al., *Magnetohydrodynamics* **36**, 275-281 (2000).
[2] C. Holm, J.-J.Weis, *Current Opinion in Colloid &Interface Science* **10**, 133 (2005).
[3] A.M. Storozhenko, et. al, *J. Magn. Magn. Materials* **431**, 66-69 (2017).

SIZE-CONTROLLABLE GROWTH OF $Au_3Fe(111)/Fe(110)$ HYBRID NANOCRYSTALS BY MBE

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Bimetallic magnetic nanomaterials are under extensive investigations now due to their possible application in nanotechnology and nanomedicine. The distinctive characteristic of such materials is their superparamagnetic behaviour, which is important for biomedical, diagnostic and therapeutic applications. At present, the Au-Fe based nanomaterials attract much attention due to higher saturation magnetisation in comparison with the Au-Fe oxide core-shell structures, which synthesis has heavily been investigated over the last decade. So far, several scientific reports about the synthesis of the Au-Fe core-shell nanostructures have been made. It is clear that this question has not been illuminated enough yet in the literature. That variety of different possible forms of nanostructures, that The Au-Fe system potentially encloses, give us a hope to understand and establish the relationship between technological procedures of their synthesis and resultant properties desirable for practical application.

We present in this report the route to produce highly-textured $Au_3Fe(111)/Fe(110)$ hybrid nanocrystals on an amorphous surface of SiO_2/Si by molecular beam epitaxy. By controlling the quantity of Au atoms deposited onto the SiO_2/Si we managed to tune the average lateral size of resultant $Au_3Fe(111)/Fe(110)$ hybrid nanocrystals from 10-20 nm up to 100-150 nm at the same Fe nominal thickness deposited (Fig.1). This process is sensitive to the initial density and size of Au islands. Examination of $Au_3Fe(111)/Fe(110)$ nanocrystals obtained was carried out using X-ray diffraction, SQUID magnetometry, ferromagnetic resonance, transmission electron microscopy, atomic force microscopy, Kerr effect measurements, Ferromagnetic resonance, spectroscopic ellipsometry and ab initio calculation methods.

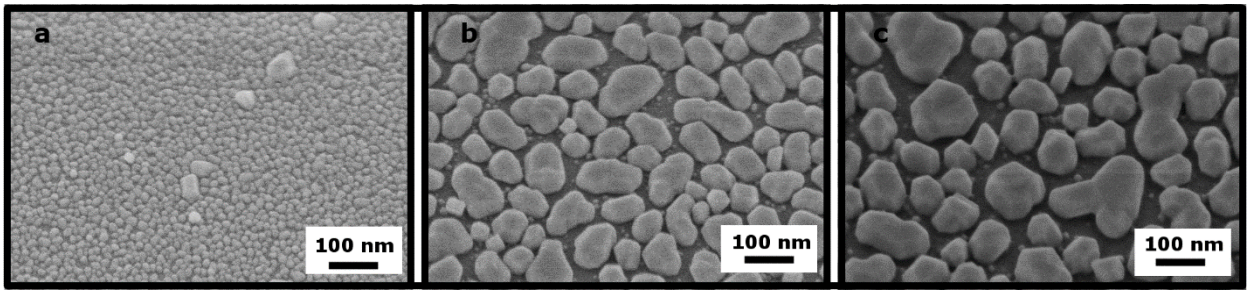

Figure 1. SEM images $Au_3Fe(111)/Fe(110)$ hybrid nanocrystals grown on $S_1O_2/S_1(100)$ the nominal Fe layer thickness is 34 nm, Au layer thickness a) 2 nm b) 8 nm c) 12 nm (samples tilting is 32˚)

The work was supported by Grant "Scientific school - 7559.2016.2" and Russian Foundation for Basic Research, Government of Krasnoyarsk Territory, Krasnoyarsk Region Science and Technology Support Fund to the research projects 16-42-243060.

