The 3rt International Baltic Conference on Magnetism

IBCM 2019

Book of Abstracts

Kaliningrad, Russia
18-22 August, 2019

International Baltic Conference on Magnetism:

nanobiomedicine and smart materials

Kaliningrad, Russia; August 18-22, 2019

IBCM 2019 is organized by Laboratory of Novel Magnetic Materials,

Institute of Physics, Mathematics and Information Technology,

Immanuel Kant Baltic Federal University

Main Topics:

- Magnetic materials for biomedicalapplications
- Manipulation of nanoparticles.Tweezers
- Hyperthermia
- Drug delivery
- Magnetic resonance imaging
- Magnetic particle imaging
- Microfluidics + nanoparticles
- Lab-on-a-chip
- Bio-sensors
- Modeling and simulation mehods
- Design of novel permanent magnets
- Magnetocaloric and multicaloric materials
- Phase transitions and magneticmaterials
- Multiphase and compositematerials
- Magnetostrictive and magnetoelasticmaterials

Organizers:

- Conference chair:

  Assoc. Prof., Dr. Valeria Rodionova (IKBFU,Kaliningrad, Russia)
  Contact phone: +7-900-3468482
  E-Mail: rodionova@lnmm.ru
- Scientific & Technical secretary:

  Mrs. **Irina Baraban** (IKBFU, Kaliningrad,Russia)
  Contact phone:+7-921-8512565
  E-mail: machay@lnmm.ru

Conference E-Mail: IBCM@lnmm.ru

Program committee:

- Prof. **Michael Farle**

  Group Leader of Research of M. Farle
  University of Duisburg-Essen, Duisburg, Germany
- Prof. **Dino Fiorani**

  Research Director Associate to Institute of Structure of Matter, Rome, Italy

Local committee:

- Dr. Kateryna Levada
- Dr. Abdulkarim Amirov
- Dr. Cristina Gritsenko
- Dr. Vladimir Rodionov
- Mr. Victor Belyaev
- Mr. Ivan Kozenkov
- Mrs. Elena Kozenkova
- Mr. Alexander Omelyanchik
- Mr. Stanislav Pshenichnilov
- Mr. Kirill Sobolev
- Mr. Dmitry Murzin
- Ms. Valeria Kolesnikova
- Mr. Anton Berg

We acknowledge:

- Dr. Maxim Demin

  Vice-Rector for Research (IKBFU, Kaliningrad, Russia)

- Prof. ArtyomYurov,

  Director of Institute of Physics, Mathematics and Information Technology (IKBFU, Kaliningrad, Russia)

- Dr. AndreyShpilevoy,

  Vice-Director of Institute of Physics, Mathematics and Information Technology (IKBFU, Kaliningrad, Russia)

Conference is sponsored and supported by:

Immanuel Kant Baltic Federal University

CONTENTS

PLENARY LECTURES

Magnetocaloric Effect: From Energy Efficient Refrigeration to Fundamental Studies of Phase Transitions

V. FRANCO[a,*]

[a]Dpto. Física de la Materia Condensada. Universidad de Sevilla. P.O. Box 1065. 41080-Sevilla, Spain

*vfranco@us.es

The magnetocaloric effect, that is, the reversible temperature change experienced by a magnetic material upon the application or removal of a magnetic field, has become a topic of increasing research interest due to its potential applications in refrigeration at ambient temperature that is energy efficient and environmentally friendly [1]. From a technological point of view, the improvement of magnetic refrigeration systems can have a notable impact on society: a large fraction of the electricity consumed in residential and commercial markets is used for temperature and climate control. From the point of view of magnetic materials, research on this topic mainly focuses on the discovery of new materials with lower cost and enhanced performance. In addition, the characterization of the magnetocaloric effect can be used for more fundamental studies of the characteristics of phase transitions.

I will cover an overview of the phenomenon and a classification of the most relevant families of alloys and compounds. I will analyze possible limitations for the optimal performance of the materials in magnetic refrigerators, including hysteretic response and cyclability. Regarding phase transitions, I will present a new method to quantitatively determine the order of thermomagnetic phase transitions using the field dependence of the magnetic entropy change [2]. For second-order phase transition materials, I will show that critical exponents can be determined using the magnetocaloric effect even in cases where the usual methods are not applicable [3]. In the case of first-order phase transitions, more details about their hysteretic response can be obtained using T-FORC [4].

[1] V. Franco, J. S. Blázquez, J. J. Ipus, J. Y. Law, L. M. Moreno-Ramírez, and A. Conde, "Magnetocaloric effect: From materials research to refrigeration devices," Prog. Mater.Sci., 93, 112-232 (2018).

[2] J. Y. Law, V. Franco, L. M. Moreno-Ramirez, A. Conde, D. Y. Karpenkov, I. Radulov, K. P. Skokov, and O. Gutfleisch, "A quantitative criterion for determining the order of magnetic phase transitions using the magnetocaloric effect," Nat. Commun., 9, 2680 (2018).

[3] V. Franco and A. Conde, "Scaling laws for the magnetocaloric effect in second order phase transitions: From physics to applications for the characterization of materials." Int. J. Refrig., 33, 465-473, (2010).

[4] V. Franco, T. Gottschall, K. P. Skokov, and O. Gutfleisch, "First-order reversal curve (FORC) analysis of magnetocaloric Heusler-type alloys," IEEE Magn. Lett., 7, 6602904, (2016).

Magnetoplasmonic Nanodomes as a Novel Structure for Biomedical Applications

J. Nogués,[A,*], Z. Li[a], A. Aranda-Ramos[b], A. López-Ortega[c], P. Güell-Grau[a], J.L. Tajada[a], L. Pou-Macayo[b], F. Pi[b], S. Lope Piedrafita[b], M.D. Baró[b], J. Sort[b], P. Vavasori[c], C. Nogués[b], B. Sepúlveda[a]

[a]Catalan Institute of Nanoscience and Nanotechnology (ICN2), Barcelona, Spain

[b]Universitat Autònoma de Barcelona, Bellaterra, Barcelona, Spain.

[c]CIC nanoGUNE, Donostia-San Sebastian, Spain

*****Josep.Nogues@icn2.cat

Advanced nanobiomedical applications have been traditionally based on chemically synthesized inorganic nanoparticles. Here we present a novel type of structure especially suited for diverse biomedical uses: magnetoplasmonic nanodomes [1,2]. The nanodomes are composed of a combined, magnetic and plasmonic, hemispherical shell deposited onto 100 nm diameter polystyrene beads. The variation of the materials and their thicknesses in the shell enables tuning both the optical and magnetic properties of the nanostructures. The very high plasmonic absorption of the nanodomes in the near-infrared is used for very efficient local optical heating, i.e., photo-hyperthermia for cancer treatment [1]. The nanodomes magnetic character allows to remotely manipulate them to easily regulate the level of photo-hyperthermia. Moreover, given their asymmetric shape they exhibit strong optic and magnetic anisotropies. Thus, the rotation of the nanodomes using alternating magnetic fields can easily tracked optically using their different absorption depending on the orientation. Since the rotation of the nanoparticles depends strongly on the viscosity of the medium, which in turn depends on the temperature, the optical tracking of the rotation can be used to accurately determine the local temperature around the nanodomes, i.e., nanothermometry [2]. Combining the nanodomes efficient photo-hyperthermia with their nanothermometry capabilities, allows in-situ tracking the efficiency of photo-hyperthermia treatments.

[1] Z. Li, et al. Appl. Mater. Today 12, 430 (2018)
[2] Z. Li, et al. Small 14, 1800868 (2018).

Tuning anisotropy in magnetic nanostructures for biomedical applications

HARI SRIKANTH

Department of Physics, University of South Florida, Tampa, FL USA

*sharihar@usf.edu

Magnetic nanoparticles have been building blocks in applications ranging from high density recording to spintronics and nanomedicine [1]. Magnetic anisotropies in nanoparticles arising from surfaces, shapes and interfaces in hybrid structures are important in determining the functional response in various applications. In this talk I will first introduce the basic aspects of anisotropy and discuss resonant RF transverse susceptibility, that we have used extensively, as a powerful method to probe the effective anisotropy in magnetic materials. Tuning anisotropy has a direct impact on the performance of functional magnetic nanoparticles in biomedical applications such as contrast enhancement in MRI and magnetic hyperthermia cancer therapy. I will focus on the role of tuning surface and interfacial anisotropy with a goal to enhance specific absorption rate (SAR) or heating efficiency. Strategies going beyond simple spherical structures such as exchange coupled core-shell nanoparticles, nanowire, nanotube geometries can be exploited to increase heating efficiency in magnetic hyperthermia [2,3]. In addition to biomedical applications, composites of anisotropic nanoparticles dispersed in polymers pave the way to a range of electrically and magnetically tunable materials for RF and microwave device applications [4]. This lecture will combine insights into fundamental physics of magnetic nanostructures along with recent research advances in their application in nanomedicine and electromagnetic devices.

[1] E.A. Périgo et al., "Fundamentals and advances in magnetic hyperthermia", *Appl. Phys. Rev.* vol. 2, 041302 (2015)
[2] Z. Nemati et al., "Core-shell iron/iron oxide nanoparticles: Are they promising for magnetic hyperthermia?",*RSC Advances* vol. 6, 38697 (2016)
[3] H. Khurshid et al., "Tuning exchange bias in Fe/γ-Fe_2O_3 core-shell nanoparticles: Impacts of interface and surface spins", *Appl. Phys. Lett.* vol. 104, 072407 (2014)
[4] K. Stojak et al., "Polymer nanocomposites exhibiting magnetically tunable microwave properties", *Nanotechnology* vol. 22, 135602 (2011)

Functional biogenic magnetism

M.Winklhofer,

University of Oldenburg

In nature, functional magnetic nanoparticle chains occur as magnetosomes in magnetotactic bacteria where they serve the purpose of magnetic navigation. Typically, a bacterial magnetosome chain consists of 10-20 magnetite particles (Fe_3O_4, 35 - 60 nm particle size), each representing a single magnetic domain, which have coherent magnetic polarity along a chain and thus sum up to produce a stable magnetic dipole moment. The magnetic to thermal ratio of a magnetosome chain is ca. 10, which keeps the cell body of the bacterium aligned with the Earth' s magnetic field when swimming in the water. Because each magnetic particle in a chain is surrounded by a biological membrane, adjacent particles are exchange decoupled and interact only through dipolar coupling. As will be shown here, a 10 GHz microwave field(3 cm wavelength in vacuum) can be accommodatedin a magnetosome chain in the form of a magnetostatic spin wave with a wavelength of only 100 nm.Also,the spin-wave spectrum and band-gap structure can be tuned via the chain geometry [1]. This has exciting consequences for truly nanoscale magnonic devices.

[1] Zingsem et al. (2019) Biologically encoded magnonics. Nature Communications (accepted)

INVITED TALKS

Magnetic nanoparticles in cancer therapy and diagnostic

M.A. ABAKUMOV[a,b*]

[a]Pirogov Russian National Research Medical University, Ostrovitianov Str. 1, Moscow, 117997, Russian Federation

[b]National Research Technological University "MISiS", Biomedical Nanomaterials, Leninskiy prospekt 4, Moscow, 119049, Russian Federation

*abakumov_ma@rsmu.ru

In past decades extensive development of nanomaterials for medicine has created new opportunities for improved of diagnostics and therapy of oncological diseases. One such new nanomaterials are magnetic nanoparticles. Possessing unique combination of magnetic, chemical and surface properties they can be used as an effective drug carriers, MRI contrast agents, for biologicl samples separation and many others. Our work is devoted to optimization of chemical design of such magnetic nanoparticles to increase their effectiveness in cancer treatment and diagnostics.

For combined drug delivery and MRI imaging we have developed complex system based on iron oxide nanocrystals, coated with human serum albumin (HSA-MNP) with following crosslinking with formation of stable biocompatible shell. Physicochemical properties of HSA-MNP were investigated in details by HAADF-TEM, DLS, AFM, also magnetization and T2 relaxation properties were investigated. HSA serves as a natural transport protein for xenobiotics in blood and can effectively bind drug molecules to surface. Our experiments have shown that HSA-MNP were able to bind doxorubucin and bacteriochlorine a (PS) molecules, effectively deliver this drugs to tumor cells and tissue. Particularly for doxorubicin loaded nanoparticles we have shown effective imaging of 4T1 mouse breast cancer model accompanied with increase of median survival from 26 to 39 days.

PS loaded HSA-MNP has shown similar photoinduced cytotoxicity in comparison with free drug and were stable in water solution for few weeks. Moreover in vivo experiments with mice bearing tumors have shown that after i.v. injection of PS loaded HSA-MNP we were able to detect PS delivery to tumor by both MRI and in vivo fluorescence. Also it was shown that PS loaded MNP can be used as a predictor for proper time management of PDT in vivo.

This results allow to propose HSA coated MNP as a perspective tool for drug delivery of different antitumor drugs for cancer treatment.

Understanding interface spin transport for smart synthetic magnetic materials

D. ATKINSON [a*]

[a]Department of Physics, Durham University, DH1 3LE, UK

*del.atkinson@durham.ac.uk

There are many exciting areas of research linked to interfacial effects in FM/NM systems, such as interface spin-orbit interactions (SOI), spin-currents from the spin Hall effect (SHE), spin-orbit torques (SOT) [1], interfacial Dzyaloshinskii-Moriya interaction (DMI), proximity-induced-magnetization (PIM) of non-magnetic metals and ferromagnetic damping where interfacial effects and spin pumping into non-magnetic layers can yield new insights. Here, interfacial DMI and proximity-induced-moments in NM transitions metals in direct contact with FM thin-films and the influence of interfacial structure and spin-diffusion length on spin-transport are described.

The interfacial DMI and PIM in Pt was studied as a function of Au and Ir spacer layers in Pt/Co/Au,Ir/Pt. The length-scale for both interactions is sensitive to sub-nanometre changes in the spacer thickness, and they correlate over sub mono-layer spacer thicknesses, but not for thicker spacers. The spacer layer thickness dependence of the Pt PIM for both Au and Ir shows a rapid monotonic decay, while the DMI changes rapidly but has a two-step approach to saturation and continues to change, even after the PIM is lost [2]. The effect of DMI and damping on domain wall behaviour in NiFe/Pt nanowires is also discussed [3].

Spin transport across FM/NM interfaces is introduced [4] and, the effects of interface structure [5] and NM thickness [6] on spin current propagation across the interface are discussed in terms of the spin-flip probability and new insight that shows a consistent understanding is obtained when a thickness dependent spin-diffusion length in the NM layer is used. An extensive set of samples varying the thickness of both the FM and NM layers was analysed with spin-pumping theory that was further developed to include a thickness dependent spin-diffusion length that was linked to the thickness dependence of the resistivity. This new analysis shows the importance of interface structure and a thickness dependent spin-diffusion length [7].

Funding is acknowledged for this work for the UK EPSRC studentships to R. Rowan-Robinson and C. Swindells and national government scholarships for S. Azzawi from Iraq and M. Tokaç from Turkey, and a *Science without Borders* Fellowship for Dr. J. Brandão from Brasil. We also acknowledge beam time and support from L. Bouchenoire at the EPSRC XMaS beamline at the ESRF. D Atkinson acknowledges funding from the Royal Society for an Industry Fellow.

[1] Rowan-Robinson R. Hindmarch A.T. & Atkinson D. *J.Appl. Phy.* 124, 183901 (2018)
[2] Rowan-Robinson R., Stashkevich A.A., Roussigne Y., Belmeguenai M., Cherif S-M, Thiaville A.,Hase T.P.A., Hindmarch A.T., & Atkinson D. nature.com/scientific reports 7: 16835 (2017)
[3] Brandão J. Azzawi S., Hindmarch A.T. & Atkinson D. scientific reports 7: 4569 (2017)
[4] Azzawi, S.Hindmarch A.T. & Atkinson D. *J Phys D: Appl. Phys.* 50,473001 (2017)
[5] Tokaç M., Bunyaev S.A., Kakazei G.N., Schmool D., Atkinson D. &HindmarchA.T. *Phys. Rev. Letts.* 115 056601 (2015)
[6] Azzawi M. Ganguly A, Tokac M., Rowan-Robinson R., Sinha J., Hindmarch A.T., Barman A. & D. Atkinson*Phys Rev B* 93, 054402 (2016)
[7] Swindells C. Hindmarch A.T. Gallant A.J. & Atkinson D. *Phys Rev B* 99, 064406(2019)

TMek: A Revolutionary Rapid Diagnostic Test For Malaria

Giacometti M.[2], Milesi F.[1], Coppadoro P.L.[2], Ferrari G.[2], Fiore G.B.[2], Rizzo A.[4], Grande R.[4], Gismondo M.R.[4], Corbellino M.[3,]Antinori S.[3] and Bertacco R.[1]

[1]Department ofPhysics, Politecnico di Milano, Milano (Italy);

[2]Department ofElettronics Informaticsand Bioengineering, Politecnico di Milano, Milano (Italy);

[3]Department of Biomedical and Clinical Sciences "Luigi Sacco", Milano, Italy; [4]CLIMVIB Sacco Teaching Hospital, Milano(Italy)

The search for new rapid diagnostic tests (RDT)for malaria is a priority to fight this endemic disease, according to WHO recommendations[1]. In fact, available RDTbased on the detection of antigens, suffer from several limitations (i.e., are not quantitative, remain positive for up to 1 month, exibit prozone effect at high parasitaemas, may be falsely negative).

We present an easy to operate lab-on-chip diagnostic test (TMek) for the quantification ofthe plasmodium parasitaemia and hemozoin concentration in a blood smear. The method is based on the absolute paramagnetic susceptibility of hemozoin crystals[2] found within the infected red blood cells (RBC) and free in the blood of patients affected by malaria. A silicon microchip with an array of Nickel posts and some suitable electrodes is put in contact with a smear of blood (5 microL) diluted (1:10) with EDTA and PBS, in the field produced by external magnets. Due to the competition between the magnetic and the gravity forces, only infected RBC and hemozoin crystals are attracted towards the Nickel concentrators and electrodes. The entity of the electrodes impedance variation isthus proportional to the parasitemia and/or the hemozoin concentration.

The microchip, fabricated via optical lithography, is placed in a cartridge where the diluted blood smear is also loaded. After insertion of the cartridge in a portable reading unit, the quantification is automatically performed.

TMekwas tested at Sacco Hospital on control blood samples from healthy donors as well from patients affected by malaria, diagnosed by haemoscopy and LAMP (MalariaIllumigene – Meridian EU). Preliminary results show that the test has a limit of detection around 0.003%, comparable with that of currently used RDT. In just 10 minutes, a distinct quantification of both parasitemia and hemozoin crystals concentrationis carried out, thus providing complementary information on the illness status.

TMek has shown to hold a great potential for implementing a rapid, quantitative and pan-plasmodic test for malaria suitable for on-field use in endemic zones. A preclinical validation is planned for next April, in Cameroon, and related results will be presented at the conference.

[1]. World Health Organization, World Malaria Report 2017 (2017).
[2]. M. Giacometti, C. Rinaldi, M. Monticelli, L. Callegari, A. Collovini, D. Petti,G. Ferrari, and R. Bertacco, Electrical and magnetic properties of hemozoin nanocrystals, Appl. Phys. Lett., 113, 203703 (2018)

Nanoparticles as Multifunctional Probes for Cancer Theranostics

YANGLONG HOU[a,*], JIUHONG QIAN[b]

[a]Beijing Key Laboratory for Magnetoelectric Materials and Devices (BKLMMD)，College of Engineering, Peking University, Beijing 100871, CHINA

[b]Editorial Office of Rare Metals, Beijing 100088, CHINA

*hou@pku.edu.cn

Photothermal therapy(PTT), using light to cause thermal damage, is a revolutionaryapproach in tumor therapy because of its spatiotemporalcontrollability, high efficiency and minimal harm to normaltissues. However, without using imaging contrast agents,it is very difficult for PTT to achieve its precise therapeuticeffects since its accuracy is compromised[1-3].