THE INFLUENCE OF THE SUBSTRATE STRUCTURE ON THE MAGNETIC ANISOTROPY OF THE COMPASSITE $(Co_{40}Fe_{40}B_{20})_{65}(SiO_2)_{35}$

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Magnetic anisotropy (Ha) is the most important functional property of ferromagnetic materials. Magnetic anisotropy of the shape of the sample is one way to control the magnitude and direction of Ha. In this paper, we considered the possibility of forming magnetic anisotropy in nanocomposite films $(Co_{40}Fe_{40}B_{20})_{65}(SiO_2)_{35}$ due to fragmentation of the film on the surface of the glass fabric. Nanostructured films were obtained by ion-beam sputtering of the composite target of the $Co_{40}Fe_{40}B_{20}$ alloy with SiO_2 samples. The thickness of the samples was 2 μm. As the substrates, the sitall plates ST50-0.6 and fiberglass were selected. The glass fiber cloth had a linen weave with a cell size of ~ 700x700 μm^2 and a filament diameter of ~6 μm^2.

A substantial anisotropy in the plane of the film was not detected on a flat sital substrate (Fig. 1a). On glass cloth, the magnetic permeability of the samples obtained is somewhat smaller and the yield of the curve in saturation is observed at high fields (Fig. 1b). In the case of fiberglass, the magnetic characteristics are the sum of the magnetization of the film on the surface of thin glass filaments. Proceeding from this, we carried out measurements of individual glass filaments extracted from fiberglass. Indeed, along the glass filaments, we see a pronounced magnetic anisotropy (Fig. 1c), which is determined by the anisotropy of the form of the films deposited on the surface of the glass fibers.

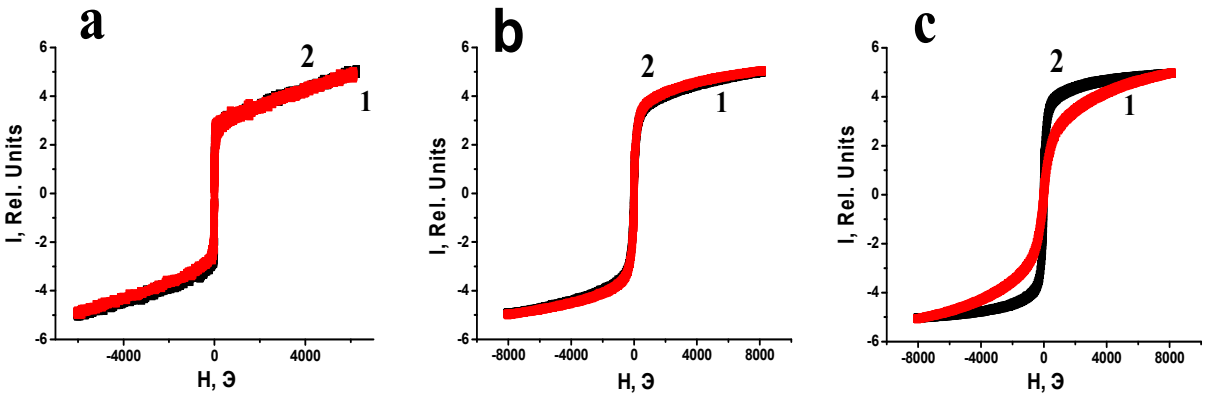

Fig. 1. The magnetization curves of the nanocomposite (Co40Fe40B20) 65 (SiO2) 35 measured in two orthogonal directions in the plane of the film (curve 1 and 2) on the sitall plates (b) and fiberglass along (curve 1) and across (curve 2) fibers of glass filaments (c).

This work was supported by RFBR grant № 16-45-360483 p_a and the Ministry of Education and Science in the framework of the project part of the state task.

DUAL CONTRAST AGENTS BASED ON GADOLINIUM DOPED MAGNETITE: SYNTHESIS, STRUCTURAL AND MAGNETIC STUDY, SURFACE MODIFICATION

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Magnetic Resonance Tomography, MRI, is one of the most used instruments for non-invasive clinical diagnostics. In contrast to radiological investigations, MRI has no danger of radiation exposure to produce images using radio frequency electromagnetic radiation with very low energy. The most researches in this area are focused on the development of contrast agents, that can provide a clearer distinction between healthy and diseased tissue. The majority of contrast agents are magnetic nanoparticles (MNP) [1]. MNPs made from iron oxide are used for the diagnostics of many diseases such as cardiovascular, neurological and cancer. Liver and prostate cancer are the most prevalent of malignant tumors. Hybrid contrast agents are among most popular trends for MRI providing comprehensive data on disease progression. Gadolinium chelates and magnetite are the most appropriate T1 and T2 contrast agents, respectively, but these compounds can provide toxic effect on healthy cells. One of the ways to prevent toxicity is the creation of hybrid contrast agents based on gadolinium doped magnetite [2], [3]. In this work gadolinium doped magnetite nanoparticles were prepared by thermal decomposition of iron-gadolinium complex in dibenzyl ether. These nanoparticles are designed to be used as a hybrid contrast agents for hepatocellular and prostate carcinomas visualization. Obtained nanoparticles were investigated by methods of transmission electron microscopy, X-ray diffraction, Mössbauer spectroscopy, dynamic light scattering, zeta potential and thermogravimetric analysis. Also the toxicity of nanoparticles and their T1 and T2-relaxation time were measured in vitro.

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[1] Z.R. Stephen, *MaterialsToday* **14**, 330 (2011).
[2] C. R. De Silva*, J. AM. CHEM. SOC*. **131**, 6336 (2009).
[3] F.J. Douglas, *RSC Adv*. **6**, 74500 (2016).

COMPUTER SIMULATION OF LOW-TEMPERATURE MAGNETIC MATERIALS SINTERING PROCESSES

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The methods of additive technologies make it possible to obtain products of complex shape with a predetermined structure and the required set of effective characteristics of the material. The technologies for creating of low-temperature materials are characterized by the fact that the material is consolidated by a low-melting matrix at a temperature lower than the melting temperature of the low-melting component. This allows to create gentle sintering conditions for refractory magnetic inclusions, providing the required set of physics-mechanical properties of the synthesized composite. The research of technological regimes of synthesis of low-temperature magnetic composite materials formed due to layer-by-layer sintering from mixtures of powders of various components were carried out by developing the approach of computer modeling of low-temperature composite materials, taking into account rheological processes in powder bodies, concentration and fractional heterogeneity of the initial mixture [1]. The model structure of the initial compact shows the general inhomogeneity of the concentrations and sizes of the powder components and pores. An approach that combine ideology and tools of solid state physics and micromechanics of media with structure is used [2].

It is believed that the model structure of a polydisperse mixture of refractory components in each microvolume is represented by particle size values of individual fractions, as well as by volume part of each fraction in a polydisperse mixture of refractory components. The ultra-microheterogeneous refractory components of the fraction are attached to the dispersion medium, forming and modifying its characteristics in a mixture of initial components. The prediction of the possibility of forming the skeleton of refractory particles at macro, meso-, or mini-levels determines the forecast of the minimum porosity of the sintered body in accordance with the conditions for achieving mechanical contact of the particles of the researching fraction depending on the nature of the discrete model distribution of fractions. The carried out researches showed that the use of refractory components with a polymodal particle size distribution in the composition of the initial mixture makes it possible to obtain low-porous low-temperature composites [1].

Numerical researches are based on an adapted computer simulation scheme [3] for powder systems. The nonlinear problems of heat and mass transfer, sintering of the disperse system with taking into account possible phase transitions, thermal destruction of individual components, changes in the phase and concentration composition are solved numerically at all technological stages of sintering. All the characteristics of the medium are considered to be effective with taking into account local concentrations and state parameters in microvolumes of the model body formed due to discretization of the computational area. All parameters of the simulated medium are refined iteratively at each time point for each micro volume.

[1] V.N. Leytsin, M.A. Dmitrieva, A.O. Tovpinets, I.V. Ivonin, S.V. Ponomarev., *AIP Conference Proceedings* **1783**, 020132 (2016).
[2] V.N. Leitsin, M.A. Dmitrieva, T.V. Kolmakova, Editors Lotte J. Smit and Julia H.Van Dijk. *Nova Science Publishers, Inc. NY* (2008).
[3] V.N. Leitsin, M.A. Dmitrieva, T.V. Kolmakova, I.V. Kobral', *Russian Physics Journal.* **49** (11) 1198-1203 (2006).

MAGNETORESISTIVE EFFECT IN OXYGEN-FREE $(Co_{47}Fe_{42}Zr_{11})_x(MgF_2)_{100-x}$ NANOCOMPOSITES

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Investigation of magnetic and electrical properties of oxygen-free thin film systems $(Co_{47}Fe_{42}Zr_{11})_x(MgF_2)_{100-x}$ were carried out. For the experiments we used samples obtained by ion-beam sputtering of composite targets. In the above studies, the following methods were used: x-ray diffraction (study of the composites structure), two-probe potentiometry (study of the electrical properties) and placing the samples in a magnetic fields up to 10 kOe (study of the magnetoresistive properties).