Herein, we firstly introduced general protocol to produce multifunctional Fe_5C_2nanoparticles, which developed as multifunctional probes for imaging-guided cancer therapy owing to their magnetic features and additive photothermal characteristics. T_2-weighted MRI and PAT signals were observed, and tumors were effectively ablated by PTT under NIR irradiation without no obvious side effects [4]. In order to further develop iron carbides, we incorporated Au element, which has excellentoptical properties, into MNPs to form nanocomposites that can show both magnetic and optical properties in one unit. The material exhibited strongPTT effects with a 30.2% calculated photothermal transductionefficiency *in vitro*. Au-Fe_2C NPs were capable of MRI/multispectral photoacoustic tomography/computed tomography tri-modal imaging-guided PTT agents [5].

What's more, Au_3Cu tetrapod nanocrystals (TPNCs) were prepared by a facile seed-mediated growth method for imaging-guided PTT for tumors in the NIR-II window. The Au_3Cu TPNCs exhibited remarkable photostability, ability for deep tissue photothermal therapy and excellent photothermal performance with 75.27% photothermal conversion efficiency under 1064 nm laser irradiation, and could serve as efficient photoacoustic and photothermal agents. Furthermore, Au_3Cu TPNCs could achieve renal clearance through degradation in the tumor microenvironment after the process of PTT [6].

In summary, we developed multifucntional nanoparticles, including Fe_5C_2, Au-Fe_2C NPs and Au_3Cu TPNCsas a multifunctional probes for cancer treatment.

[1] R. Hao, R. Xing, Z. Xu, Y. Hou, S. Gao, S. Sun, *Adv. Mate*r. 22 (2010) 2729–2742.
[2] Z. Xu, C. Shen, Y. Hou, H. Gao, S. Sun. *Chem. Mater*.21(2009), 1778−1780.
[3] J. Yu, F. Chen, W. Gao, Y. Ju, X. Chu, S. Che, Y. Hou. *Nanoscale Horiz.* 2 (2017), 81-88.
[4] J. Yu, C. Yang, J. Li, Y. Ding, L. Zhang, M.Z. Yousaf, J. Lin, R. Pang, L. Wei, L. Xu, *Adv. Mater.* 26 (2014) 4114−4120.
[5] Y. Ju, H. Zhang, J. Yu, S. Tong, N. Tian, Z. Wang, X. Wang, X. Su, X. Chu, J. Lin, Y. Ding, G. Li, F. Sheng, Y. Hou, *ACS Nano* 11(2017), 9239−9248.
[6] Z. Wang, Y. Ju, S. Tong, H. Zhang, J. Lin, B. Wang , Y. Hou, *Nano Horiz.*2018, DOI: 10.1039/c8nh00135a

Amorphous magnetic films with embedded nanostructures

P. E. JÖNSSON[a,*], G. MUSCAS[a], I. G. SERRANO[a],R. BRUCAS[b], M. MENNITI[a], M. V. KAMALAKAR[a]

[a]Department of Physics and Astronomy, Uppsala University, Sweden

[b]Department of Physics and Astronomy, Uppsala University, Sweden

*petra.jonsson@physics.uu.se

Flexible magnetic materials are used in e.g. flexible electronics, sensors, and strain-mediated magnetoelectric devices combining magnetoelastic and piezoelectric materials in composite structures [1]–[3]. Magnetic metallic glasses are in this respect very interesting since they can be as elastic as polymers, with excellent soft magnetic properties and metallic conduction. The fast cooling rates obtained using physical vapor deposition techniques make it possible to produce amorphous thin metallic films in a wide range of compositions. In addition, the anisotropy of the films can be tuned during deposition by e.g. an applied magnetic field, depositing compositionally graded films, or by straining the substrate during the deposition [4].

In this work, we investigate how to tune the magnetic properties of magnetic amorphous thin films post-deposition by strain or by creating purely magnetic non-topographic nanostructures. Due to the magnetoelastic coupling (the inverse magnetostriction effect), strain induces magnetic anisotropy. The uniaxial anisotropy of flexible thin CoFeZr films, subjected to tensile and compressive strain, have been investigated using magneto-optical Kerr effect (MOKE) magnetometry. Magnetic non-topographic nanostructures have been created by taking advantage of the physical properties of metallic glasses being extremely sensitive to small changes in the local chemical composition. The local chemical composition was modified by ion implantation through a Cr-mask. The mask was removed after ion implantation leaving a flat film with embedded magnetic nanostructures for which the magnetic anisotropy is tunable by the shape and symmetry of the implanted regions. Choosing the matrix to be paramagnetic at room temperature and the implanted parts to be ferromagnetic, properties similar to those of ordinary topographic nanostructures have been observed in paramagnetic FeZr films with ferromagnetic FeZrB structures using magneto-optical Kerr effect (MOKE) microscopy and magnetometry [5]. The properties of nanocomposites with two ferromagnetic phases have been investigated using first-order reversal curves (FORC) measurements.

[1] M. Melzer et al., ‘Imperceptible magnetoelectronics’, Nat. Commun., 6, 6080 (2015).
[2] S. Amara et al., ‘High-Performance Flexible Magnetic Tunnel Junctions for Smart Miniaturized Instruments’, Adv. Eng. Mater., 20, 1800471 (2018).
[3] A. A. Bukharaev, A. K. Zvezdin, A. P. Pyatakov, and Y. K. Fetisov, ‘Straintronics: a new trend in micro- and nanoelectronics and material science’, Physics-Uspekhi, 61, 1175 (2018).
[4] X. Qiao et al., ‘Enhanced stress-invariance of magnetization direction in magnetic thin films’, Appl. Phys. Lett., 111, 132405 (2017).
[5] G. Muscas, R. Brucas, and P. E. Jönsson, ‘Bringing nanomagnetism to the mesoscale with artificial amorphous structures’, Phys. Rev. B, 97, 174409 (2018).

The role ofheteroatoms on the structural and magnetic properties of cobalt ferrite nanoparticles

S. JOVANOVIĆ[a,b*], D. PEDDIS[c,d], M. SPREITZER[a], M. VUKOMANOVIĆ[a]

[a]Advanced Materials Department, Jožef Stefan Institute, Jamovacesta 39, Ljubljana, Slovenia

[b]Laboratory of Physics, Vinča Institute of Nuclear Sciences, University of Belgrade, Mike PetrovićaAlasa 12-14, Belgrade, Serbia

[c]nM2-Lab, Istituto di StrutturadellaMateria, CNR, MonterotondoScalo (Roma) 00015, Italy

[d]Department of Chemistry and Industrial Chemistry, University of Genova, Genova, Italy

*****sonja.jovanovic@ijs.si; sonja.jovanovic@vin.bg.ac.rs

In the last two decades the magnetic nanoparticles have attracted considerable attention due to theirimportance in data storage, catalysis, energy, environment, and in particular, biomedicine. However, for each application, the magnetic nanoparticles with specific properties are required. The synthesis of such nanoparticles is often challenging since numerous parameters influence their physicochemical properties.

In this talk, a case of cobalt ferrite nanoparticles (CFO NPs) will be presented in which solvothermal method was used for designing a non-agglomerated particles with uniformmorpho-structural properties. It will be described how the ability to attain uniformity of size and shape distribution (Figure 1) can enable more detailed insight into the role of heteroatoms *i.e.* chemical composition on the magnetic properties of CFO NPs.

The talk will address the role of oleic acid in the synthesis of non-agglomerated, sphere-like particles, with uniform size distribution. This will be done from the point of view ofoptimal concentration of oleic acid and the nature of its bonding to the surface of CFO NPs.In the next step, it will be discussed how substitution of Co^{2+} and $Fe^{3+}$with Zn^{2+} and Ga^{3+}, respectively, can influence physicochemical properties of CFO NPs and how this can be used for tuning the magnetic properties for specific applications.

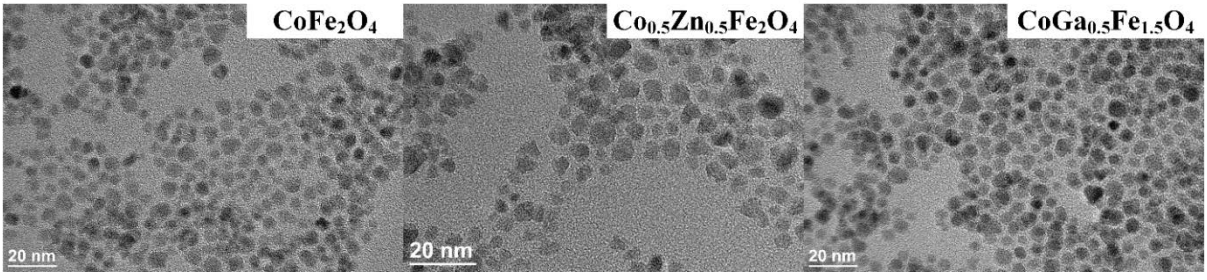


Figure 1.Nanoparticles of $CoFe_2O_4$, $Co_{0.5}Zn_{0.5}Fe_2O_4$ and $CoGa_{0.5}Fe_{1.5}O_4$.

Acknowledgements: The authors thanks the Ministry of Higher Education, Science and Technology of the Republic of Slovenia (Grant No. P2-0091), Slovenian Research Agency (Grant No.J2-8169) and the Ministry of Education, Science and Technological Development of Republic of Serbia (ProjectIII45006).

Physics of Mesoscopic Hybrid Ferromagnet-Superconductor Systems

Goran Karapetrov

Department of Physics, Drexel University

Ferromagnets and singlet superconductors are considered incompatible as exchange interaction in the ferromagnetic material suppresses superconductivity. On the other hand, superconductors are one of the few materials that exhibit coherent electron behavior on macroscopic scale. This apparent antagonism can be exploited in engineered ferromagnet-superconductor hybrid electronic devices to spatially guide the electron correlations. Scanning probe microscopy and spectroscopy tools allow us to image the spatial modulation of the superconducting condensate with atomic precision, and at the same time magnetic force microscopy and magneto-optical imaging reveals the magnetic domain structure in the ferromagnet. We explore the rich physics of mesoscopic superconductors on the example of magnetically coupled superconductor-ferromagnet hybrids. Ferromagnetic materials are used as a template that modulates the superconducting order parameter on nanometer scale. As we change the external parameters such as temperature and magnetic field, we can track the evolution of both local magnetism and superconductivity in these templated systems. In the process we have an opportunity to control the electronic behavior in the hybrid system on nanoscale distances by exploiting the quantum mechanical nature of the two interacting correlated electron subsystems.

Magneto-Polymer Coatings with a Magneto-Tunable Surface Relief

E.YU. KRAMARENKO[a,b*], G.V. STEPANOV[a,c], B.O. SOKOLOV[a], S.A.KANTOROVICH[d,e], P.A. SANCHEZ[d], E.S. MININA[d],

[a]Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

[b]A.N. Nesmeyanov Institute of Organoelement Compounds of Russian Academy of Sciences, Moscow 119991, Russia

[c]State Scientific Research Institute of Chemistry and Technology of Organoelement Compounds, 105118, Moscow, Russia

[d]University of Vienna, Sensengasse 8, 1090, Vienna, Austria

[e]Ural Federal University, Lenin av. 51, 620000, Ekaterinburg, Russian Federation

*****kram@polly.phys.msu.ru

Development of materials with tunable surface properties is an important task of modern materials science.It is known that controlling the surface wettability and, in particular, achieving the effect of superhydrophobicity is associated with the formation of a hierarchical relief on the surface. In this work, we explore the possibility of creating tunable hydrophobic and superhydrophobic coatings based on the so-called magnetoactive elastomers (MAEs) whose structure and properties can be controlled by external magnetic fields [1].

MAEs consist of a soft polymer matrix filled with magnetic microparticles. When a magnetic field is applied to a MAE, magnetic particles within a soft matrix tend to form chain-like aggregates aligned with the field lines. It is some restructuring of the magnetic filler that causes considerable changes of MAE physical properties [1].Not only bulk but also surface properties of MAEs can be tuned by external magnetic field. If the magnetic field is perpendicular to the MAE film surface the magnetic chains can grow from the bulk material to its surface producing some mountain-type surface relief [2,3]. Magnetic-field induced roughness defines rather high values of the water contact angles on a MAE surface [2].

In this talk an introduction into the field of MAEs is first presented with a short review of MAE synthesis, composition, bulk properties being sensitive to external magnetic field as well as possible practical applications. Then the results of complex experimental and theoretical studies on the structure and wettability of thin layers of magnetoactive elastomers in external magnetic fields are shown. The main focus is on the effects of magnetic filler concentration and polymer matrix modulus on the surface structure and wettability in magnetic fields.

Acknowledgements: Financial support of the Russian Foundation for Basic Research (grant No. 16-29-05276) is gratefully acknowledged.

[1]M. Shamonin and E. Y. Kramarenko, Highly responsive magnetoactive elastomers. In: Novel Magnetic Nanostructures, Elsevier, 2018, pp. 221–245.
[2] V.V. Sorokin, B.O. Sokolov, G.V. Stepanov, E. Yu. Kramarenko, Journal of Magnetism and Magnetic Materials 459, 268-271 (2018).
[3] P.A. Sanchez, E.S. Minina, S.S. Kantorovich, E.Yu. Kramarenko. Soft Matter,15, 175 (2019).

Functionalized Nanoparticles Modulate Cell Signaling: A Critical Overview

Oleg Lunov

Head of the Laboratory of Biophysics,Department of optical and biophysical systems,Institute of Physics of the Czech Academy of SciencesNa Slovance 2,18221 Prague, Czech Republic

lunov@fzu.cz

Nanoparticles are being increasingly used in different biological and biomedical applications. Along with the progress in the biomedical applications of nanoparticles, we start to realize the challenges and opportunities that lie ahead. Here, we summarize current state-of-the-art on modulation of cellular activity by nanoparticles. We demonstrate the complexity of cellular responses to functionalized nanoparticles and underline challenges lying in the identification of molecular mechanisms affected by nanoparticles. We propose an idea that subcytotoxic doses of nanoparticles could be relevant for induction of subcellular structural changes with possible involvement of mTORC1 signaling.

Deciphering molecular mechanisms of nanoparticle-mediated mTOR modulation will provide fundamental knowledge which could help in developing safe and efficient nano-therapeutics.

Magneto-Thermoelectricity in Ferrofluids

S. NAKAMAE[a,*]

[a]Service de Physique de l'État Condensé, CEA, CNRS, Université Paris-Saclay, 91191 Gif sur Yvette CEDEX, France

*Sawako.nakamae@cea.fr

The unique properties of magnetic nanoparticles and their interactions with their environment have given rise to innovative R&D opportunities beyond the field of conventional magnetism. One such example is in the energy science, and in particular, thermal engineering. In this respect, the 'cooling' (magnetocalorics, in nanostructured materials) and 'heating' (magnetic hyperthermia in dilute ferrofluids) phenomena have garnered much attention in the last 20 years. The electricity energy storage and conversion applications using magnetic nanoparticles, on the other hand, have been remained so far under-explored. Recently, we have demonstrated an enhanced thermoelectric and magneto-thermoelectric effects in charge stabilized ferrofluids. [1],[2] The suggested underlying mechanisms include the magneto-thermodiffusion of magnetic particles and the temperature dependent adsorption effect at the electrodes.

In this presentation, a quick review of the experimental findings on the subject will be given first, followed by an analytical model developed to describe the thermoelectric potential production in magnetic nanofluids (ferrofluids) [3]. Both the thermogalvanic and thermodiffusion processes are considered. The thermodiffusion term is described in terms of three physical parameters; the diffusion coefficient, the Eastman entropy of transfer and the electrophoretic charge number of colloidal particles, which all depend on the particle concentration and the applied magnetic field strength and direction. The comparison between the experimental results and the theoretical models clearly indicate the shortcomings of our current understanding of magneto-thermoelectric phenomena in ferrofluids and in nanofluids. With time permitting, possible future technological paths for thermoelectric nanofluids will also be discussed

[1] T. Salez *et al*. *Physical Chemistry Chemical Physics* 2017, 9409 (2017)
[2] T. Salez, *et al.*, *Nanoscale Advances*, submitted (2019)
[2] T. Salez, *et al.*, *Entropy*, 20, 405 (2018)

Arrays of Ferromagnetic Microwires as Sensing and Guiding Systems for Bio-Medical Applications

L.V. Panina[a,b*], N. A. Yudanov[a], A. T. Morchenko[a]

[a]National University of Science and Technology, MISIS, Moscow 119991, Russia

[b]Immanuel Kant Baltic Federal University, 236004, Kaliningrad, Russia

Ferromagnetic micro-wires of appropriate design have attractive features making them suitablefor a variety of sensing applications including bio-medical area. Apart from thin-film technology, the use of micro and nano-sized magnetics in sensing technology is very limited.This paper discusses the use of amorphous soft magnetic wires as embedded sensing elements for detection of local stresses and temperature, for example, in human implants and temperature control at thermotherapy.The physical effects employed are: fast magnetization switching generating a voltage signal with higher harmonics, giant magnetoimpedance at MHz and GHz frequencies and dynamic magnetoelectric coupling.In order to realize efficient sensing properties, magnetic microwires of CoFeSiBcompositions in amorphous state are of interest. The absence of the crystalline structure is very useful since it is possible to establish a required magnetic anisotropy through the induced anisotropy and magnetoelastic interactions by a specific combination of alloy composition, geometry, and heat treatments. The external stress then may substantially modify the magnetic anisotropy and the magnetization processes.For temperature monitoring in a range of 40-60 C, microwires of CoFe-amorphous alloys with addition of Cr or Ni are proposed since the Curie temperature can be controllably placed within this interval by optimal annealing.

The arrays of ferromagnetic microwires can be also used to produce high gradient magnetic fields of the order $10^3 - 10^5$ T/m, which is sufficient to guide magnetic nanoparticles and even diamagnetic cells.Thus, a dual micro-wire dipole system magnetized along a diameter produces a unique magnetic field energy profile which can be used for trapping diamagnetic cells. The spatiotemporal precision of generating magnetic fields from magnetized micro-wire arrays may offer a compelling interface for magnetophoretic devices to control the migration of living cells and targeted drag delivery.

Designing magnetic and electronic phases at oxide interfaces from first principles

ROSSITZA PENTCHEVA[a,*]

[a]Department of Physics and Center for Nanointegration (CENIDE), University of Duisburg-Essen, Germany

*Rossitza.Pentcheva@uni-due.de

Transition metal oxide interfaces exhibit a broad spectrum of functional properties that are not available in the respective bulk compounds and open possibilities for applications in electronics, spintronics and energy conversion. Based on the insight from density functional theory calculations including an on-site Hubbard term, I will address the formation of unanticipated charge, spin and orbital reconstructions in oxide superlattices containing a honeycomb pattern (perovskites [1], corundum [2,3]), leading to a rich set of Mott and topologically nontrivial phases with strong spin-orbit effects. Furthermore, I will address the electrostatic doping in hybrid heterostructures [4].

Research in collaboration with D. Doennig, O. Köksal, B. Geisler and W.E. Pickett; supported by the German Research Foundation DFG within SFB/TRR80.

[1] D. Doennig, S. Baidya, W. E. Pickett and R. Pentcheva, Phys. Rev. B **93**, 165145 (2016).
[2] O. Köksal, S. Baidya and R. Pentcheva, Phys. Rev. B **97**, 035126 (2018).
[3] O. Köksal and R. Pentcheva, J. Phys. Chem. Solids (Special Issue: Spin-Orbit Materials), **128**, 301-309 (2019)..
[4] F. Wrobel, B. Geisler, Y. Wang, G. Christiani, G. Logvenov, M. Bluschke, E. Schierle, P. A. van Aken, B. Keimer, R. Pentcheva, and E. Benckiser, Phys. Rev. Materials **2**, 035001 (2018)

Smart materials based on magnetorheological medium

N.S. Perov[a,B*], YU.A. Alekhina[a], D.A. Isaev[a], M.F. Khairullin[a], E.YU. Kramarenko[a], L.A. Makarova[a,B], A.S. Semisalova[a,C], G.V. Stepanov[d]

[a]Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

[b]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[c]Duisburg-Essen University, Faculty of Physics, 47057, Lotharstr. 1, Duisburg, Germany

[d]State Scientific Research Institute of Chemistry and Technology of Organoelemet Compounds, 105118, Enthusiasts 38, Moscow, Russia

* perov@magn.ru

Magnetorheological materials reveal both elastic/viscous and magnetic properties due to it composite structure. These materials, especially elastomers, are multiferroic due to hysteresis behavior of both magnetic field dependence of magnetization and strain dependence of stress. Magnetorheological elastomers can be easily prepared; the material is flexible and it properties (elastic, deformation, permittivity, etc.) can be tuned by external magnetic field [1-3]. The area of application such smart materials with multiferroic properties are extremely wide and include sensors, autonomous sources of energy, actuators as well as applications in biomedical areas (hyperthermia, manipulators in robotic devices, etc.) [4].

The mechanisms of magnetization, magnetodielectric effect, magnetoelectric transformation and other physical properties of composite rheological materials based on ferromagnetic and/or ferroelectric micro-fillers were investigated in the work. It is shown that rotation, relative displacement and moving of particles in magnetic elastomers under external loads have a significant effect on their magnetic, mechanical and electrical properties. It was found that in the crossed DC and AC magnetic fields the frequency resonance of the nondiagonal components of complex permeability of elastomers is detected. The change in the dielectric constant of magnetic elastomers in an external magnetic field depends on the aggregation state of the polymer matrix and can exceed 40%/kOe under external mechanical stresses. Also new three-component multiferroic material based on polymer and a mixture of ferromagnetic (NdFeB or iron microparticles) and ferroelectric (PZT particles) fillers was developed; the static magnetoelectric transformation coefficient was up to 730 mV/cm·Oe [5].

Based on magnetorheological and electrorheological elastomers different spatially structured composites were developed. It was shown inverse magnetodeformation and magnetoelectric effect can be improved in the composites.

Acknowledgements: Financial Support of RFBR Grant No. 18-32-00354 is acknowledged.

[1] A.S. Semisalova et al., Soft Matter 9, 47 (2013)
[2] G.V. Stepanov et al., J. Phys. Condens. Matter. 20, 20 (2008)
[3] E.Yu. Kramarenko et al., Smart Mater. Struct. 24, 3 (2015)
[4] L.A. Makarova et al., Smart Mater, Struct. 26 (2017)
[5] L.A. Makarova et al., JMMM 470, 6 (2019)

Paper-based magnetic immunoassays using magneticnanoparticles: An affordable and fast tool for bioanalysis

M. Rivas[a,*], J.C. Martínez-García[a], M. Salvador[a,C], A. Moyano[a,B], M.C. Blanco[b]

[a] Department of Physics & IUTA, University of Oviedo, 33204 Gijón, Spain

[b]Department of Physical and Analytical Chemistry, University of Oviedo, 33006 Oviedo,Spain

[c]Institute of Structure of Matter (CNR), 00015 Monterotondo Scalo (RM), Italy

*rivas@uniovi.es

Bioanalysis of a large number of samples, in short times, and at low cost is a challenge of modern times. It applies to health issues, but also to food safety, drug control, or environmental monitoring. One of the desired features of this technology is frequently that analyses can be performed in situ, by the patient's bed, in the ambulance or in the industry plant. This type of technology, named point-of-care or point-of-use, is aimed to be used by untrained staff, so it should be also user-friendly. These requirements are fulfilled by the so-called Lateral Flow Immunoassays (LFIA.) These are chromatographic tests based on nitrocellulose strips [1], the most popular of which is the well-known pregnancy test. The molecule of interest is immobilized across the paper strip. To make it visible, it is bonded to a reporter agent, frequently a gold or silver bead. This kind of LFIA is designed for a presence/absence response. But, what if quantification is needed?

I will talk about magnetic LFIAs, and its advantages and challenges for biomarker detection. I will analyze the key points, concerning the characteristics of the magnetic labels and the reading out of the test, which should be addressed without adding excessive complexity to the method, eluding compromising its main advantages regarding costs, duration, and portability [2].

[1] X. Huang, Z. P. Aguilar, H. Xu, W. Lai, Y. Xiong, Biosensors and Bioelectronics 75 pp. 166-180 (2016)

[2] W.C. Mak, V. Beni, A.P.F. Turner, TrAC Trends in Analytical Chemistry 79 pp. 297-305 (2016)

X-ray Magnetic Spectroscopies of Functional Materials

Andrei Rogalev

European Synchrotron Radiation Facility (ESRF), 71 avenue des Martyrs, 38000, Grenoble, France

rogalev@esrf.fr

Development of the third generation synchrotron radiation sources has boosted X-ray spectroscopy, as illustrated by the discovery of a variety of new experimental techniques associated with the exploitation of the polarisation properties of x-rays. Firstly, it concerns x-ray magnetic circular dichroism (XMCD) that is now a workhorse technique in modern magnetism research, leading to a deeper understanding of the microscopic origin of the magnetic state of matter as well as to major technological advances. Today, the applications of XMCD are vast and this method enables a broad range of novel and exciting studies of various functional magnetic materials ranging from bulk permanent magnets, magnetocaloric compounds and thin films to nanoparticles.Secondly, the recently discovered x-ray magnetochiral dichroism (XMχD) which is observable in magnetoelectric systems or chiral molecular magnets, is described. Potential applications of this new spectroscopy to measure toroidal moments in multiferroic materials are reviewed.

Opto-magnetic properties of nanoscale functional materials for dual-bioimaging and theranostics.

R. ROTOMSKIS*[,a,b]

[a]Laboratory of Biomedical Physics, National Cancer Institute, LT-08408, P.Baublio 3b, Vilnius, Lithuania

[b]Biophotonics group of Vilnius university Laser Research Center, LT-10222, Sauletekio ave., 9 corp. III, Vilnius, Lithuania

*corresponding author email ricardas.rotomskis@nvi.lt

The development of nanoparticles for use in biomedicine has shown great progress over the past two decades, and has been tailored for use as contrast enhancement agents for imaging. Magnetic nanoparticles (MNPs), with their unique magnetic properties and controllable sizes, are being actively investigated as the next generation of magnetic resonance imaging (MRI) contrast agents. Theranostic nanoagents targeted for personalized medicine provide a unified platform for therapeutics and diagnostics. Through combination with biologically active molecules, MNPs and upconverting nanoparticles (UCNPs) could be multifunctional in both therapy and diagnostics (theranostics).

Upconversion is a nonlinear optical process that converts two or more photons to a higher-energy out-put photon. Compared to traditional photoluminescence agents they offer many advantages, for example, working in near-infrared (NIR) transparency window (~650-1350 nm) of biological tissues, and possibility to add second imaging source, such as (MRI). Combining UCNPs with photosensitizer may settle the major problem for cancer imaging and therapy. Such multifunctional up-conversion nanoprobes were demonstrated to be feasible in photo/radiotherapy and in vivo imaging executed by either MRI or NIR irradiation.

Opto-magnetic properties of nanoscale superparamagnetic iron oxide (Fe3O4) nanoparticles (SPIONs) and hexagonal phase NaGdF4:Yb/ Er@NaGdF4 core-shell structures UCNPs and application for dual bioimaging and theranostics were investigated. The uptake and distribution of SPIONs and UCNPs in cancerous and healthy cells, and MRI signal influenced by SPIONs and UCNPs injected into experimental animals, were analyzed. Cellular uptake and distribution of the SPIONs in cells were visualized by a bright-field, fluorescence and confocal microscopes. An in vitro uptake and cytotoxicity (tested with cell viability assay (XTT) evaluation study showed that SPIONs, UCNPs internalized into healthy and breast cancer cell lines and possessed low cytotoxicity and good biocompatibility.

MRI studies on Wistar rats using a clinical 1.5 T MRI scanner were performed. The dynamic MRI measurements of SPIONs clearance from the injection site shows that SPIONs slowly disappear from injection sites and only a low concentration of nanoparticles was completely eliminated within three weeks. Non-functionalized SPIONs and UCNPs accumulate in cells by endocytic mechanism, non-accumulate in the nucleus, and are non-toxic at a desirable concentration. The optical and MR signals indicate, that these nanoparticles could be applied as an efficient dual optical-MRI contrast agent. On the contrary, 980 nm NIR irradiation is upconverted by the UCNPs to UV/visible light, which triggers secondary photochemical processes, e.g., generation of reactive oxygen species by photosensitizers coupled to the UCNPs, causing damage to cancer cells.

Topological protected structures for magnetic sensors and storage applications

Dieter Suess*[1], Anton Bachleitner-Hofmann[1], Herbert Weitensfelder[1], Hubert Brück[2], Armin Satz[3]

[1]University of Vienna, Christian Doppler Laboratory, Faculty of Physics, Physics of Functional Materials, Währinger Straße 17, 1090 Vienna, Austria

[2]Center for Integrated Sensor Systems, Danube University Krems, Viktor Kaplan Str. 2 E, 2700 Wiener Neustadt, Austria

[3]Infineon Technologies AG, Siemensstraße 2, 9500 Villach, Austria

Within this talk I will review our activities of magnetic sensors for automotive applications that is done in cooperation with Infineon AG[1]. We will present a disruptive sensor design utilizing a magnetic vortex state in the free layer in order to overcome the fundamental phase noise problem of state of the art speed wheel sensors. The presented sensor design will enter the market in 2019. Due to the nature of this topological protected state it intrinsically does not show the dominant noise of state of the art xMR sensors. A further advantage of this vortex sensor is a significant increased linear range as compared to state of the art sensors. Furthermore only a very weak dependence of the sensitivity with respect to external orthogonal strayfields and stress will be reported.

In the second part of the talk we will present the requirements of skyrmions for storage applications by means of bit error rate estimates and calculation of the thermal stability. We will present atomistic simulations of the thermal stability of skyrmions by means of the transition state theory and forward flux sampling [3,4]. We will conclude with an optimized structure that allows to move skyrmions in a stable manner by two adjacent and coupled layers [5].

[1] D. Suess, A. Bachleitner-Hofmann, A. Satz, H. Weitensfelder, C. Vogler, et al. *NATURE ELECTRONICS* 6 (2018) 362.
[2] H. Weitensfelder, et al. PHYSICAL REVIEW APPLIED 10.5 (2018) 054056.
[3] L. Desplat, D. Suess, J.-V. Kim, and R. L. Stamps, *PHYSICAL REVIEW B*, 98 (2018) 134407.
[4] P. Heistracher, C. Abert, F. Bruckner, C. Vogler, and D. Suess, *IEEE TRANSACTIONS ON MAGNETICS*, 54 (2018) 7206105.
[5] D. Suess, C. Vogler, F. Bruckner et al, *AIP ADVANCES*, 8 (2018) 115301.

Spin-caloritronics in ordered alloy thin films

K. TAKANASHI[a,b,*], M. MIZUGUCHI[a,b,c], T. SEKI[a,b]

[a]Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan

[b]Center for Spintronics Research Network, Tohoku University, Sendai 980-8577, Japan

[c]CREST, Japan Science and Technology Agency, Sanbancho, Tokyo 102-0075, Japan

Spin-caloritronics, which concerns the interplay between spin, charge and heat, has attracted much attention as a development of spintronics. Anomalous Nernst effect (ANE), which induces an electric voltage in the direction perpendicular to both temperature gradient and magnetization, is one of well-known classical thermomagnetic phenomena. However, there have been only a few studies on ANE for metals and alloys. From the viewpoint of modern spin-caloritronics, we may say ANE is a phenomenon that a spin current induced by temperature gradient is converted into an electric current in the transverse direction due to inverse spin Hall effect.

In this work, systematic investigation of ANE has been made for perpendicularly magnetized ordered-alloy thin films, compared with uniaxial magnetic anisotropy (K_u) and anomalous Hall effect (AHE). 30 nm-thick $L1_0$-FePt, $L1_0$-FePd $L1_0$-MnGa and $D0_{22}$-Mn_2Ga thin films were prepared on MgO(001) substrates by sputtering. The ANE increases with temperature although the signs of ANE for Fe-based ordered alloys are opposite to those for Mn-based ordered alloys. Ordered alloys with higher K_u show higher ANE, suggesting high K_u materials are suitable for thermoelectric applications [1]. The temperature dependence of ANE and AHE for $L1_0$-FePt follows the Mott relation at low temperatures (<100 K); however ANE is remarkably enhanced in comparison with the Mott relation at high temperatures. This enhancement of ANE is explained from a model: magnon spin current induced by temperature gradient is converted into conduction-electron spin current via s-d interaction, giving additional contribution to ANE [2]. Recently we have also succeeded in the observation of anomalous Ettingshausen effect as a reciprocal phenomenon of ANE through the use of lock-in thermography [3,4].

[1] K. Hasegawa *et al.*, Appl. Phys. Lett., 106, 242405 (2015).
[2] M. Mizuguchi *et al.*, arXiv:1804.03751.
[3] T. Seki *et al.*, Appl. Phys. Lett., 112, 152403 (2018).
[4] T. Seki *et al.*, J. Phys. D: Appl. Phys., 51, 254001 (2018).

Dynamic magnetization property of magnetic nanoparticles for hyperthermia and magnetic particle imaging

YASUSHI TAKEMURA

Yokohama National University, Japan

*takemura@ynu.ac.jp

I demonstrate recent understanding of dynamic magnetization properties of magnetic nanoparticles for further development of hyperthermia and magnetic particle imaging (MPI). Static and dynamic magnetization properties of Fe_3O_4 and γ-Fe_2O_3 nanoparticles including Ferucarbotran and Resovist were evaluated. The samples were prepared as dispersed in liquid (mobile), fixed in solid (immobile), and intracellular states. Static (major and minor) magnetization curves and dynamic magnetization curves up to 500 kHz were measured.

Dynamic magnetization curves of Resovist which exhibits superparamagnetic feature under a static field show hysteresis due to phase delay in magnetization response (Fig. 1). Specific loss power (SLP) and intrinsic loss power (ILP) were derived from area of the dynamic hysteresis curve not by caloric measurement (temperature rise)[1]. Their dependences on applied field intensity and frequency, density of nanoparticles, fluid viscosity and other parameters were analyzed.

An effective relaxation time is dominated by a faster process of Néel or Brownian relaxation time, but it is not adequate in discussing some experimental results, *e.g.* ILP of immobile and mobile MNPs shown in Fig. 2 [2]. We could clearly observed two step magnetization response of Néel and Brownian relaxations [3,4].

In this presentation, harmonic signal intensity analyzed for MPI [5], and optimum particle structures for hyperthermia and MPI are also discussed.

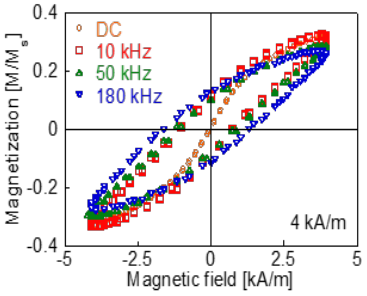


Fig. 1 Magnetization curves of Resovist.

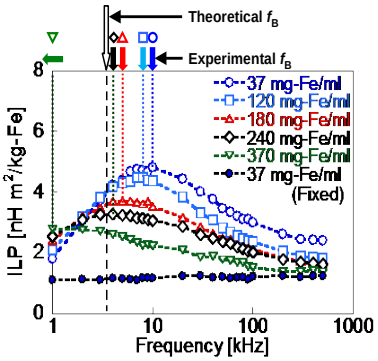


Fig. 2 Intrinsic loos power (ILP) depending on

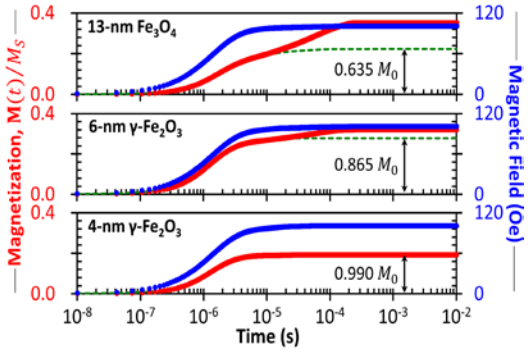


Fig. 3 Temporal magnetization responses to a pulse field [3].

[1] Ota, Yamada, Takemura, *J. Nanomaterials*, **2015**, 836761, 2015.
[2] Ota, Yamada, Takemura, *J. Appl. Phys.*, **117**, 17D713, 2015.
[3] Trisnanto, Ota, Takemura, *Appl. Phys. Exp. (APEX)*, **11**, 075001, 2018.
[4] Ota, Takemura, *Appl. Phys. Exp. (APEX)*, **10**, 085001, 2017.
[5] Ota, Takeda, Yamada, Kato, Nohara, Takemura, *Int. J. Mag. Part. Imag.*, **3**, 1703003, 2017.

Stress-induced Magnetic Anisotropy Enabling Engineering of Magnetic Softness and Domain Wall Dynamics of Fe-rich Amorphous Microwires.

A. Zhukov[1,2,3*], P. Corte-Leon[1], L. Gonzalez-Legarreta[1], M. Ipatov[1,2], J. M. Blanco[2], V Zhukova[1,2]

[1]Dept. Phys. Mater., University of Basque Country, UPV/EHU San Sebastián 20018, Spain

[2]Dpto. de Física Aplicada, EIG, UPV/EHU, 20018, San Sebastian, Spain

[3]IKERBASQUE, Basque Foundation for Science, 48011 Bilbao, Spain

F.A. FirstAuthor[1], S.A.

[*]corarkadi.joukov@ehu.es

Magnetic nano-micro wires can present excellent magnetic properties such as fast domain wall (DW) propagation reported for various families of magnetic wires, as well as extremely soft magnetic properties and Giant magnetoimpedance (GMI) effect observed mostly in amorphous and nanocrystalline magnetic microwires [1]. These properties are essentially relevant for industries, i.e., magnetic sensors, electronic surveillance, electrical engineering, medicine, informatics, magnetic recording among others.To great extend these properties are related to cylindrical geometry and therefore can be observed in either amorphous or crystalline wires with rather different dimensions [1]. However, amorphous wires prepared using melt quenching provide a number of great advantages, such as excellent magnetic softness combined with better mechanical properties.

Less expensive Fe-rich microwires are preferable for the applications. But amorphous Fe-rich materials exhibit rather high magnetostriction coefficient and consequently present quite low GMI effect [1]. The most common method for magnetic softness optimization is the annealing.