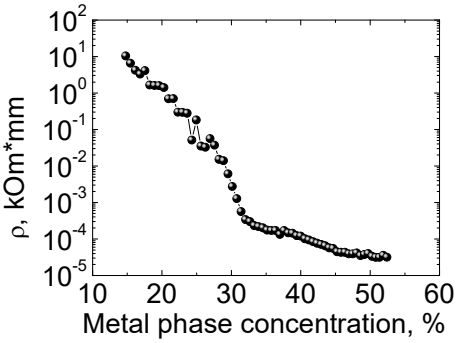

Figure 1 - Concentration dependence of the electrical resistivity of the $(Co_{47}Fe_{42}Zr_{11})_x$ $(MgF_2)_{(100-x)}$ composites

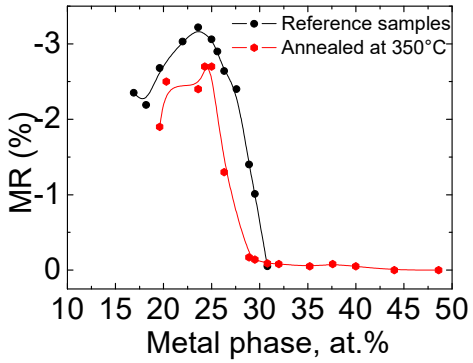

Figure 2 - Concentration dependence of magnetoresistance of the $(Co_{47}Fe_{42}Zr_{11})_x(MgF_2)_{100-x}$ composites

The composition of the obtained samples smoothly varies in a wide range of the metal phase concentrations (7≤ metallic phase, at.% ≤ 55). As a result of the deposition process a heterogeneous two-phase structure was formed. The x-ray diffraction confirms the presence of two-phase (composite) structure in all studied samples.

The thickness of the obtained thin films varies from 1 to 3 μm. The graph of the dependence is shown in Figure 1. The concentration dependence of the resistivity of the samples is typical for metal-insulator composite systems. There is a section of sharp decrease in resistance, which corresponds to the percolation threshold. The estimation of the percolation threshold position corresponds to 27 at.% of the metal phase. The magnetoresistive (MR) effect of $(Co_{47}Fe_{42}Zr_{11})_x(MgF_2)_{100-x}$ samples with different concentrations of the metal phase was studied (Figure 2). The magnetoresistive effect is isotropic and has a tunneling nature. The maximum values of MR in this system do not exceed 3.25% at 25-26 at. % Me, which corresponds to the percolation threshold of the studied system.

It is assumed that relatively small values of MR can be associated with the defectiveness of the dielectric matrix, which leads to a significant contribution of the hopping conductivity independent of the magnetic field and not contributing to the magnetoresistive effect. Defects in the matrix can be explained by the formation of zirconium fluoride, since this process is energetically favorable.

MAGNETIC PROPERTIES AND STRUCTURAL PHASE TRANSITION OF A_2MMoO_6 (A = Sr, Ba; M = Ni, Mg, Co)

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Compounds with double perovskites structures can be described by the general formula $A_2MM'O_6$, where A is rare-earth ion, M and M' are transition metal cations [1]. These materials have recently attracted extensive attractions in both scientific research and practical industrial applications as anode for intermediate temperature solid oxide fuel cell (IT-SOFC) [2]. SOFCs are highly efficient devices for direct production of electricity from hydrocarbon fuels.

The aim of this work is to study the structural and magnetic properties of A_2MMoO_6 compounds (A = Sr, Ba; M = Ni, Mg, Co). Polycrystalline samples were synthesized by nitrate solutions method. X-ray powder diffraction (XRD) measurements were performed at high-resolution diffractometer BRUKER, Advance D8 (Seoul, Korea). Magnetic measurements were recorded with MPMS-XL-7 (Ekaterinburg, Russia) with a primary converter based on SQUID.