Consequently, the purpose of this paper is to present our recent l results on effect of stress- annealing on magnetic properties and GMI effect of Fe- based glass-coated microwires. Observed stress-induced anisotropy depends on annealing temperature, T_{ann}, time, t_{ann} and stress, σ, applied during the annealing. We observed remarkable magnetic softening, improvement of DW mobility, DW velocity, and GMI ratio at appropriate stress-annealing conditions of Fe-rich microwires.

Beneficial effect of stress-annealing on GMI effect and DW dynamics is attributed to the induced transverse magnetic anisotropy. An improvement of the circumferential permeability in the surface layer of metallic nucleus is evidenced from observed magnetic softening and growing volume of outer domain shell with transverse magnetic anisotropy. We assumed that this outer domain shell with transverse magnetic anisotropy affects the travelling DW in a similar way as application of transversal bias magnetic field allowing enhancement the DW velocity. Consequently, stress annealing enabled us to design the magnetic anisotropy distribution beneficial for optimization of either GMI effect or DW dynamics.

[1] A. Zhukov, M. Ipatov, M. Churyukanova, A. Talaat, J. M. Blanco and V. Zhukova, J. Alloys Compound. 727, 887-901 (2017),

ORAL TALKS

Magnetocaloric Effect in Cyclic Magnetic Fields: Degradation and Frequency Dependency

A.M. ALIEV[a,*], A.A. AMIROV[a,b], L.N. KHANOV[a], K.P. SKOKOV[c]

[a]Amirkhanov Institute of Physics of Dagestan Scientific Center RAS, 367003, Yaragskogo 94, Makhachkala, Russia

[b] Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[c]Technische Universität Darmstadt, Institut für Materialwissenschaft, D-64287 Darmstadt, Germany

*lowtemp@mail.ru

Since a refrigerating machine is a device with periodic sweeps of cycles, there is a substantial need to study magnetocaloric properties of the materials under continuously applied cyclic magnetic fields. Magnetocaloric properties of the materials under single and repeated application of the cyclic magnetic fields can exhibit significantly different behavior for a variety of reasons. Furthermore, the magnetocaloric properties of materials with a magnetostructural phase transition in cyclic fields can degrade over time. Obviously, materials with time-stable and no frequency dependence magnetocaloric properties are require for practical applications.

In this work, we present results of studying the magnetocaloric properties in several families of promising magnetic materials, namely $La(FeSi)_{13}$-(H) and $Gd_5(GeSi)_4$ in cyclic magnetic fields with frequencies up to 20 Hz. The dependency of the MCE on the frequency of alternating magnetic field and the effect of prolonged action of cyclic magnetic fields on magnetocaloric properties of the materials are studied in detail.

It was found that in the materials studied the MCE value decreases with increasing frequency of the magnetic field. This means that for each material there is an upper limit of the frequency at which the cooling efficiency has a maximum. It was also found that the effect of degradation of the magnetocaloric properties as a decrease in the magnitude of the MCE under the action of a cyclic magnetic field is observed. The effect of degradation is different in the studied materials. An explanation of the observed behavior of the MCE in cyclic magnetic fields is given in the report. It is shown that the degradation effect results in some limitations for using the magnetocaloric materials in magnetic cooling technology.

The research was supported by a grant of the Russian Science Foundation (Project No. 18-12-00415).

Polymer multiferroic composites with combined caloric and magnetoelectric effects

A. AMIROV[a,b*], V. ANDRADE[c] ,V. RODIONOV[a], A. KAMANTSEV[d]

[a]Laboratory of Novel Magnetic Materials & Institute of Physics Mathematics and Informational Technologies, Immanuel Kant Baltic Federal University, 236029 Kaliningrad, Russia

[b]Amirkhanov Institute of Physics, Daghestan Scientific Center, Russian Academy of Sciences,367003 Makhachkala, Russia

[c]GlebWataghin Physics Institute, Campinas State University (UNICAMP), C.P. 6165,13.083-970 Campinas S.P, Brazil

[d]Kotelnikov Institute of Radio Engineering and Electronics, Russian Academy of Sciences, 125009 Moscow, Russia

*****amiroff_a@mail.ru

Recently, the scientific interest has focused on the designand studies of smart materialsfor biomedicine and energy efficient technologies, which exhibit large caloric effects (CE) combined with strongmagnetoelectric (ME) coupling.

As known, caloric materials are observed adiabatic temperature (isothermal entropy) changes, when the applied external field (magnetic, electric, mechanic) changes. Depending on type of external field stimulus, these caloric effects deals to magnetocaloric, electrocaloric and mechanocaloric effects. The phenomena relates with observation of two or more caloric effect, called as multicaloric effects and the materials, which demonstrate these effects-multicalorics.

Multiferroics are advanced materials for multicaloric studies and the ME composites were proposed for it, due to their strong ME coupling. In this connection, recent studies conducted a search for multicalorics with high caloric effects and ME coupling around room temperature.

The new type of multiferroic polymer composites with large magnetocaloric and ME effects around room temperature were fabricated, their structure, caloric, magnetic and ME properties were studied. Two series of polymeric 0-3 type composites FeRh / PVDF and GdGeSi / PVDF, consisting of magnetocaloric microparticles $Fe_{50}Rh_{50}$ and $Gd_5Ge_{1.6}Si_{2.4}$ embedded into a piezopolymer matrix of polyfilidenedenedluoride (PVDF) in mass ratios from 2 to 40% were fabricated using modified solvent-casting methodic.

Preliminary experiments on samples with mass fractions of the magnetic phase of 2 and 12% observed the presence of a ME interaction in the vicinity of the magnetic phase transition temperature of the magnetocaloric component of the composite, which can be used for applications in smart composites. In was experimentally demonstrated that the introduction of Gd-Ge-Si microparticles into an electroactive PVDF with a volume fraction of 2 and 12%, gives rise to a ME coupling and, consequently, a multicaloric effect.

The work was supported by Russian Science Foundation (project № 18-79-10176).

Superconductivity in Thin Layer Dirac Semimetals Cd_3As_2

B. Aronzon[a,*], A. Davydov[a], L. Oveshnikov[a], V. Zakhvalinskii[b], A. Kochura[c], A. Ril[d], S. Marenkin[d]

P. N. Lebedev Physical Institute, RAS, Moscow 119991, Russia

Belgorod National Research University, Belgorod 308015, Russia

South-West State University, Kursk 305040, Russia

[d] N. S. Kyrnakov Institute General and Inorganic Chemistry, RAS, Moscow 119991, Russia

*****aronzon@mail.ru*

We report a first experimental observation of superconductivity in thin layer Dirac semimetals Cd_3As_2 [1]. Dirac semimetals currently attract wide related to the existence of Dirac nodes in electron spectrum and nontrivial topological characteristics of both bulk and surface states. The films under study were synthesized by two methods: magnetron and thermal sputtering. Both technics give the analogues results: the polycrystalline continuous part of the films with a homogeneous distribution of elements and the Cd-to-As ratio close to stoichiometric Cd_3As_2, difference was not more 2%. The latter is also supported by Raman spectra of the studied films were two pronounced peaks inherent to Cd_3As_2 were observed. The obtained X-ray diffraction patterns for studied films also correspond to the Cd_3As_2lattice.The formation superconducting phase in the films is confirmedbythe characteristic behavior of the temperature and the magnetic field dependence of the sample resistivity (see Fig 1), as well as by the presence of pronounced zero-resistance plateaus in the *dV/dI* characteristics. The H_c-$T_c$plots reveal linear behavior within the intermediate temperature range suggesting possibility a nontrivial pairing in the films under investigation.

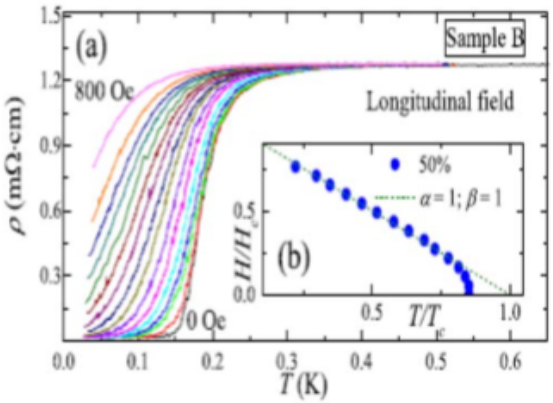


FIG. 1. (a) Temperature dependence of resistivity for one sample at various longitudinal magnetic fields.
(b) Corresponding *Hc-Tc* diagrams for the SC transition (midpoint). Fitting of experimental data is shown by the dashed line.

The work was supported by the Russian Science Foundation, Grant No. 17-12 01345.

[1] A.V. Suslov et al., Phys. Rev.B.**99**, 094512 (2019)

The energy of formation of vacancies in the alloy Mn3GaC:ab initio study

D.R. Baigutlin [a] *, M.A. Zagrebin [a,b], V.V. Sokolovskiy [a,c], V.D. Buchelnikov [a,c]

[a]Chelyabinsk State University, Chelyabinsk, Russia

[b]National Research South Ural State University, Chelyabinsk, Russia

[c]National University of Science and Technology "MISiS", Moscow, Russia

*d0nik1996@mail.ru

Antiperovskite compounds of the Mn3GaC type are interesting due to their numerous possible technological applications (sensors, microelectromechanical systems, etc.) [1,2]. Moreover, this of compounds can be used as a refrigerant for magnetic cooling devices [3], thanks to the presence of its magnetocaloric effect, which is observed around the magnetic phase transitions [4,5].

The total energy of the studied alloy was calculated using the density functional theory (DFT) using VASP program package [6, 7]. The exchange correlation potential was calculated the generalized gradient approximation (GGA) in the Perdew–Burke–Ernzerhof (PBE) formulation [7]. Calculations of the energy of the crystal containing the vacancy were performed on 90 atomic supercells.

According to the results of ionic relaxation, 3 stable magnetic states of the alloy under study were found. For these states are defined equilibrium lattice parameter, energy, and magnetic moment. These results are quite close to the experimental results [3]. The results are shown in Table 1.

Table1 Energy per atom, magnetic moment per unit cell, lattice parameter and elastic properties for Mn3GaC

Magnetic configuration	Total energy, eV	Magnetic moment, μB	Equilibrium lattice parameter, Å	ν	E, GPa	Θ_D, K
FM	–7,971	4,711	3,824	0,242	266,0	570,2
NC	–7,959	0,020	3,862	0,284	179,5	465,3
AFM	–7,947	0,000	3,803	0,277	286,6	584,4

Table 2. The energy of the formation of a vacancy at the site of the atom Mn, Ga and C, respectively

	Mn	Ga	C
Ev, eV	0,625	0,692	0,604

The calculated energy of job formation is shown in Table 2. It was determined that, although C atoms have a lower formation energy, the concentration of vacancies of C atoms and Mn atoms is almost the same. This is due to the large number of atoms Mn compared to C.

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

[1]. D. Fruchart, Journal of the Physical Society of Japan. 44, 781–791 (1978)
[2]. K. Kamishima, T. Goto, H. Nakagawa et al. Phys. Rev. B. 63, 024426 (2000)
[3]. K.A. Gschneidner Jr., V.K. Pecharsky, A.O. Tsokol. Rep. Prog. Phys. 68, 1479–1539 (2005)
[4]. M.-H. Yu, L.H. Lewis, A.R. Moodenbaugh, J. Appl. Phys. 93, 10128 (2003).
[5]. Ö. Çakır, M. Acet, Appl. Phys. Lett. 100, 202404 (2012).
[6]. E.T. Dias, K.R. Priolkar, Ö. Çakır et al. J. Appl. Phys. 117, 123901 (2015).
[7]. J.P. Perdew, K. Burke, M. Enzerhof. Phys. Rev. Lett. 77, 3865 (1996).

Detailed Mossbauer investigation of the magnetic spin reorientation in Fe_7Se_8

T. BALUYAN*, A.NOVAKOVA

Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

*tarinax@yandex.ru

Iron selenide Fe7Se8 has two superstructural modifications: 3c-Fe_7Se_8 and 4c-Fe_7Se_8. Both of them contain structural vacancies, that has influence on their magnetic structure due to the system of nonequivalent iron ions states formation [1]. In our previous works [2,3] we found out that the spin reorientation occurs in both 3c- and 4c-Fe7Se8 in a temperature range of 110-130K for 3c- and 125-145K for 4c-Fe_7Se_8. In this work we performed a detailed study of temperature spin reorientation for all the sublattices of the both samples applying Mossbauer spectroscopy data.

The temperature dependences of the effective magnetic fields for the samples under investigation consist of two parts: the Broullien component and the reorientational component:

$$H_{eff}(T) = H^{B}_{eff}(T) + H^{R}_{eff}(T) \qquad (1)$$

The Broullien component was calculated for all the sublattices of the samples and the reorientational component and it's derivative were calculated by the numeric means. The obtained data were analyzed and the following results were obtained: the temperatures of the active phase the spin reorientation were determined to be 115-138K for 3c-Fe_7Se_8 and 125-158K for 4c-Fe_7Se_8. The direction and dynamics of the temperature induced spin reorientation for all the sublattices were calculated and the detailed model of the low temperature spin reorientation if the iron selenide Fe_7Se_8 was proposed for both samples. In 3c-Fe_7Se_8 the reorientation occurs in the opposite directions for A- and C-sublattices and the B-sublattice is used to compensate the rapid changes in their spin directions, and in 4c-Fe_7Se_8 the main reorientation occurs in A-sublattice and the velocities of it's spin rotation is compensated by B-and C- sublattices.

[1] Magnetic properties of the iron selenide Fe_7Se_8 / C. Boumford, A.H. Morrish // Phys.stat.sol. (a). – 1974. – V. 22. – №. 2. – P. 435-444

[2] Li G., Zhang B., Baluyan T., Wu P., Novakova A., Rudolf P., Blake G., de Groot R., Palstra Th Metal-insulator transition induced by spin reorientation in Fe_7Se_8 grain boundaries / // Inorganic Chemistry. — 2016. — P. 12912–12922.

[3] Tigran Baluyan, Alla Novakova, Marat Khairullin. Magnetic investigation of low temperature phase transition in iron selenides. EPJ Web of Conferences, 185:04019–04021, 2018

Influence of a low-frequency magnetic field on the permeability of polyelectrolyte microcapsules with magnetic nanoparticles

I.A. Burmistrov[1,*], D.B. Trushina[2,3], T.N. Borodina[2], M.M. Veselov[1], N.L. Klyachko[1], Y. González-Alfaro[4], T.V. Bukreeva [2,3]

[1] Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

[2]Shubnikov Institute of Crystallography of Federal Scientific Research Centre "Crystallography and Photonics" of Russian Academy of Sciences, 119333, Leninskiy pr. 59, Moscow, Russia

[3]National Research Centre "Kurchatov Institute", 123098, pl. Ac. Kurchatova, 1, Moscow,Russia

[4]Centro de Estudios Avanzados de Cuba (CEAC), CITMA, La Lisa, 17100 La Habana, Cuba

[*]burmiivan@gmail.com

Polyelectrolyte microcapsules obtained by the method of sequential deposition of oppositely charged molecules on the surface of colloidal particles are promising vehicles for the delivery and release of biologically active substances. Modification of capsule shells with magnetite nanoparticles aims not only to control the localization of capsules, but also to tune their permeability. Application of low frequency non heating magnetic field for these purposes offer prospects of high penetration ability into tissues, high locality and safety, which makes this method more preferable for using *in vivo* than magnetic hyperthermia.

In this work, we study the influence of low frequency magnetic field (50 Hz) with different properties on the morphology, integrity and permeability of the Poly(allylamine hydrochloride)/Poly(styrene sulfonate) multilayer capsules modified by magnetite nanoparticles. The capsules were obtained by the method of electrostatic Layer-by-Layer adsorption on the surface of calcium carbonate templates. The integrity, size, morphology of the capsules, as well as the distribution of nanoparticles in the shell were investigated using scanning and transmission electron microscopy, and confocal microscopy. The magnetic properties of the synthesized nanoparticles were studied using magnetometry measurements and mössbauer spectroscopy. We suppose that the irradiation by magnetic field cause some defects in the polyelectrolyte shell, which contribute to the penetration of the dye into the multilayer shell. To detect changes in capsules permeability a fluorescently labeled dextran with different molecular weight were used. Somesamples of microcapsules were incubated in fluorescein isothiocyanate-labeled dextran. In other samples, the fluorescein isothiocyanate-labeled dextran was encapsulated at the stage of calciumcarbonate core synthesis. The fluorescence intensity profiles were obtained in the microcapsules irradiated with a pulsed magnetic field with varying pulse duration (100-300 ms) and the pause between pulses (3-100 ms). From the analysis of the experimental data the most promising exposure parameters of the magnetic field was found. It was found that the major impact on the permeability of the capsule shell has a pause between the pulses.

This research was supported by the Russian Foundation of Basic Research (Project No. 18-53-34007 Cuba_t). This work was performed using the equipment of the Shared Research Center FSRC "Crystallography and Photonics" RAS and was supported by the Russian Ministry of Education and Science".

Heat transport in spin systems: the good, the bad, and the realistic

A. L. Chernyshev[a,*]

[a]University of California, Irvine, 92617, Irvine, CA, USA

*sasha@uci.edu

I will provide a brief overview of the studies of thermal transport in large-J spin systems of the cuprate family and will discuss a recent theoretical progress in its understanding for the spin-chain materials. In our approach, the heat conductivity in *S=1/2* Heisenberg spin chains is by 1D spin excitations, described within the bosonization framework and coupled to optical phonons, which are responsible for a large-momentum scattering. Our theory provides an excellent fit to the data and stands out from previous considerations that require large spin-phonon coupling constants and thus imply a spin-Peierls transition, absent in real materials. Our description of the spin-phonon scattering is also in accord with a physically intuitive picture of phonons playing the role of thermally-populated weak impurities for the fast spin excitations.

[1] A. L. Chernyshev and A. V. Rozhkov, Phys. Rev. Lett. **116**, 017204 (2016).

Spark plasma sintering of manganese silicide based ferromagnetic materials for multiple applications

M.V. DOROKHIN[a,*], YU.M. KUZNETSOV[a], P.B. DEMINA[a], I.V. EROFEEVA[a], M.S. BOLDIN[a], E.A. LANTSEV[a],A.A. POPOV[a], A.V. BORYAKOV[a]

[a]N.I. Lobachevsky State University of Nizhny Novgorod, 603950, Gagarin ave. 23/3, Nizhny Novgorod, Russia

*dorokhin@nifti.unn.ru

Manganese silicide based compounds and solid solutions are considered promising materials for multiple applications in silicon-based spintronics [1], and as thermoelectric energy converter [2]. In spintronics, manganese silicide can be applied as a source of spin-polarized carriers for spin injection into silicon [3]. It's fabrication technology should then provide a room-temperature ferromagnetism as in [1]. A thin-film vacuum deposition technology is most often used for the material fabrication in this case. Considering thermoelectric application the main effort is focused on the fabrication of higher manganese silicide, which is a compound with the approximate formula of $MnSi_{1.75}$. In the latter case bulk materials are most often being fabricated [2].

In the present paper, we report on the fabrication of manganese-silicide based compound by means of spark plasma sintering (SPS) technique. The SPS provides wide range of opportunities for controlling the material composition and structure parameters [2]. The investigated samples were sintered from the Mn and Si powders using the DR SINTER model SPS-625 spark plasma sintering system. The samples were sintered at a constant heating rate to the limiting temperature of 850 °C. The material composition Mn vs Si was varied between 50×50 at.% and 33×66 at. %. The composition was set by weighting the initial powders and recalculating weight percent into atomic.