XRD patterns were carried out in the temperature interval (290–600) K, with a step of 50 K for Sr_2NiMoO_6, $Sr_2Ni_{0.75}Mg_{0.25}MoO_6$, Sr_2CoMoO_6 and $SrBaNiMoO_6$ samples. The Sr_2NiMoO_6 sample possesses tetragonal structure (*I4/m*) in the temperature range of (297–490) K, and above 500 K, there is a phase transition to cubic structure (*Fm3m* space group). The phase transition temperature increases to 530 K when the magnesium doped with Sr_2NiMoO_6 samples. It may be connected with a more significant tetragonal distortion introduced by Mg^{2+}, as described in [2]. By doping Sr_2NiMoO_6 with Barium, the structural phase transition disappears. Similar to Sr_2NiMoO_6 samples, the Sr_2CoMoO_6 has possessed tetragonal structure in the temperature range of (297–380) K and above 390 K, there is a phase transition to cubic structure (*Fm3m* space group). But comparing with literature [3], this temperature is lower by about 100 degrees. We measured also the low-temperature dependences of the magnetic susceptibility A_2MMoO_6 on cooling in a constant magnetic field ($\mu_0 H$ = 1 kOe) in the temperature range (2–300) K and 1 K step. The susceptibility increases, when temperature decreases from 300 K. The susceptibility achieves a maximum value (Neel temperature) at ~83 K, 70 K and 36 K for Sr_2NiMoO_6, $SrBaNiMoO_6$ and Sr_2CoMoO_6 respectively.

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[1] A. Eriksson, et. al., *Mat. Res. Bul.* **41**, 144 (2006).
[2] E. Filonova, et. al., *Sol. St. I.* **262**, 365 (2014).
[3] A. Aguadero, et. al., *J. App. Ph.* **109**, 034907 (2011).

INVESTIGATION OF STRUCTURAL AND MAGNETIC PROPERTIES OF Sm-Fe-BASED ALLOYS MODIFIED BY PARTIALLY SUBSTITUTING Sm WITH Ho, THEIR HYDRIDES AND NITRIDES

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R_2Fe_{17} binary compounds (R is a rare earth element) attract the greatest attention of reseachers as permanent magnet materials due to their large iron content. They have low Curie temperature values and planar anisotropy at room temperature, therefore it makes them unsuitable for their technological applications as hard magnetic materials. But it has been well known that substantial improvements in the magnetic properties is observed after hydrogenation and particularly nitrogenation of Sm_2Fe_{17}. Thus, for $Sm_2Fe_{17}N_y$ the easy magnetization direction changes to the *c*-axis and Curie temperature is increased significantly. As it has been previously reported, the substitution of Sm for R or by substituting Fe by nonmagnetic or weak magnetic atom M in Sm_2Fe_{17}-based ternary compounds such as $Sm_{2-z}R_zFe_{17}$, $Sm_2Fe_{17-y}M_y$ and hydrogen, nitrogen insertion was employed to enhance magnetic properties. In this context, it may turn out to be interesting to investigate the combining effects to the structural and magnetic properties of Sm_2Fe_{17} by the substituting atoms R or M and interstitial atoms H/N simultaneously.

The aim of this work is the synthesis of parent alloys having nominal compositions $Sm_{2-x}Ho_xFe_{17}$ with x = 0,4 and 0,8 as well as hydrides, nitrides based on them, studing of the influence effects of H and N on the structural and magnetic properties of test samples. Alloys with indicated composition were prepared by induction melting constituent elements of at least 99,9 % purity in Ar atmosphere, followed by annealling in vacuum at 1050 °C for 7 and 14 days respectively. Then all synthesized materials were characterized by XRD, SEM, VSM. X-ray diffraction experiments were performed on powder samples and as-milled powders using Co Kα radiation to determine the phase structure and the lattice parameters, the data were analyzed by means of the Rietveld prifile refinement technique. The analysis of the XRD patterns demonstrated for all compositions and interstitial hydrides, nitrides the rhombohedral Th_2Zn_{17}-type structure is observed. There is a small amount of α-Fe in addition to the main phase. $Sm_{2-m}Ho_mFe_{17}H_n$ where n=4,8 and 4,4 hydrogen atoms per f.u. were produced in the temperature range 180-250 °C under pressure 30 atm. The nitrides with preliminary hydrogenation-dehydrogenation cycle were received near 450÷10 °C in a N_2 gas atmosphere with a pressure up to 40 atm. The maximum nitrogen content was determined to be 2,5H/f.u. The X-ray reflections of hydrides, nitrides are shifted to lower angles as a result of the lattice expansion. It was establised that the introduction of H and N atoms leads to an increase in the lattice constants and saturation magnetization, but this fact becomes smaller with raising Ho concentration. Magnetic measurements at temperature 300 K were measured using a PPMS Ever Cool-II magnetometer in a maximum magnetising field of 5T respectively. It has been shown that magnetic properties such as the specific saturation magnetization, specific remanent magnetization, and coercive force by the magnetization depend strongly on the Ho concentration. It was found that the Sm-Ho-Fe-N powders milled for different time (15, 30, 45 min) possess better intrinsic magnetic properties than parent samples, their hydrides and nitrides before RT milling.