The sintering process involves application of ~ 70 MPa pressure to the sample and continuous heating up to limiting temperature. It was found that during heating the Mn-Si powder a solid state chemical reaction and formation of manganese monosilicide compound takes place. The temperature of reaction triggering was about 470 °C. This temperature and the reaction itself did not depend on the Mn-Si composition and was detected even in nominally $MnSi_2$ mixture. The electronic microscopy measurements have revealed that the samples with composition different from 50×50 at.% were indeed multiphase system. One of the phases is a MnSi compound, which was formed during the solid-state reaction. The other phase is an excessive silicon weakly doped with manganese. The phase ratio as well as the Mn doping level of Si phase depended on the initial powder composition.

The magnetization measurements carried out using alternating gradient magnetometer have shown that the fabricated samples are weakly ferromagnetic at the room temperature. The measurement of thermoelectric parameters have shown that the highest Seebeck voltage is characteristic of a sample composition close to higher manganese silicide. The typical value was about 150 μV/K.

Thus, we have fabricated and investigated a manganese silicide based multiphase materials, which are applicable in spintronics (as a magnetic material) and thermoelectricity (as a thermoelectric power source).

This work supported by the Russian Science Foundation (project 17-79-20173).

[1] E.S. Demidov, E.D. Pavlova, A.I. Bobrov, JETP Lett. 96, 706(2013).
[2] R. Jansen, Nature mat. 11, 400 (2012).
[3] Y. Sadia, L. Dinnerman, Y. Gelbstein, J. of Electronic Materials. 42, 1926 (2013).

ε-Fe_2O_3 nanoparticles embedded in silica xerogel – Magnetic metamaterial: magnetic and dielectric properties.

A. DUBROVSKIY[a,*], D. BALAEV[a], YU. KNYAZEV[a], S. YAKUSHKIN[b], V. KIRILOV[b], O. MARTYANOV[b]

[a]Kirensky Institute of Physics, Federal Research Center KSC SB RAS, Krasnoyarsk 660036, Russia

[b]Boreskov Institute of Catalysis, Russian Academy of Sciences, Siberian Branch, Novosibirsk 630090, Russia

*andre-do@yandex.ru

A novel method for synthesizing a new metamaterial based on ε-Fe_2O_3 nanoparticles immobilized in the xerogel matrix was proposed. Samples with different contents of ε-Fe_2O_3 nanoparticles dispersed in silica xerogel were synthesized by impregnation of as prepared hydrogel with iron (II) salts with the subsequent calcination. The structure and magnetic properties of the prepared composites were studied by transmission electron microscopy, X-ray diffraction, Mössbauer spectroscopy, and static magnetic measurements. The absence of other iron oxide polymorphs, controllable particle size distribution, and high ε-Fe_2O_3 nanoparticle concentration in combination with the weak interparticle magnetic interactions ensured the preservation of the unique magnetic properties of individual ε-Fe_2O_3 nanoparticles and allowed us to obtain a novel metamaterial. The high optical transparency and homogeneity of the prepared composites made it possible to detect the magnetic circular dichroism (MCD) of the magnetic silica xerogel, which is typical of the ε-Fe_2O_3-based systems [1].

The ε-Fe_2O_3 is magnetically ordered iron oxide, which exhibits a significant room-temperature coercivity, is a ferroelectric; therefore, the magnetoelectric and magnetodielectric properties of this material evoke keen interest. It was investigated the magnetodielectric (MD) effect in mentioned above metamaterial consisting of xerogel SiO_2 with embedded ε-Fe_2O_3 nanoparticles 9 nm in size on average in a concentration of 20 mass.%. This bulk material exhibits the MD effect in a wide temperature range. The temperature behavior of the permittivity is related to the magnetic state of the ε-Fe_2O_3 oxide, which undergoes the magnetic transition from the magnetically hard to magnetically soft phase in the temperature range of 80–150 K, indicating the interplay of the ε-Fe_2O_3 magnetic and charge subsystems [2].

This work was supported by the Russian Science Foundation, project no. 17-12-01111.

[1] S. S. Yakushkin, D. A. Balaev,A. A. Dubrovskiy et al., Ceramics International 44, 17852 (2018).
[2] A.A. Dubrovskiy, D.A. Balaev, A.A. Krasikov et al., Solid State Communications 289, 27 (2019).

Magnetostriction and enhanced second harmonic generationin$Fe_{80-x}Co_xP_{14}B_6$metallic glasses

I.V. SEKIRIN[a], V.S. IGNAKHIN[a], A.M. GRISHIN [a,b,c*]

[a]Petrozavodsk State University, 185910Petrozavodsk, Karelian Republic, Russia

[b]KTH Royal Institute of Technology, SE-164 40 Stockholm-Kista, Sweden

[c]INMATECH Intelligent Materials Technology, SE-127 51, Skärholmen, Sweden

*grishin@kth.se

We report magnetoelastic properties in Fe-Co-P-B metallic glasses. Series of $Fe_{80-x}Co_xP_{14}B_6$ (x = 25, 32, 35, and 40 at.%) and a reference $Fe_{40}Ni_{40}P_{14}B_6$alloys were prepared in a glassy state in the form of 15–30 μm thick ribbons by a melt-spinning process. [1] The main characteristics of magnetic *B-H* hysteresis loops (coercive field, saturation and remnant magnetization) have been evaluated at various tensile and torsional mechanical deformations. [2] Narita's method of measuring magnetostriction was employed to obtain saturation magnetostrictiongrowing with a cobalt content from$\lambda = 1.75 \times 10^{-6}$ in $Fe_{55}Co_{25}P_{14}B_6$ up to 1.6×10^{-5} in $Fe_{40}Co_{40}P_{14}B_6$.

The Narita method consists of a low-frequency f transversal magnetic field H_{ac}excitation of a small-angle magnetization rotation in a ribbon exposed to a longitudinal magnetic field $H_{||}$.[3] At strong magnetic field the following expression for the second harmonic e_{2f}EMF signal

$$1/\sqrt{e_{2f}} = (2\pi N M_s)^{-1/2} \frac{H_{\parallel} + 3\lambda\sigma/M_s + M_s N_{\perp}}{H_{ac}}$$

is used to determine magnetostriction constant λ as the asymptote $1/\sqrt{e_{2f}} \to 0$of a linear $H_{||}$ dependence.

Reduction of magnetic field $H_{||}$causes the nucleation of Bloch domain wall (DW) and appearance of two antiparallel along ribbon oriented domains. Transversal magnetic field H_{ac} excites oscillations of DW adding a big contribution to e_{2f} EMF. Strong enhancement of the amplitude of the second harmonic manifests itself with a sharp "beak" in $1/\sqrt{e_{2f}}$vs. $H_{\parallel}$ dependence in Figure below attached.

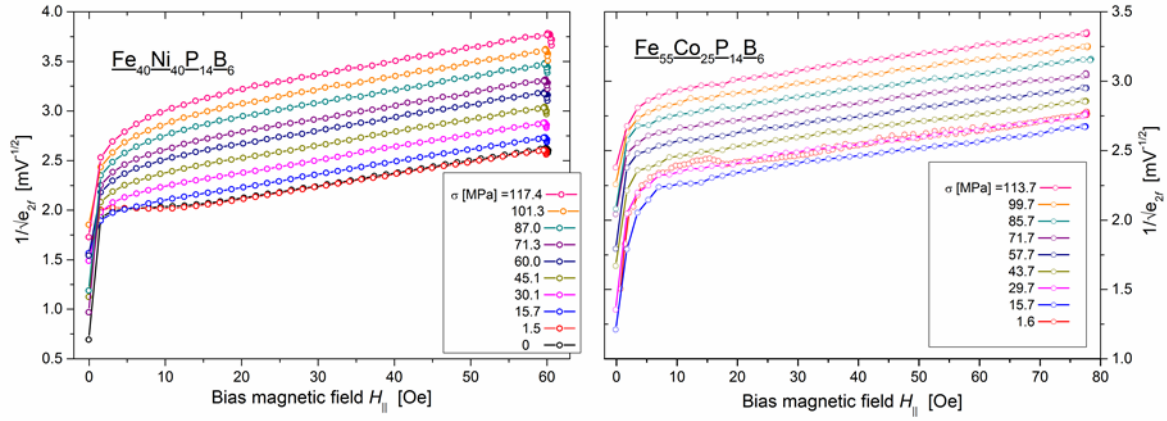


Figure - EMF signal $1/\sqrt{e_{2f}}$as a function of bias field $H_{||}$ for as-cast melt-spun $Fe_{40}Ni_{40}P_{14}B_6$ and $Fe_{55}Co_{25}P_{14}B_6$ ribbons under various tensile stresses σ.

[1] V.I. Tkatch, A.M. Grishin, S.I. Khartsev, Mater. Sci. Eng.**A 337**, 187 (2002).
[2] V.S. Ignakhin, V.S. Severikov, A.M. Grishin, J. Magn. Magn.Mater.**476**, 382 (2019).
[3] K. Narita, J. Yamasaki, H. Fukunaga, IEEE Transactions on Magnetics **16**, 435-439 (1980).

LASER CONROL OF PROPAGATING SPIN WAVES IN CURVED MAGNONIC STRIPE

V. A. GUBANOV *, A.V. SADOVNIKOV

Saratov State University, 410012, 83 Astrakhanskaya Street, Saratov, Russia

*vladmeen@gmail.com

The study of physical principles that determine the possibility of using spin waves (SW) to create information signal processing devices based on magnonics principles is of great interest [1]. Microstructures based on the iron-yttrium garnet (YIG) can be used in the processing of spin-wave signals due to the low attenuation. To control the properties of propagating spin waves (SW), the method of structuring YIG films and creating irregular micro- and nanoscale waveguides, including structures with broken translational symmetry, can be used [2].

In this work, the numerical simulations results of the spin wave propagation in a magnon irregular microwave, as well as the propagation of spin waves when creating a temperature gradient by laser radiation [3] in the waveguide curvature region (shown in Fig. 1a) are presented. The structure is an irregular YIG microwaveguide with a width of w = 500 μm, thick d_1 = 10 μm placed at 500 μm-thick (d_2) gallium gadolinium garnet (GGG) substrate. The structure was placed in an external magnetic field with the magnitude H_0= 1200 Oe directed along the *x*-axis in order to excite a surface magnetostatic wave (SMSW).

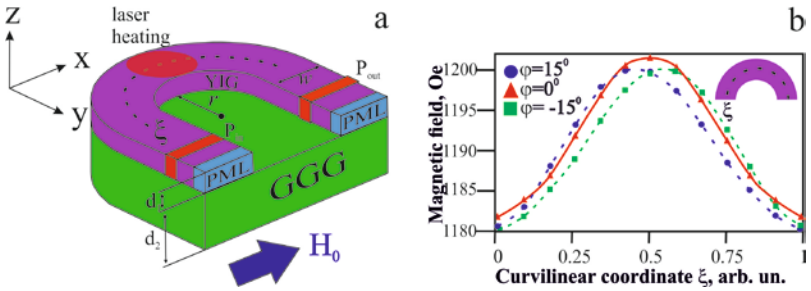


Figure 1.: *a)Scheme of the irregular curved magnonic stripe; b) profile of the internal magnetic field when the external magnetic field is deflected for a bias angle φ = 15 ^{0}(circles), φ = 0 ^{0} (triangles), φ = -15 ^{0}(squares);*

It is shown that the control of the characteristics of the propagation of the SW is possible due to the inhomogeneous configuration of the internal magnetic field along the direction of propagation of the SW. Also, the main modes of operation of the proposed structure were revealed with local modulation of the structure properties (magnetization and the internal magnetic field by laser heating).

This work was supported by the Russian Science Foundation (project no. 18-79-00198).

[1] Kruglyak, V. V. Magnonics / V. V. Kruglyak, S. O. Demokritov, D. Grundler. // Journal of Physics D: Applied Physics. — 2010. — Vol. 43. — P. 260301.

[2] Sadovnikov, A. V. Spin wave propagation in a uniformly biased curved magnonic waveguide/ A. V. Sadovnikov, C. S. Davies, V. V. Kruglyak, [at al.]. // PHYSICAL REVIEW B. — 2017. — Vol. 96. — P. 060401(R).

[3] Vogel, M. Optically reconfigurable magnetic materials / M. Vogel, A. V. Chumak, E. H. Waller, T. Langner, V. I. Vasyuchka, B. Hillebrands, G.von Freymann. // Nature Physics — 2015. — Vol. 11. — P. 487–491.

The effect of a weak electromagnetic field on the vascular wall endothelium function of healthy volunteers

Yu. Gurfinkel[a,*], N.Novikov[b] , Y.Remezova[b], A.Tishin[b]

[a]Medical Research and Educational Centre, Lomonosov Moscow State University

Lomonosovskyprospect 27/10, 119991, Moscow, Russia

[b]Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

*yugurf@yandex.ru

The mechanisms of a weak electromagnetic field influence (EMF) on humans are not well understood. There are practically no data on their effect on the vascular wall and endothelial function. Over the past three decades, these cells, lining the inner wall of blood vessels, have attracted the special attention of researchers primarily because they are in direct contact with blood, releasing nitrogen monoxide and other substances into the lumen of vessels, which play an important role in regulating blood pressure, blood rheology, immunity and other important functions. The level of this interest is evidenced by the Nobel Prize in Medicine in 1998, which was awarded to a group of scientists from three different laboratories in the US.

The study included 32 healthy volunteers who signed informed consent, approved by the Ethics Committee of the Medical Research and Educational Center, Lomonosov Moscow State University. On the eve of the study, subjects were asked to refrain from smoking and from taking caffeine-containing beverages. The sequence diagram of the study displays 5 identical consecutive measurement sessions, during which endothelial function (EF), heart rate and blood pressure were determined using the Tonocard instrument ("AMDT", Russia). The sequence of stages of the experiment is shown in Figure 1, where T1 is the initial study before exposure to EMP, T2 is the measurement 20 minutes after the start of exposure, T3 is the measurement 40 minutes after the start of exposure, T4 is the measurement 60 minutes after the start of EMF exposure, T5 - study 30 minutes after the end of the exposure EMF. EMF parameters: induction 0.05 mT, frequency 800 Hz.

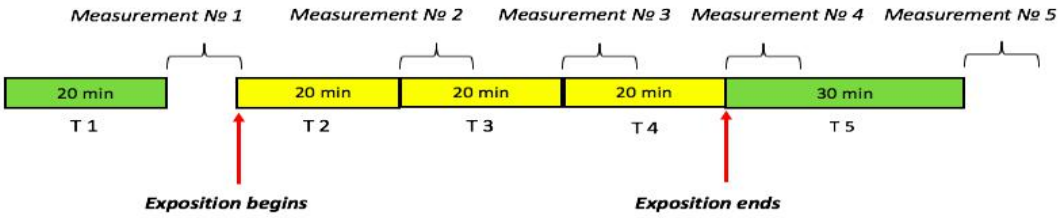


Fig. 1 The sequence diagram of the study before, during and after EMF exposure

The results of the study showed that the EF increases during exposure of EMF in healthy volunteers by the 40th minute from 2 to 10 times compare with the initial measurement. The rise in EF continues for 30 minutes after the termination of EMF exposure. The reason for this increase requires additional experimental and theoretical study. Probably, this effect could be useful in the treatment of diseases with endothelial dysfunction, typical for coronary heart disease, type 2 diabetes mellitus. No significant effect of EMF exposure on heart rate and blood pressure was detected during the study.

Tuning Electronic Phase Separation in CaFe3O5 by Doping

B. V. Hakala [A,B], K. H. Hong [A,B], J. P. Attfield [A,B*]

Centre for Science at Extreme Conditions, The University of Edinburgh, Erskine Williamson Building,

School of Chemistry, The University of Edinburgh, Joseph Black Building, David Brewster Road,

Edinburgh, EH9 3FJ United Kingdom

*****j.p.attfield@ed.ac.uk

Recent study of the CaFe3O5 revealed an electronic phase separation into two phases withdifferent electronic and antiferromagnetic spin orders below their joint magnetic transition at 302 K,[1] similar to ones widely reported in manganite perovskites.[2] Electronic phase separation in manganites is known to be very sensitive to perturbations by field, pressure, and chemical substitutions.

We are investigating effects of substituting Fe^{2+} with Co^{2+} and Mn^{2+} in CaFe3O5. Following the successful preparation of CaFe3-*x*M*x*O5 (*M* = Co, Mn) with *x* up to 0.5, changes in lattice parameters, consistent with the ionic radius of substituting M^{2+} cation, were observed.

The magnetic susceptibilities show small net magnetisation observed at 2 K and an increase in *T*M for the Mn and Co samples, respectively.

Subsequent neutron study on WISH has shown that Mn^{2+} and Co^{2+} have different influence on the phase separation. Synchrotron data were used to refine HT structure and confirm the anisotropic thermal expansion observed in MnFe3O5.

[1]K.H. Hong, A.M. Arevalo-Lopez, J. Cumby, C. Ritter and J.P. Attfield, Nat. Commun. 9, 2975 (2018).

[2]M. Uehara, et al. Nature 399, 560–563 (1999).

[3]K.H. Hong, G.M Mcnally, M. Coduri and J.P. Attfield, Z. Anorg. Allg. Chem. 642(23), 1355-1358 (2016)

Synthesis Optimization of Mn-Zn Ferrites for Ferrofluid Applications

André Horta[a,*], F. Mohseni[1], C. O. Amorim[1], J. H. Belo[1], J. S. Amaral[1]

Departamento de Física and CICECO – Aveiro Institute of Materials, Universidade de Aveiro, Portugal

* andre.horta@ua.pt

Manganese-Zinc ferrite nanoparticles have been the subject of increasing research due to their desired properties for a wide range of applications. These properties include nanometer particle size, tunable magnetic behavior, and high saturation magnetization, providing these ferrites with the necessary requirements for cancer treatment via magnetic hyperthermia. During this ongoing research, we have synthetized and characterized Mn-Zn ferrite powders, aiming to optimize their structural and magnetic properties for further application in a ferrofluid [1].

In this work, samples of Mn1-xZnxFe2O4 (x=0; 0.5; 0.8; 1) were synthetized via the sol-gel auto-combustion and hydrothermal methods. Synthetized powders were characterized by XRD, SQUID, SEM, TEM and induction heating setup. The XRD diffractograms of hydrothermally produced samples presented low percentage of secondary phases, such as hematite (α-Fe2O3) (<10%) for all samples. The Williamson-Hall analysis revealed the crystallite size increasing with the increase of Mn content. SEM images displays agglomerates composed of few nanoparticles, 150 < mean size < 250 nm, and a spherical agglomerate shape. SQUID results showed that with the increase of Zn changed in saturation magnetization that varies from 79 to 19 emu/g, coercive field from 41 to 11 Oe, remnant magnetization from 5 to 0 emu/g. More noticeably the M(T) curves revealed a shift in the samples Curie temperature towards lower temperatures with the increase of Zn content, from ~610 (estimated) to ~250 K. Figure 1 a) are the M(T) curves for Curie temperature estimation, figure 1 a). Whereas in Figure 1 b) are presents the magnetic hysteresis loops and figure 1.c) the heating rate, in an AC field. All figures are composition dependent.

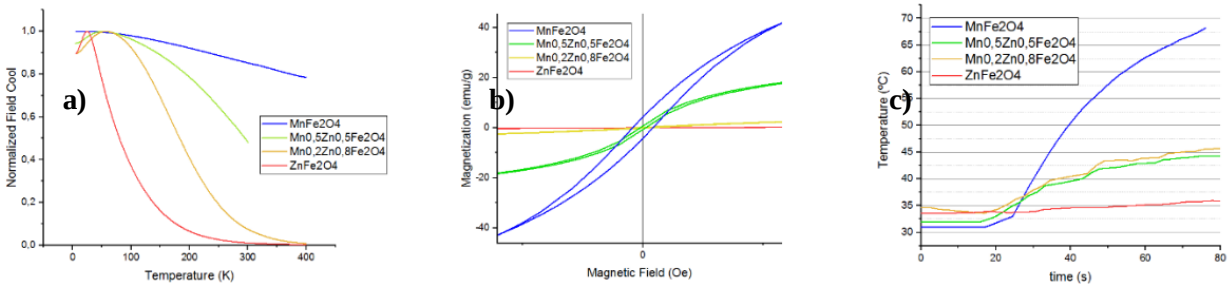


***Figure 1** – a) M/MMAX curves at 100 Oe. b) Magnetic hysteresis loops at 300 K c) magnetic induction heating, in an AC field of 364 kHz and field amplitude of 250 Oe. Composition: Mn1-xZnxFe2O4 x= 0;0,5;0,8,1*

The nanocrystals of Mn-Zn ferrite produced by the hydrothermal method present better crystallinity and magnetic properties than the sol-gel auto-combustion samples. The hydrothermally synthetized samples revealed dependence of its structural and magnetic properties with Mn/Zn ratio. The Curie temperature of these ferrites can be used as a self-controlled mechanism of heating, rising these ferrites to a class of intelligent materials.

[1]N. Zhu et al, IEEE Trans. on Applied Superconductivity ASEMD18-8265
[2]P. H. Nam et al, Physica B: Condensed Matter 550 (2018) 428-435
[3]Y. Xuan et all, Jour. of Magnetism and Magnetic Materials 312 (2007) 464-469

Transport and magnetotransport properties of multifunctional Gd5(Si,Ge)4 granular thin film

H.Belo[a*], A. L. Pires[a], V.Andrade[a], R.L.Hadimani[b,C], D. C. Jiles[b] , A. M. Pereira[a] And J. P. Araújo[a]

[A]IFIMUP and IN-Institute of Nanoscience and Nanotechnology, Departamento de Física e Astronomia da Faculdade de Ciências da Universidade do Porto, Rua do Campo Alegre, 687, 4169-007 Porto, Portugal

[B]Department of Electrical and Computer Engineering,Iowa State University,Ames,Iowa 50011,USA

[C]Department of Mechanical and Nuclear Engineering, Virginia Commonwealth University, Richmond, Virginia 23059.

* joao.horta.belo@gmail.com

In 1997 the discovery of the giant magnetocaloric effect (GMCE) at room temperature revitalized the magnetocaloric materials field, unveiling the real potential of magnetic refrigeration at room temperature and setting the beginning of a race for the best magnetocaloric material. In the last ten years, the broad interest on these materials lead to the extension of their study to the micro- and nanoscale where the main motivations are purely scientific (explore new underlying mechanisms) and technological (micro-refrigeration, sensors/actuators, ferrofluids).

The R5(Si,Ge)4 (R=Rare Earth) are multifunctional compounds presenting the highest MCE for the broadest temperature interval, colossal magnetostriction and giant magnetoresistance

Unfortunately, so far, few reports have been dedicated to the study of Gd5(SixGe1-x)4 compounds at micro and nanoscale.

In the recent past years, our team has been working on different methods to fabricate nanostructures of R5(SixGe1-x)4 compounds (R = Gd and Tb), focused on thin films and nanoparticles. Recently, Gd5Si1.3Ge2.7 thin film was grown by pulsed femtosecond laser deposition (PLD) which undergoes a magnetostructural transition at TMS~ 190K. As a consequence, a giant expansion on the unit cell volume of 0.81% and a magnetic entropy change of ΔSm^{MAX} ~ 13.6 J Kg^{-1} K^{-1} were observed [3] together with a significant reduction of the magnetic hysteresis in comparison with the bulk compound.

In this particular work, the nanogranular thin film magnetostructural transition was inspected by electrical resistivity measurements as a function of temperature, magnetic field and thermal cycles. The resistivity as a function of temperature profile displays a hysteretic abrupt change from a high to a low resistivity state while cooling, consequence of the magnetostructural transition. Furthermore, as the number of cycles increase, this profile evolves from a single transition towards a two-fold transition at TMS~ 190K and Tc ~ 250K. Magnetic measurements before and after the cyclings confirm this evolution. In addition, magnetotransport measurements performed along a broad temperature range [5, 300]K will be presented and discussed in detail, mainly for its interesting features, such as the: the magnetoresistance maxima at 50K (6%), its change of sign and its behavior at the magnetostructural transition. These results highlight the multifunctionality of the R5(SixGe1-x)4 family also at the nanoscale, the multi-step evolution of their metamagnetic transitions and the importance of cycling, as a critical study envisaging technological applications.

[1]R. Niemann et al., Appl. Phys. Lett. 97, 222507 (2010).
[2]K. A. Jr. Gschneidner et al., Reports on Progress in Physics, 68, (2005) 1479-1539.
[3]R. L. Hadimani, J. H. B. Silva, et al., Appl. Phys. Lett. 106, 032402 (2015).

Multifunctional bismuth ferrite nanoparticles

D.A. KALGANOV[a*], M.S. GRYAZNOVA[a], A.A. ANZULEVICH[a],

YU.A. LUPITSKAYA[a], I.V. BYCHKOV[a,b]

[a]Chelyabinsk State University, 454001, Br. Kashirinykh 129, Chelyabinsk, Russia

[b]South Ural State University, pr. Lenina 76, Chelyabinsk 454080, Chelyabinsk, Russia

*dezwark@gmail.com

Bismuth ferrite $BiFeO_3$ is a well-known multiferroic compound, in which dipole ordering occurs near 1100 K and antiferromagnetic ordering – near 640 K. Hence, it can be used for the room temperature applications [1]. Besides, on the base of bismuth ferrite it is possible to create, using sol-gel processing and solid-state synthesis, solid solutions with the broad homogeneous region by double isovalent alloying of a part of Bi^{3+} ions by rare earth metal ions Ln^{3+}, and of the same amount of Fe^{3+} by Co^{3+} ions. This modification can increase the possible number of application of such compounds [1]. However, the synthesis of monophase ceramic $BiFeO_3$ in the system Bi_2O_3–Fe_2O_3 is hindered by the formation of transitional crystalline phases $Bi_2Fe_4O_9$ and $Bi_{25}FeO_{39}$. The structural deformation introduced by cation substitution/doping in $BiFeO_3$ or reduction of the linear dimensions of crystallites to the nanoscale could be used to destroy the spin cycloid and release the inherent magnetization [1,2].

In the present work, cation-exchange synthesis on a previously synthesized organic matrix [3] was used to obtain nanodispersed bismuth ferrite powder. The phase composition of the samples was investigated by X-ray diffraction (Fig. 1,a). Using scanning electron microscopy images of powder particles were obtained, their morphology and size were studied (Fig. 1,b). The microwave properties of BiFeO3 nanopowder sample with an appropriate sample-thickness about 1 mm. was investigated in rectangular waveguide using scalar network analyzer R2M40 in frequencies range 28-40 GHz at room temperature. The dependences of the transmission of electromagnetic waves on the magnitude of the external magnetic field are obtained (Fig. 1,c).

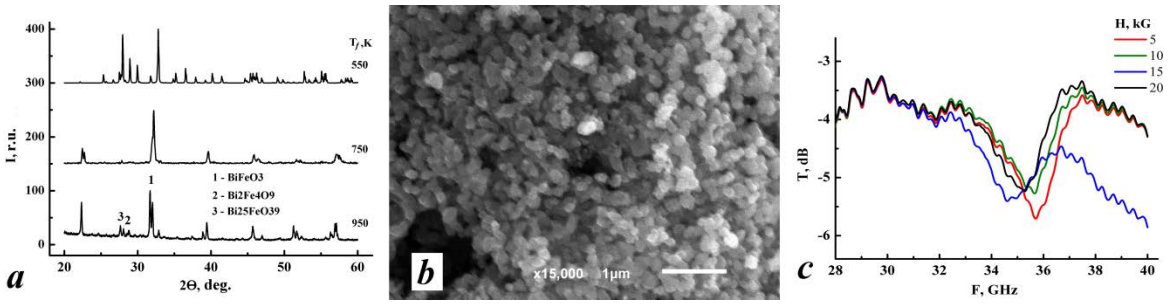


*Figure 1.Phase composition – **a**, microscopy image - **b** and microwave properites of samples - **c**.*

This work was supported by Chelyabinsk State University internal funding support, and by the Ministry of Education and Science of the Russian Federation (State Contract No. 3.5698.2017/9.10).

[1] L. Wang, Journal of Magnetism and Magnetic Materials. 421, (2017)
[2] Yu.A. Lupitskaya, D.A. Kalganov, Yu.O. Afanasev, Bulletin of the South Ural State University. Ser. Mechanics. Physics. 10, 2 (2018)
[3] E.A. Belaya, M.S. Gryaznova, V.V. Victorov, I.N. Kovalev, D.A. Zherebtsov, Butlerov Communications 52, 10 (2017)

Field dependence of magnetocaloric effect in prospective materials under adiabatic and isothermal conditions

A. KAMANTSEV[a,b*], V. KOLEDOV[a], V. SHAVROV[a]

[a] Kotelnikov IRE RAS, 125009, Mokhovaya 11/7, Moscow, Russia

[b]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

*kaman4@gmail.com

An experimental verification of the field dependence of the magnetocaloric effect (MCE) for Gd near the Curie point was performed. It turned out that the value of the degree in the ratio $\Delta T \sim H^k$ strongly depends on the external conditions of the experiment. In a stationary calorimeter in quasiadiabatic conditions [1] (when a sufficiently large outflow of heat from the sample is observed when the magnetic field is turned on), the value of k in certain experiments exactly coincides with the theoretical $k = 0.65...0.66$. Summarizing the experimental results in an extraction calorimeter [2] (insertion/removal of the calorimeter to/from the magnetic field avoids the heat outflow from the sample by reducing the duration of the experiment) showed that $k = 0.73..0.85$, which is significantly higher than the theoretical value of 2/3. The results of measurements in a pulsed magnetic field [3] show that in single experiments the value $k = 0.96..1.07$, and when summarizing the results of different experiments, the value $k = 0.95$ (close to 1, which much higher than theoretical value).

The field dependence of the MCE in quasi-isothermal conditions can be expressed as $\Delta Q \sim H^n$. The ΔQ values for Gd were obtained using an extraction calorimeter [2]. For different temperatures, the exponents will be the following $n(273K) = 0.95$, $n(293K) = 0.76$, $n(297\ K) = 0.76$. The data obtained confirm the conclusions made in [4] that for soft magnetic materials $n = 1$ is lower than the Curie temperature, and $n \approx 0.75$ at $T = T_C$.

The perspective MCE materials with the 1st order phase transitions also demonstrate interesting $\Delta T(H)$ and $\Delta Q(H)$ dependences. For example, the $Mn_{1.22}Fe_{0.73}P_{0.47}Si_{0.53}$ alloy with $T_C = 313$ K has $k(310K) = 0,72$, $k(311K) = 1,01$, $k(314K) = 1,59$ at fields 10-40 kOe, and $k(310K) = 0,29$, $k(311K) = 0,47$, $k(314K) = 0,62$ at fields 50-140 kOe [5], which indicates non-equilibrium processes occurring in vicinity of the phase transition. The ΔQ values for $Mn_{1.22}Fe_{0.73}P_{0.47}Si_{0.53}$ are following: $n(310K) = 0.66$, $n(314K) = 0.50$, which agrees well with theoretical predictions in [6].

The work was carried out within the framework of the state task.

[1] E.T. Dilmieva, et al. Phys. Solid State 58, 81-85 (2016).
[2] A.P. Kamantsev, et al. Solid State Phenom. 233, 216-219 (2015).
[3] A.P. Kamantsev, et al. J. Magn. Magn.Mater.440, 70-73 (2017).
[4] V. Franco, et al. Appl. Phys. Lett. 89, 222512 (2006).
[5] F. Guillou, et al. IEEE Trans. Magn. 51, 2503904 (2015).
[6] H. Oesterreicher, F.T. Parker. J. Appl. Phys. 55, 4334-4338 (1984).

Spinel-ferrites magnetic nanoparticles for biomedical applications: Synthesis and magnetic structure.

A. S. KAMZIN*

Ioffe Physical-Techncal Institute RAS, St. Petersburg, 194021, Russia

*ASKam@mail.ioffe.ru

Magnetic hyperthermia (MHT) is a therapeutic treatment in that magnetic nanoparticles (MNPs), placed in the malignant tumor, are heated up to 43–45°C by an external alternating magnetic field (EAMF), which leads to thermal destruction of malignant cells without affecting healthy cells how it has been shown in 1957 [3]. The use of iron oxide MNPs for the treatment of cancer by magnetic hyperthermia (MHT) was first demonstrated in 1957 [3]. But, research in the application of MNPs in medicine has developed rapidly last two decades. However, MHT by MNPs has not found widespread use in clinics, because, optimized MNPs for the MHT treatment are required. Such MNPs should have biological compatibility with a living organism and should automatically stop heating above 45°C, because, above this temperature, healthy cells die. So, it is necessary to develop methods for synthesizing MNPs suitable for magnetic hyperthermia and to control the properties of synthesized particles strictly, as the properties of MNPs strongly depend on the methods of synthesis. MNPs of MFe_2O_4 spinel ferrites (M = Mg, Mn and so on) are very promising for use in biomedicine (see [2] and references therein). In many studies of spinel ferrites MNPs, non-collinear spin structures (spin-canting) have been observed. For many years, it has been discussed whether the spin-canting is mainly a surface effect or a phenomenon, which is also common in the interior of the particles.

The purpose of this work was to investigate the phase state, spin structure in the bulk and on the surface of MNPs of different MFe_2O_4 spinel ferrites and to find the technology for producing MFe_2O_4 MNPs optimized for biomedicine.

A large fraction of atoms in the MNPs is located on the surface and the exchange interactions of these atoms are broken. This can lead to a change in the spin structure of only the surface layer of MNP or the entire volume of MNPs. For studying of MNPs has been used Mössbauer spectroscopy giving very useful information about surface effects and spin structure of MNPs.

[1] R. K. Gilchrist, B.S. Richard Medal, William D. Shorey, Russell C. Hanselman, John C. Parrott, and C. Bruce Taylor. An Surg. 146, 596 (1957)
[2] A. S. Kamzin, A. A. Valiullin, V. G. Semenov, Harinarayan Das, and Naoki Wakiya. Phys. Solid State, 61, No. 6, 1113 (2019)

Magnetism and structure of atom-wide Co and Fe wires on a metallic substrate

A. Klavsyuk , A. Syromyatnikov, A. Saletsky

Faculty of Physics, Moscow State University, Leninskie Gory, 1-2, 119991 Moscow, Russia

klavsyuk@physics.msu.ru

Using kinetic Monte-Carlo method, the formation of atom-wide Co and Fe wires on Pt(997) and Cu(775) is investigated on an atomic scale [1]. The atomic processes responsible for the formation wires are identi ed. We show that for a large value of the bond energy, the antiripening mechanism [2] and quantum e ects do not a ect the length of metal monatomic wires. The conditions under which wires with magic length [3] appear are determined. The observed mechanism of wire growth will be useful both for explaining the experimental data and for creating atomic wires with a given length. The magnetic properties of the structures forming are calculated using density functional theory. The spin and orbital magnetic moments and the magnetic anisotropy energy of these embedded nanostructures are obtained.

Finally, we have demonstrated the existence of two ferromagnetic states of Co wires on a vicinal Cu111 surface [4]. The low phase transition temperature is explained by small di erence in energy between the states. Our results completely refute the conclusion made by Zaki et al. [5] that DFT qualitatively fails to predict the dimerized structural phase for a monatomic Co wire on a vicinal Cu111 surface. In addition, it was found that the phase transition temperature depends drastically on the length of the wire and the tip bias. In the rst instance, tip-bias dependency is related with deformation of wire and surface. We believe that a dimerized Co spin wire can potentially behave as a linear array of spin-memory bits.

[1]Syromyatnikov, A. G., Saletsky, A. M. and Klavsyuk, A. L. Distributions of atomic wire lengths. Phys. Rev. B 97, 235444 (2018).
[2]Tokar V. I. and Dreysse H. Monotonic and bimodal size distributions of surface nanowires caused by post-deposition annealing. Phys. Rev. B 84, 085456 (2011).
[2]Mocking, T. F. et al. Electronically stabilized nanowire growth. Nature Communications 4, 2387 (2013).
[3]Syromyatnikov, A. G. et al. The structure phase transition in atom-wide Co wires on a vicinal Cu111 surface. Mater. Lett. 179, 6972 (2016).
[4]Zaki, N. et al. Experimental observation of spin-exchange-induced dimerization of an atomic one-dimensional system. Phys. Rev. B 87, 161406 (2013).

Phonon anomaly in a Haldane magnet Sm_2BaNiO_5

S. A. KLIMIN[a,*], E. A. POPOVA[b]

[a]Institute of Spectroscopy, Russian Academy of Sciences, 108840, Fizicheskaya 5, Troitsk, Moscow, Russia

[b]National Research University Higher School of Economics, 101000, Myasnitskaya 20, Moscow, Russia

*klimin@isan.troitsk.ru

Family of the rare-earth (RE) chain nickelates $RE_2BaNiO_5$are recognized to be a model compounds for studying one-dimensional magnetism. In their *Immm* crystallographic structure, Ni^{2+} ions (S=1) form chains directed along the *a*-axis. Y_2BaNiO_5 is believed to be almost ideal Haldane magnet [1,2]. Recently, chain nickelates attract attention from the point of view of their multiferroicity. In Sm_2BaNiO_5, a dielectric constant ε(ω) reveals a peak with increasing T around 22 K [3,4]. Authors of the Ref. [3] explained this by the depopulation of the exchange-split excited state of Kramers doublet. In this study we present results on the temperature behavior of the low-energy phonon modes as well as of Sm^{3+} Kramers doublets, with the aim to find correlations in the vibrational, electronic, and dielectric properties of samarium nickelate.

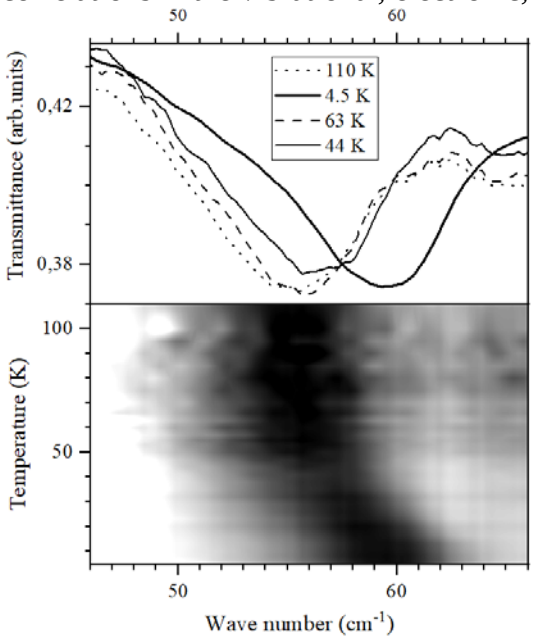


Fig.1 Anomalous behavior of the lowest-energy phonon of Sm_2BaNiO_5 in the vicinity of T_N=55. Spectra at different temperatures (upper panel) and black-white intensity map (lower panel)

Transmittance spectra in a wide spectral range were measured using a Fourier–spectrometer Bruker IFS125HR. Mixture of Sm_2BaNiO_5 and optical grade KBr powders pressed into tablets were places in an optical closed-cycle cryostat Cryomech PT403.