MAGNETIC FIELD CONTROLLED HEATING OF FUNCTIONALIZED POLYMERIC IMPLANTS

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It's known that implantation of foreign synthetical biomaterials produces immune response, which implies the inflammation and formation of connective tissue shell [1]. Magnetic implants based on magnetically functionalized electrospun polymeric matrices are proposed to be used for preventing fibrotic structures formation as well as for malignant tumor treatment [2].

In our experiment we observed the heating dynamics of functionalized implants in the form of polymeric electrospun matrices with magnetite nanoparticles of average size 650 nm (size dispersion 350 nm) at various frequencies of AC magnetic field. The sample size, thickness and mass were 2x2 cm, 0.25 mm, and 0.060 mg, respectively. The heating of 1 ml of water up to temperature of 45 C was reached (fig. 1).

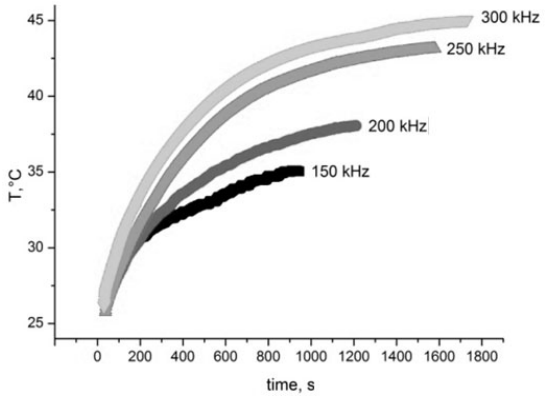

Figure 1. Heating of 1 ml of water by polymeric implant sample on different frequencies of oscillating magnetic field.

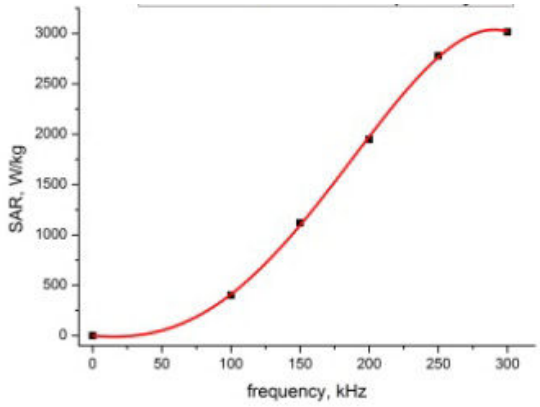

Figure 2. Dependence of SAR on frequency.

The dependence of SAR (Specific Absorption Rate) on frequency calculated from Fig.1 shows the saturation that can be attributed to the large value of Neel relaxation time for these type of submicron particles (figure 2). Since the temperature in the range of 40-45°C was achieved, the proposed approach for control of undesirable foreign body reaction using magnetically functionalized polymeric matrices is technologically feasible.

The support of Foundation for Assistance to Small Innovative Enterprises in Science and Technology (project #C1-21200) is acknowledged.

[1] Spear SL, Baker JL Jr., *Plast Reconstr Surg.* **96**, 1119 (1995).
[2] Huang C et al., *Advanced Functional Materials* **22**, 2479 (2012).