We have found that in Sm_2BaNiO_5 the lowest-frequency mode at ~55 cm^{-1} experience the influence of the magnetic ordering (see Fig.1). Studying of the transmittance spectra in the region of *f-f* transitions enabled us to find crystal field energies as well as their temperature behavior. The consistency of the data obtained was checked by applying this data for the modeling of experimental magnetic susceptibility. It was revealed the fact of repulsion between split components of the ground (0) and the first excited (25 cm^{-1}) Kramers doublets. The correlations between phonon, electronic, and dielectric anomalies are discussed.

The article was prepared within the framework of the Academic Fund Program at the National Research University Higher School of Economics (HSE University) in 2019 (grant №19-04-030) and the Russian Academic Excellence Project «5-100». SAK acknowledges the support of the Presidium RAS (Program 5 “Photonic technologies in probing inhomogeneous media and biological objects”).

[1]Kojima K., Keren A., Le L.P., Luke G.M., et al., Phys. Rev. Lett. 74, 3471 (1995)
[2] Xu G., DiTusa J.F., Ito T., et al., Phys. Rev. B 54, 6827 (1996)
[3] Sanjay Kumar Upadhyay, , et al., Physica B: Condensed Matter 524, 123 (2017)
[4] Indra A., Dey K., Majumdar S., et al., Phys. Rev. B 95, 094402 (2017)
[5] Klimin S.A., Kuzmenko A.B., Popova M.N., et al., Phys.Rev. B, **82**, 174425(2010)

The magnetization reversal time of ferromagnetic and antiferromagnetic chains in the framework of the Heisenberg Model

S.V. KOLESNIKOV

Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

kolesnikov@physics.msu.ru

It is known that, according to the Mermin–Wagner theorem [1], ferromagnetism and antiferromagnetism in one- and two-dimensional isotropic Heisenberg models is absent. However, ferromagnetism and antiferromagnetism was found experimentally in finite atomic chains in the presence of magnetic anisotropy. The kinetic Monte Carlo (kMC) method for magnetic moments [2] was proposed for the explanation of ferromagnetism and antiferromagnetism of atomic chains. The kMC approach allows calculating the different magnetic characteristics of the finite chains at the wide range of temperatures. However, the kMC simulations are time-consuming. Fortunately, less time-consuming theoretical methods can be used at the temperatures below the critical temperature.

Here, we discuss a theoretical model [3,4] that allows studying the magnetic properties of atomic chains without using the KMC method. Within the Heisenberg model in the presence of uniaxial magnetic anisotropy, formulas are obtained that allow one to estimate the spontaneous magnetization reversal time of both ferromagnetic and antiferromagnetic chains. In the case of the ferromagnetic chains [3], the presented method can be generalized to the case of a nonzero external magnetic field. After that, the equation for the magnetization of the atomic chains can be obtained from the master equation. To obtain the magnetization curves, the equation for the magnetization can be easily solved numerically. In the case of the antiferromagnetic chains [4], we can calculate the magnetization reversal time of the chain during its interaction with an STM tip. This problem is related to the possible use of the antiferromagnetic chains for storing information [5].

The presented method is applied to the single and double chains in the cases of both ferromagnetic and antiferromagnetic chains. The effects of an external magnetic field, an interaction with STM, the size effect and the edge effects are discussed. In all cases the presented results are in the excellent agreement with the results of kMC simulations at the same parameters of Heisenberg Hamiltonian.

[1] N. D. Mermin and H. Wagner, Phys. Rev. Lett. 17, 1133 (1966).
[2] Y. Li and B.-G. Liu, Phys. Rev. B 73, 174418 (2006).
[3] S.V. Kolesnikov, JETP Letters, 103, 588 (2016).
[4] S.V. Kolesnikov, I.N. Kolesnikova, Journal of Experimental and Theoretical Physics, 125, 644 (2017).
[5] S. Loth, S. Baumann, C. P. Lutz, D. M. Eigler, and A. J. Heinrich, Science 335, 196 (2012).

High temperature treatment of nanochains composed of Fe1–xCox nanoparticles

M. Krajewski[a,*], M. Tokarczyk[b], T. Stefaniuk[b], G. Kowalski[b], S. Lewinska[c], Slawska-Waniewska[c]

[a]Institute of Fundamental Technological Research, Polish Academy of Sciences, Pawinskiego 5B,02-106 Warsaw, Poland

[b]University of Warsaw, Faculty of Physics, Institute of Experimental Physics, Pasteura 5,02-093 Warsaw, Poland

[c]Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland

***** mkraj@ippt.pan.pl

Recently, more and more attention is directed towards one-dimensional (1D) magnetic nanostructures such as nanowires, nanorods, nanochains, etc. because these nanomaterials provide unique electrical, optical, magnetic, surface, and chemical properties [1]. Moreover, these properties can be controlled by changing aspect ratios or chemical compositions of materials [2].

Among the simple magnetic materials, the iron-cobalt alloy possesses the highest saturation magnetization and Curie temperature [3]. This causes that this material is interesting for many applications. One of the approaches which allow producing the 1D Fe-Co nanomaterials is a magnetic-filed-induced (MFI) synthesis [4]. In fact, this process leads to the formation of iron-cobalt nanoalloy which reveals a specific structure. Namely, the obtained Fe-Co wires have a form of long straight chains composed of nanoparticles linked each other. Nevertheless, such a structure is very stable due to dipole-dipole interactions between particles forming it.

It is well known that the iron, cobalt as well as iron-cobalt materials are very sensitive to oxygen and tend to oxidize easily [4, 5]. This can be referred as a serious drawback, in particular, in the case of relatively small nanomaterials in which properties depends more on the surface than the bulk. On the other hand, the oxide layer adheres well to the material and prevents against its further oxidation. Secondly, it provides the active sites where the covalent or hydrogen bonds with other compounds can be formed. Lastly, its thickness and chemical composition can be modified with a thermal treatment in presence of different atmospheres. Therefore, this work describes how the nanochains composed of $Fe_{1-x}Co_x$ nanoparticles (where x = 0.75 and 0.25) change their morphologies, chemical compositions and magnetic properties under annealing at 400 °C and 500 °C in two atmospheres containing different content of oxygen. These changes have been traced applying a series of complementary experiments, including scanning electron microscopy (SEM), transmission electron microscopy (TEM), powder X-ray diffraction (XRD), Raman spectroscopy (RS), and vibrating sample magnetometry (VSM).

The authors acknowledge funding from the National Science Centre (Poland) (grant no.2016/23/D/ST8/03268).

[1]L. Hu, R. R. Zhang, Q. W. Chen, Nanoscale 6, 14064 (2014)
[2]L. Sun, Y. Hao, C. L. Chien et al., IBM J. Res. Dev. 49, 79 (2005)
[3]Z. Y. Chen, Q. F. Zhan, D. S. Xue et al., J. Phys.: Condens. Matter 14, 613 (2002)
[4]M. Krajewski, Nanoscale 9, 16511 (2017)
[5]M. Z. Wu, G. Q. Liu, M. T. Li et al., J. Alloys Compd. 491, 689 (2010)

Production of tetrataenite nanorods via nitriding technique

V. KURICHENKO[a,*], D. KARPENKOV[a]

[a]National University of Technology and Science MISIS, 119991, Leninskiy prospect 4, Moscow, Russia

*vkurichenko@gmail.com

Recently, a new energy paradigm has been established, which is related to a wider usage of renewable energy sources, as well as to an increased consideration of energy effective technologies. This has stimulated the development of new functional materials, including magnetic materials, which play the key role in efficiency and performance enhancement of devices for energy generation and conversion. Another reason of increased demand for magnetic materials is associated with global spreading of wind turbines and hybrid/electro-cars.

However, magnetic materials market still faces the consequences of the recent rare-earth crisis, which resulted in the increase of prices of raw materials for the most abundant hard-magnets, based on neodymium ($Nd_2Fe_{14}B$). This situation has accelerated research projects in the area of new substitutional perspective materials for magnetic materials production.

Amongst all rare-earth free systems, FeNi with $L1_0$ structure (tetrataenite) has the highest theoretical value of energy product (320 kJ/m^3), which is one of the figures of merit in magnetic materials. The main challenge of laboratory synthesis of this phase is attributed to slow diffusion at the temperature of its stability (320 °C), which makes it difficult for atoms to undergo disorder-order transformation for laboratory-scale periods of time. It is worth mentioning that in nature tetrataenite phase is found only in meteorites, in which the phase forms over billions of years, thereby allowing atomic rearrangement into the ordered $L1_0$ structure.

Therefore, researchers try to apply various methods that can accelerate diffusion rate at low temperatures. One of the methods that can enhance stabilization of the desired phase is called “nitriding and topotactical extraction” and is comprised of two steps. The first step is the formation of iron-nickel nitrides with ordered structure, in which nitrogen is obtained from thermal decomposition of ammonia on the surface of specimens. The second one corresponds to the subsequent denitriding of samples, in order to preserve the initial ordered structure of nitride in the resulted sample. This method allows formation of $L1_0$ structure in samples after processing [1].

Even though neodymium magnets have the highest energy product amongst magnetic materials, it is believed that exchange-biased ferromagnetic/antiferromagnetic composite magnetic materials have prospects for catching up or even being superior to neodymium magnets in terms of energy product. Thus, stabilization of FeNi with $L1_0$ structure can allow production of high-energy product magnetic composites, with tetrataenite as one of its components.

Initially, we have created the setup that allows to perform treatments of samples in the furnace at controllable parameters of atmosphere (speed of gas flow, pressure value). After that, the first goal of our work was to subject iron-nickel nanopowders, obtained by chemical co-precipitation method, to different processings in order to estimate the optimal set of treatment parameters for obtaining desired FeNi $L1_0$ phase. The second goal was to obtain textured structure of nanoparticles, which is a challenging task, as nanoparticles tend to agglomerate. To solve this problem FeNi nanorods were produced by means of electrodeposition on polycarbonate membranes and subjected to the same nitriding treatment. In this work, magnetic properties of obtained samples were investigated.

[1] S. Goto et al, Sci. Rep., 7, 13216 (2017)

Heisenberg chain in terms of Fockian covariance with electric field account and multiferroics in fine particles world

S. LEBLE

[a]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

*lebleu@mail.ru

Having in mind surface states contribution via allotted exchange integrals Heitler-Heisenberg multispin states marked by irreducible representations of the symmetry united permutation and space group are studied. The system Fockian covariance [1] incorporates its exchange integral of the self-consistent states into the Heisenberg chain theory. The corresponding mean energy is given in explicit form in terms of the characters of the joint group irreducible representations. External fields account is delivered by perturbation theory. Its application to statistical physics approach with the energies Gauss distribution leads to the thermodynamic parameters' evaluation. The Gauss distribution parameters are expressed also in terms of the symmetry group characters [2]. The nanoparticle example with space symmetry including rotations and translations is studied. Its symmetry introduces basic closest neighbor exchange integrals that enter the statistical sum. The polarisation and magnetisation moments are derived by conventional formulas, differentiating the statistical sum by external electric and magnetic fields, obtaining basic relations for multiferroics [3]

[1] V. A. Fock. An Approximate Method for Solving the Quantum Many-Body Problem.
[2] W. Heisenberg. Zur Theorie des Ferromagnetismus. Zeitschrift fur Physik. 1928. Vol. 49, 9-10. P. 619-636
[3] Spaldin, Nicola A.; Fiebig, Manfred (2005). "The renaissance of magnetoelectric multiferroics".Science. 309 (5733): 3912. doi:10.1126/science.1113357. PMID 16020720

Cubic magnetic nanoparticles induce different cell death types in human hepatic cell lines

K. LEVADA[a,*], S. PSHENICHNIKOV[a], A. OMELYANCHIK[a], V. RODIONOVA[a],A. NIKITIN[b], M. ABAKUMOV[b], A. MAJOUGA[b], M.LUNOVA[c], A.DEJNEKA[d] and O.LUNOV[d]

[a]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[b]National University of Science and Technology "MISIS", 119049, LeninskiyProspekt, 4, Moscow, Russia

[c]Institute for Clinical & Experimental Medicine, Videnska 1958/9, Prague, 14021, Czech Republic

[d]Institute of Physics of the Academy of Sciences of the Czech Republic, Na Slovance 1999/2, Prague, 18221, Czech Republic

*kateryna.levada@gmail.com

Currently, magnetic nanomaterials are promising tool for biomedical application due to relatively easy synthesis in a wide range of sizes, shapes and coating. Magnetic nanomaterials are widely used in diagnostics (as MRI contrast and platform for fluorescent microscopy markers) and in therapy(as agent for target drug delivery).However, for the development of efficient and safe nanoparticle-based treatmentsand diagnostics, it is crucial to establish systematic investigations of adverse effects of nanomaterials.

The aim of this study was to investigate how 2 types of magnetic nanoparticles with Fe_3O_4 core and nitrodophamin-PEG covering would affect cell survival and death signaling. For this study we chose 2 types of cubic magnetic nanoparticles with different structure: single cubes and clusters. Taking into count that iron oxide nanoparticles predominantly accumulate in the liver after i.v.administration, we selectedthree different human hepatic cell lines: HepG2, HuH7 and Alexander cell line as a model for assessment of nanoparticle induced liver toxicity.Cytotoxicity was assessed by alamarBlue viability assay. Immunoblotting was utilized to identify thesignaling pathways affected by nanoparticle treatment. To examine mitochondrial and lysosomal damage cells were stained with MitoTracker and LysoTracker, respectively. In order to visualize the morphological changes of cells upon nanoparticle treatment, we utilized brand new high-resolution spinning disk confocal microscopy IXploreSpinSR (Olympus).

We found that both types of nanoparticles induced cell death in time and concentration-dependent manner. Exposure of all three hepatic cell lines to either cubic or clusters nanoparticles for 24 h induced early signs of apoptosis. Moreover, clusters nanoparticles were enhanced caspase-3 cleavage in HepG2 cell lines, neither in Huh7 or Alexander cells. Mitochondrial fragmentation in all three cell lines with application both types of nanoparticles after 24 h were detected by microscopy. Furthermore, cubic nanoparticles induced endogenous LC3-II transformation in Alexander and Huh7 cells, but not in HepG2 cells. Interestingly, clusters had no effect on LC3 lipidation.Additionally, cluster nanoparticles induced progressively higher lysosomal membrane permeabilization in comparison with cubic nanoparticles in Alexander and Huh7 cells, but not in HepG2 cells.

These data suggest that molecular mechanisms of cell death strongly depend on thegenetic background of human hepatic cells. We found how shape and surface modification of nanoparticles affect subcellular signaling. Specifically, clusters induced higher lysosomal damage in comparison with cubes. Our research provides fundamental background for developing safe and efficient novel nanoparticle-based therapies.

The work was supported partially by the mobility grant provided by the 5 top 100 Russian Academic Excellence Project at the Immanuel Kant Baltic Federal University.

Phase-transition-induced large magnetic anisotropy change in $VO_2/(Co/Pt)_2$ heterostructure

GUODONG WEI[a], XIAOYANG LIN[a,*], WEISHENG ZHAO[a]

[a]Fert Beijing Research Institute, School of Microelectronics & Beijing Advanced Innovation Center for Big Data and Brain Computing (BDBC), Beihang University, Beijing 100191, China

*XYLin@buaa.edu.cn

Perpendicular magnetic anisotropy (PMA) is one of the most significant technologies to be used in next generation spintronics devices as its potential in promoting thermal stability and device miniaturization. It is an important issue to find an efficient way to modulate its property in the process of PMA application. In this work, we report the phase-transition controlled magnetic anisotropy modulation in the $VO_2/(Co/Pt)_2$ heterostructure (Figure 1), where VO_2 is introduced into the system to applied an interfacial strain by its metal-insulator transition. A large reversible modulation of the perpendicular magnetic anisotropy (PMA) reaching 3×10^5 erg/cm^3 is observed during this process. The calculated energy density variation of interfacial anisotropy reaches 0.85 erg/cm^2, which shows significant advantage over traditional modulation strategies. Further experimental results including magnetization change versus temperature, strain buffered modulation and pre-strained sample comparison prove that the interfacial coupling between VO_2 and PMA layers plays a crucial role in this modulation. This work, demonstrating the great potential of phase-transition material in efficient magnetic anisotropy modulation, would benefit the exploration of low-power consumption devices.

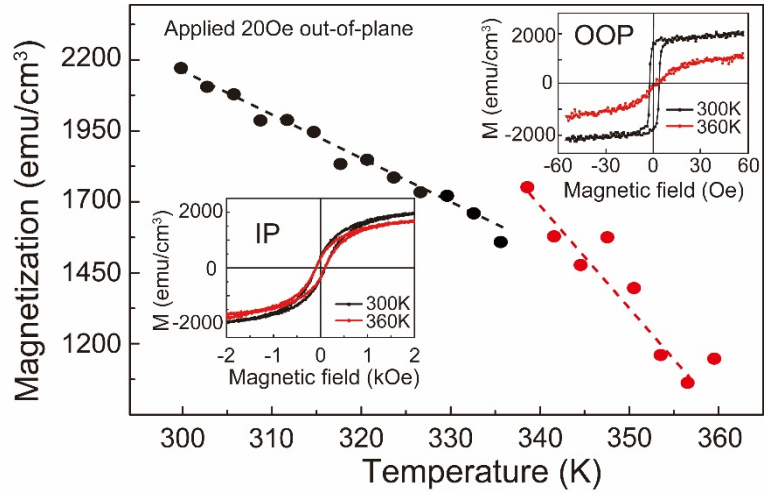


Figure 1. Temperature dependence of magnetization with 20 Oe magnetic field applied out-of-plane (OOP). The inset gives the hysteresis loops in-plane (IP) and OOP measured at 300 K and 360 K.

[1] M. Wang, A. Fert, W. Zhao *et al.*, Nat. Commun. **9**, 671 (2018).
[2] G. Wei, X. Lin, W. Zhao *et al.*, Appl. Phys. Lett.**114**, 012407 (2019)

Insights into magnetite bulk, surface and nanoparticlesby first-principles

H. Liu[a], G. Seifert[b], C. Di Valentin[a*]

[a]Dipartimento di Scienza dei Materiali, Università di Milano-Bicocca, via R. Cozzi 55, I-20125 Milano, Italy

[b]Theoretische Chemie, Technische Universität Dresden, 01062, Dresden, Germany

***** cristiana.divalentin@unimib.it

Magnetite exhibits an interesting phase transition, called Verwey transition, at the critical temperature T_V of about 120 K. [1] Though numerous efforts have been devoted to the understanding of this interesting transition, up to now, it is still under debate whether a charge ordering and a band gap exist in magnetite above T_V. In addition, magnetic nanoparticles show promising applications in biomedicine, such as drug delivery, magnetic resonance imaging, magnetic hyperthermia, bio-separation and biosensor. [2-6]. Here, we systematically investigate the structural, electronic and magnetic properties of cubic magnetite bulk, (001) surface and nanoparticles using different methods based on density functional theory (DFT). [7-10] Our results show that, for bulk magnetite, upon release of symmetry constraints on the electron density but not on the geometry, charge disproportionation (Fe^{2+}/Fe^{3+}) is observed, resulting in a band gap of around 0.2 eV at the Fermi level. This implies that the Verwey transition is probably a semiconductor-to-semiconductor transition and that the conductivity mechanism above T_V is small polaron hopping. The (001) surface shows a band gap (about 0.6 eV) larger than that in the bulk. A mixed adsorption mode of water is favorable on Fe_3O_4(001) surfaces at a high coverage, indicating that the cooperative effect between adjacent water molecules is important in the dissociation reaction. Self-consistent charge density functional tight-binding (SCC-DFTB) with on-site Coulomb correction and newly proposed parameters for Fe-O interactions is valued as an efficient and reliable method for the description of magnetite. The atomic-scale structures of different Fe_3O_4 nanoparticles were established using SCC-DFTB molecular dynamics simulations. The electronic and magnetic properties of the nanoparticles were investigated by hybrid functional method based on DFT. Our work gives a clear understanding of the structural, electronic and magnetic properties of magnetite bulk, (001) surface and nanoparticles with state of art methods and paves the way to further quantum mechanical studies, which are fundamental for Fe_3O_4 nanomaterials' applications.