SINGLE CRYSTAL GROWTH OF STRONTIUM HEXAFERRITE $SrFe_{12}O_{19}$

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The raw materials that were used in this study consist the iron oxide Fe_2O_3 and strontium carbonate $SrCO_3$. Sodium carbonate Na_2CO_3 was chosen as solvent. Before weighing all substances were dried at 500 °C during 5 hours. The initial mixture (24.5 g) was ground in a ball milling and filled into a 30 mL platinum crucible.The crucible was placed in a resistance furnace equipped with a thermocouple type B and a precision thermoregulatory RIF-101. To homogenize the starting materials, the furnace was maintained at 1260 °C for 3 h followed by cooling at a rate of 4.5 K/h to 900 °C. Then the system was allowed to naturally cool to room temperature. The spontaneously obtainedcrystals were separated from the flux by leaching in hot nitric acid.

The compositions of the samples were determined using an electron microscope Jeol JSM7001F with an energy dispersive spectrometer Oxford INCA X-max 80. The average compositions of one of the samples are listed in Table 2. There were 3 elements: O, Fe and Sr. Mapping elements showed a uniform distribution of strontium over the entire surface and the only one phase in the samples.

Powder X-ray diffraction analysis was performed on a Rigaku Ultima IV diffractometer in the angular range from 10° to 90°. For investigations 8 hexagonal single crystal plates were selected from experiment.The diffractograms of all the samples corresponds to magnetoplumbite M-type strontium hexaferrite (space group P63/mmc). PXRD pattern is presented in Fig.1 in the top. Spikes in bottom correspond to $SrFe_{12}O_{19}$ [1]. The range from 25° to 40° is presented in the right top corner.The cell parameters are given in Table 3. The last column consists of cell parameters of data [2].

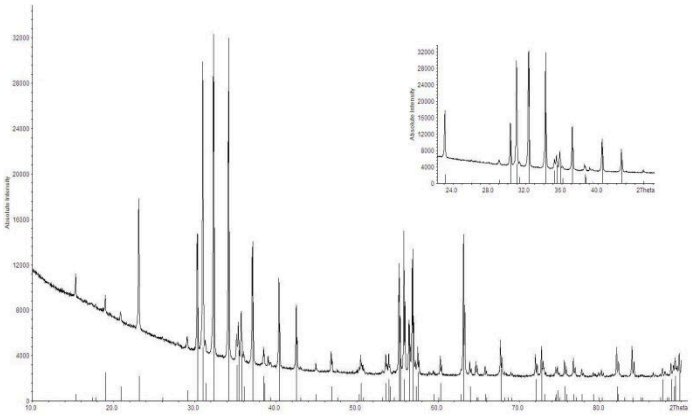

Fig.1. PXRD patterns of sample

$SrFe_{12}O_{19}$ ferrite single crystals were grown from sodium oxide based flux using spontaneous crystallization. The structural and morphological characterization of the grown samples were done. It can be concluded that all samples have hexagonal crystal structure. Only one magnetoplumbite phase was detected. The diffraction patterns of $SrFe_{12}O_{19}$ are in agreement with literature data. Experimental cell parameters were calculated: a=5.8832(4) Å, c=23.0361(14) Å. The cell volume is V=690.51(6) $Å^3$.

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[1] J. Muller, A. Collomb, *J. Magn. Magn. Mater.* **103**, 194 (1992).
[2] F. Bertaut, A. Delapalme, G. Bassi, *J. de Physique France.* **25**, 545 (1964).

MODELING OF FERROFLUID-BASED MICROVALVES IN THE MAGNETIC FIELD CREATED BY A CURRENT-CARRYING WIRE

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Introduction. The use of ferrofluid in microvalves is one of actuation methods in microfluidics. In [1] it is shown that a level of pressure in the range of decades of millibar can be expected from a ferrofluid. Different magnetic fields could be used to actuate the ferrofluid: for example, external magnets [2] and a microcoil [3]. In the present paper, we propose a ferrofluid-based microvalve to open or close the flow in a microchannel by imposing the magnetic field of a straight current-carrying wire.

Methods. We consider a microvalve (Figure 1) based on a heavy, incompressible, homogenous, isothermal ferrofluid between two conical surfaces with different apex angles α_1, α_2 and a cylinder of the radius R_c. There is a wire of the radius r_0 with the current I on the axis of these surfaces. It should be noted that such ferrofluid bridge between coaxial cylinders [4] cannot sustain any pressure drop in contrast to this problem where there is the pressure drop $\Delta p = p_1 - p_2$. The ferrofluid is immersed in a non-magnetic liquid with the same density. We use the Langevin law to describe a ferrofluid magnetization. We get the general analytical solution for any axially symmetric shape of the ferrofluid surface in the magnetic field of a wire from the hydrostatic equation and the boundary condition on the ferrofluid surface. Numerical modeling of the microvalve behavior for different values of ferrofluid volumes and currents based on this analytical solution is done in the computing environment Maple.

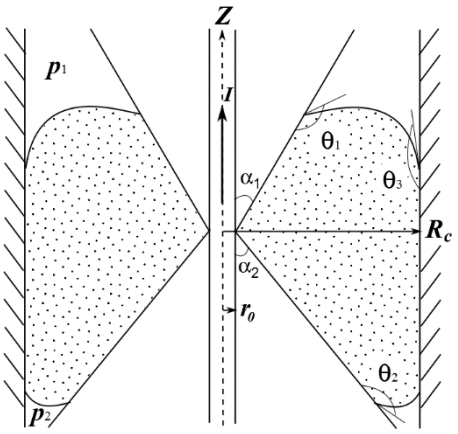

Figure 1

Results. It is shown that the presence of limiting conical surfaces allows the ferrofluid to sustain the pressure drop, which is much bigger in case of non-wetting ($90° < \theta_1, \theta_2, \theta_3 \leq 180°$) than in case of wetting ($0° \leq \theta_1, \theta_2, \theta_3 \leq 90°$). In case of wetting the ferrofluid cannot sustain any pressure drop for small currents in the wire, but in case of non-wetting the ferrofluid-based microvalve can do it even for zero current. Spasmodic and hysteresis phenomena are possible for some values of ferrofluid volumes and currents. Presence or absence of these phenomena should be taken into account in the design of microvalves with controlled ferrofluid volumes, in which the magnetic field is changed periodically.

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[1] R. Pérez-Castillejos, J.A. Plaza, J. Esteve, et al., *Sensors and Actuators A* **84** (2000).
[2] H. Hartshorne, C.J. Backhouse, W.E. Lee, *Sensors and Actuators B* **99** (2004).
[3] T.G. Liu, J. Wu, C. Xia, Z.H. Qian, *Advanced Materials Research*, 433-440 (2012).
[4] V.A. Naletova, V.A. Turkov, A.S. Vinogradova, *Physics Procedia* **9** (2010).

LARGE MAGNETOCALORIC EFFECTS IN $Ni_{43}Mn_{46}Sn_8In_3$ HEUSLER ALLOY

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Ni-Mn-X-based Heusler alloy (X = Sn, In, Sb) is one of the most interesting materials due to its physical effects related to the martensitic distortion, ferromagnetism and various exotic phenomena. The coexistence of the conventional and the inverse magnetocaloric effects associated with negative and positive values, respectively, of magnetic entropy change (ΔS_m) with the large values of maximum magnetic entropy change (denote as $|\Delta S_{max}|$) have been found. In this work, a systematic study of the magnetocaloric effect and the critical behavior in $Ni_{43}Mn_{46}Sn_8In_3$ Heusler alloy has been performed. The results reveal the sample exhibiting structural and magnetic phase transitions at temperatures T_C^M = 166 K (T_C of the martensitic phase), $T_{M\text{-}A}$ = 260 K (the martensitic-to-austenitic phase transformation) and T_C^A = 296 K (T_C of the austenitic phase). Large values of refrigerant capacity (*RC*) around $T_{M\text{-}A}$ and T_C^A are found to be $RC_{M\text{-}A}$ = 172.6 and RC_A = 155.9 $J \cdot kg^{-1}$, respectively, under an applied field change of 30 kOe. Using the Modified Arrott plots method, the critical behaviors near T_C^M and T_C^A have been also analyzed. We pointed out that a coexistence of the long- and short-range ferromagnetic order in the martensitic phase, while the long-range ferromagnetic order exists in the austenitic phase. Interestingly, at around T_C^A, the maximum magnetic entropy change ($|\Delta S_{max}|$) versus magnetic field *H* obeys a power law of $|\Delta S_{max}| = a \cdot H^n$, where the exponent *n* is found to be about 0.66, which is very close to that of the mean-field theory. The nature of the observed phenomena is discussed thoroughly via the coupling between the structure and magnetism.

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