[1] Verwey, E. J. W. Nature **144**, 327 (1939).
[2] Wu, W., et al. Sci. Technol. Adv. Mater. **16**, 023501 (2015).
[3] Pankhurst, Q. A., et al. J. Phys. D: Appl. Phys. **42**, 224001 (2009).
[4] Sun, C., Lee, J. S. & Zhang, M. Adv. Drug Deliv. Rev. **60**, 1252-1265 (2008).
[5] Laurent, S., et al. Chem. Rev. **108**, 2064-2110 (2008).
[6] Colombo, M., et al. Chem. Soc. Rev. **41**, 4306-4334 (2012).
[7] Liu, H. & Di Valentin, C. J. Phys. Chem. C **121**, 25736-25742 (2017).
[8] Liu, H. & Di Valentin, C. Nanoscale, **10**, 11021 (2018).
[9] Liu, H., Seifert, G. & Di Valentin, C. J. Chem. Phys. **150**, 094703 (2019).
[10] Liu, H. & Di Valentin, C. submitted.

An investigation on fabrication of YIG nano powders via a microwave-accelerated chemical co-precipitation method and their low temperature sintering

JUNLIANG LIU[a], QIMEI JIN[a], MIN YANG[a], MING ZHANG[a,*]

[a]School of Chemistry and Chemical Engineering, Yangzhou University, Yangzhou, 225002, China

* lxyzhangm@yzu.edu.cn

Yttrium iron garnet (YIG) has been utilized in microwave communication devices such as circulators, gyrators and phase shifters due to its narrow ferromagnetic resonance linewidth, high electrical resistivity and low dielectric loss. With the development of integrated circuits operating at the frequency at microwave or millimeter wave ranges, YIG has attracted increasing attention for its potential applications in various electronic chip devices owing to their high permeability in high frequency regions, high electrical resistivity and chemical stability. However, the conventional high sintering temperature about 1450 oC of YIG constrains its industrial production by the low temperature co-fired ceramic (LTCC) technology, which is supposed to be a feasible way to fabricate monolithic ceramic devices and modules with three-dimensional integration structures. To overcome this obstacle, there are several basic strategies available to use: 1) making the staring powders nano-sized, and improving their sintering activities; 2) adapting [ele]mental doping to decrease the sintering enthalpy; 3) employing proper sintering aids to activate the diffusion process; 4) developing novel sintering techniques by using physical fields to accelerate the sintering. Therefore, a microwave-accelerated chemcial co-precipation method has been develoed and used to fabricate YIG nano powders. By using this technique, single phase Bi-YIG nano powders with average partcile size of 30 nm have been rapdily synthesized at 800 ^{o}C for 10 min. Based on this, the dense YIG ceramic could be sintered at a low temperature about 950 ^{o}C for 4 hours. The grain of the sintered YIG ceramic was hommogenous with the particle size about 1 μm, could satisfy the requirement of low temperature co-fired ceramic (LTCC) technology.

Keywords: YIG ; Nano powders ; Low temperature sintering

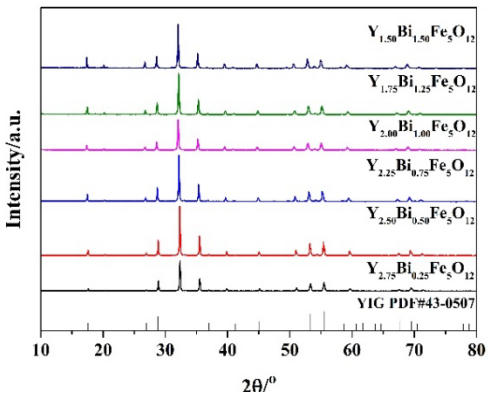


Fig.1 XRD patterns of the synthesized Bi-YIG nano powders

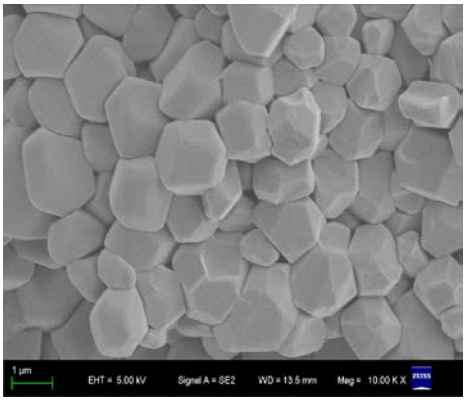


Fig.2 SEM image of the sintered Bi-YIG ceramic

[1] Vincent G. Harris,IEEE Trans. Mag. 48, 1075 (2012)
[2] Ning Jia, Zhang Huaiwu, Jie Li, et al., J. Alloy. Compd. 695, 931 (2017)
[3]W.F. Fai, W. Ali, N.S. Abdullah, et al., Ceram. Int. 42, 13996 (2016)
[4] Junliang Liu, Ping Yu, Qimei Jin, et al., Mater.Res. Lett. 6, 36(2018)

Kondo-like behaviour and GMR effect in Co-Cu thin films obtained by sputtering

R. LÓPEZ ANTÓN[a,*], J.P. ANDRÉS[a], J.A. GONZÁLEZ[a], M. IPATOV[b, c], V. ZHUKOVA[b, c], J. GONZÁLEZ[b,c], A. ZHUKOV[b, c, d]

[a]Instituto Regional de Investigación Científica Aplicada (IRICA) and Departamento de Física Aplicada, Universidad de Castilla-La Mancha, 13071, Ciudad Real, Spain

[b]Dept. Phys. Mater., University of Basque Country UPV/EHU, 20018, San Sebastian, Spain

[c]Dept. Appl. Phys., EUPDS, University of Basque Country UPV/EHU, 20018, San Sebastian, Spain

[d]Ikerbasque, Basque Foundation for Science, 48011, Bilbao, Spain

* ricardo.lopez@uclm.es

Granular alloyshave attracted considerable attention since the beginning of 1990s, due to the existence of giant magnetoresistance (GMR) effectin those materials [1]. The origin of the GMR effect is usually attributed to spin-dependent scattering of the conduction electrons, specially at the interface between the magnetic clusters and the nonmagnetic matrix [2]. An annealing process can help to segregate the magnetic element from the matrix, improving the quality of the interfaces, and increasing accordingly the GMR effect.In particular, one of those systems is the granular alloy Co-Cu. Solubility of Co in Cu at room temperature is almost negligible but several preparation methods allow to obtain a metastable solid solution of a small quantity of Co in Cu. Sputtering technique, given its simplicity of use and its abilityto obtain thin films [3], is highly convenient. It is also noteworthy the observation of Kondo-like resistivity minimums versus temperature in as-prepared and annealed Cu-Co microwires [4].

$Cu_{100-x}Co_x$ (x= 3, 9) thin films have been obtained by magnetron sputtering at room temperature using a mosaic-like Co-Cu target with the adequate ratio. The samples were annealed in high vacuum (about 10^{-5} mbar) for one hour at 400 ºC (673 K). Transport properties have been measured using aQD PPMS device in the temperature range 5-300 K whereas the magnetic measurements were performed in a QDMPMS-XL device.

The as-deposited sample with 3 % of Co (Co3) presentsan almost negligible GMR effect at low temperature, whereas the sample with 9 % of Co (Co9) exhibits a GMR of 4.3 %. Meanwhile, the R(T) shows a clear minimum in both samples without applied field (at 25 K for the Co3 and 40 K for the Co9). However, as we increase the applied field (up to 50 kOe), the minimum of the Co3 is not affected at all whereas in the case of the other sample is strongly affected (practically disappearing at higher fields). These results agree quite well with the results found in as-prepared Co-Cu microwires [4]. The zero-field-cooling and field-cooling curves of both samples show a certain irreversibility and a sharp increase of the magnetization at very low temperatures (likely due to the paramagnetic contribution of diluted atoms or very small Co clusters). In the case of the Co9 sample, also a peak is observed in the ZFC at 8 K, pointing out the possible presence of very small superparamagnetic clusters (in the other sample, they should be even smaller). We are currently studying the effect of the annealing in both the transport and magnetic properties and relating them with the structural changes.

We acknowledge the support provided by SGIker (UPV/EHU) and the UCLM (FEDER, EU)

[1] A.E. Berkowitz et al, Phys. Rev. Lett. 68, 3745 (1992)
[2] J.Q. Xiao et al, Phys. Rev. Lett. 68, 3749 (1992)
[3] J.Q. Wang et al, Phys. Rev. B 49, 3982 (1994)
[4] A. Zhukov et al, J. of Alloys and Compounds 695, 976 (2017)

SPIN-WAVE TRANSPORT IN 3D MAGNONIC WAVEGUIDES

A. MARTYSHKIN[a,*], E. BEGININ[a], A. SADOVNIKOV[a]

[a]Saratov State University, 410012, Astrakhanskaya Street 83, Saratov, Russia

*e-mail: aamartyshkin@gmail.com

The development of the fabrication methods of the thin film magnetic structures of micro- and nanometer-size results in the new trends in the emerging field of magnonics [1]. Spin waves are promising candidates for carriers of information signals and magnonic logic concept [2–4]. The development of integrated circuit technology has made it possible to implement a whole class of signal processing devices based on the principles of magnonics and magnon spintronics [4,5]. Here we report on the various topologies of curved magnon microstripes. The formation of three-dimensional (3D) integrated circuits based on their assembly into a 3D stack leads to fabrication of multi-layered structures with vertical spin-wave transport having a high density of magnetic functional elements.

The use of yttrium-iron garnet (YIG) as a material for the formation of films is very promising due to the low attenuation of the spin wave in the YIG. To study the static and dynamic characteristics in the structures the micromagnetic simulation was performed. The schematic images of the studied structures with a perfectly match layer on the boundaries of the computational region are shown in Figure 1. Waveguiding structures were placed in an external uniform magnetic field H0 = 1200 Oe so that, in the P0 antenna region, it was possible to excite a surface magnetostatic spin wave.

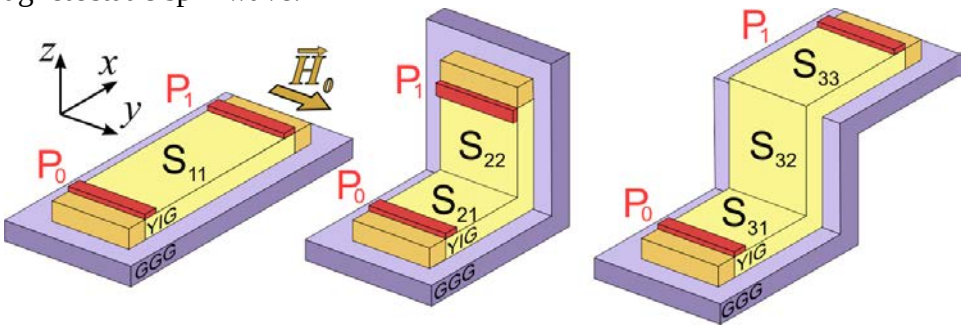


Fig1. Schematic representation of the studied magnetic microwave: (a) a reference waveguide, (b) a waveguide with vertical connection at 90 degrees, (c) a waveguide in the form of a step

The proposed structures can act as junction of thin-film magnetic waveguides and open the possibility of transmitting spin-wave signals in the vertical (along z-axis in Fig.1) direction in a wide frequency range. The ability to create vertical connections by orthogonal connections of microwaveguide sections can be an advantage when fabricating spintronics devices. The latter circumstance is important in the way of miniaturization of three-dimensional magnonic networks in devices for neuromorphic processing of the information signal.

This work was supported by the grant from Russian Foundation For Basic Research (No. 18-29-27026)

[1] D. Sander et. al., Journal of Physics D: Applied Physics, V. 50, N. 36, (2017)
[2] A.V. Sadovnikov et.al, Phys. Rev. B. Vol. 96.P. 060401. (2017)
[3] A.V. Sadovnikov et.al, Magnon Straintronics: Reconfigurable Spin-Wave Routing in Strain-Controlled Bilateral Magnetic Stripes//Physical Review Letters. Vol. 120.P. 257203. (2018)
[4] A.Khitun, et.al, Magnonic logic circuits//Journal. Physics.D 43.P. 264005. (2010)
[5] V.V.Kruglyak et.al,Magnonics//Journal of Physics D:Applied Physics. Vol. 43 P. 264001. (2010)
[6] S.A. Nikitov, et.al, Magnonics: a new research area in spintronics and spin wave electronics // Physics Uspekhi. Vol. 185.P. 1099. (2015)

Magnetostriction of Fe-(Al,Ga,Ge) alloys from first-principles

M. MATYUNINA*, M. ZAGREBIN, V. SOKOLOVSKIY, V. BUCHELNIKOV

Chelyabinsk State University, 454001, Brat'ev Kashirinykh Str. 129, Chelyabinsk, Russia

*matunins.fam@mail.ru

Multifunctional iron-rich compounds Fe-(Al, Ga, Ge) are interesting due to their unusual mechanical, magnetic and electrical properties, in particular, significant magnetostrictive properties [1,2,3,4]. The study of magnetic ordering and magnetic properties, the elucidation of the mechanisms of magnetostriction and the conditions for its increase in Fe-based alloys with different composition will make it possible to create more efficient and miniaturized devices possessing large magnetostriction at low magnetic fields.

This work presents ab initio study of magnetic properties of $Fe_{100-x}(Al, Ga, Ge)_x$ ($15.625 \leq x \leq 21.875$ at. %) alloys with the help of density functional theory, implemented into Vienna Ab initio Simulation package [5, 6]. The exchange-correlation effects were taken into account the generalized gradient approximation in Perdew-Burke-Ernzerhof form [7] for the supercell approach (32 atoms in supercell).

The tetragonal (λ_{001}) and rhombohedral (λ_{111}) magnetostriction of Fe-Al, Fe-Ga, and Fe-Ge alloys, was investigated. Dependencies of magnetocrystalline anisotropy energy, as a function of small deformation and concentration of doping atoms (Al, Ga, Ge) for A2 (Im-3m), $D0_3$ (Fm-3m), and B2 (Pm-3m) cubic phases were obtained.

This work was supported by Russian Science Foundation No. 18-12-00283.

[1] G. Petculescu, J. B. LeBlanc, M. Wun-Fogle, et al., *J. Appl. Phys.* **105**, 07A932 (2009)
[2] J.B. Restorff, M. Wun-Fogle, K.B. Hathaway et al., J. Appl. Phys. 111, 023905 (2012).
[3] I.S.Golovin, A.M. Balagurov, I.A. Bobrikov, and J. Cifre, J. Alloys Compd. 688, 310 (2016).
[4] T.A. Lograsso, A.R. Ross, D.L. Schlagel, A.E. Clark, J Alloys Compd, 35095 (2003)
[5] G. Kresse, and J. Furthmüller, *Phys. Rev. B* 54, 11169 (1996).
[6] G. Kresse, and D. Joubert, *Phys. Rev. B* 59, 1758 (1999).
[7] J. P. Perdew, K. Burke and M. Enzerhof, Phys. Rev. Lett. 77, 3865 (1996).

Numerical investigation of an influence of the matrix internal structure on a behavior of the small ferrogel sample

P. MELENEV [a,b*], A. RYZHKOV [b,c], YU. RAIKHER[b], M. BALASOIU [d]

[a]Ural Federal University, 619026, Kuybisheva 48, Russia

[b]Institute of Continuous Media Mechanics UB RAS, 614013, Korolyeva 1, Russia

[c]Perm National Research Polytechnic University, 614990, Komsomolsky avenue 29, Perm, Russia

[d]Joint Institute for Nuclear Research, 141980, Joliot-Curie 6, Dubna, Moscow region, Russia

*****melenev@icmm.ru

Ferrogels represent an example of the soft magnetoactive composite materials (SMC), which demonstrate pronounced interrelation between magnetic and mechanical characteristics [1]. One of the expected manifestations of unique properties of ferrogel is magnetically controlled shape memory effect, which consists in partial conservation of mechanical deformation of the sample due to occurrence of particle aggregates maintained by dipolar magnetic forces. This effect was observed in experiments on samples of soft magnetic elastomer [2] – variant of SMC filled by micron-size carbonyl iron particles. Despite the escalating number of experimental works, devoted to ferrogels, the examples of direct observations of their internal structure during the magneto-deformation processes are still practically absent. That is why theoretical investigations on mesolevel of ferrogel could be especially helpful for an understanding of mechanisms, which account for desired effects in material behavior.

In our work we employ the model, based on coarse-grained molecular dynamics approach [3]. Magnetic filler is modeled by monodisperse single-domain spherical particles, which possess uniaxial magnetic anisotropy with finite energy barrier height. Polymer matrix is represented by lattice with given topology, composed of chains of spheres (smaller than magnetic particles) connected by rigid bonds. Magnetic particles are located in the lattice nodes. Langevin thermostat is established for account of temperature in calculation. Earlier we have used this model with quasi-cubic lattice [4] and have observed noticeable magneto-deformational effect but practically without hysteresis. We suppose that the reason consists in relatively high stiffness of the chosen matrix model because of high density of cross-links – each node particle is bound to lattice by 6 chains. In order to soften the material we decided to consider diamond-like lattice, where node has only 4 connections to the lattice.

Modified model is used for examination of dependence of sample state on the external field as well as on the filler characteristics: concentration of the particles, magnitudes of dipole moments and anisotropy energy. Particularly, the cycles of quasi-equilibrium magnetization of the samples are simulated with purpose to reveal the mentioned above hysteresis effects in magneto-mechanical behavior of ferrogel. The latter is described based on “macro characteristics” of the sample (e.g. its volume) and analysis of filler structure, i.e. magnetic particles rearrangements. The results, obtained for both variants (with quasi-cubic and diamond-like lattice), are compared in an attempt to clarify the role of matrix structure in magneto-mechanical response of ferrogel.

The work has financial support from RFBR project 17-41-590123.

[1] P. Datta, chapter 17 in *Polymeric Gels*, Springer, 442-465 (2018)

[2] P. Andriushchenko et al, *Eur. Phys. J. B* **87**, 11 (2014)

[3] A. Arnold et al in *Meshfree Methods for Partial Differential Equations VI*, Springer, 1-23 (2013)

[4] A. Ryzhkov et al, *J. Chem. Phys.***145**, 074905 (2016)

On-chip detection of antibiotic resistance in Tuberculosis using isothermal amplification and optomagnetic detection.

GABRIEL ANTONIO S. MINERO[a], FRANCESCA GARBARINO[a], ELISABETA TEFIKU[a], JEPPE FOCK[b], AND MIKKEL F. HANSEN[a],*

[a]Department of Health Technology, Technical University of Denmark, Kongens Lyngby, Denmark

[b]BluSenseDiagnostics, Fruebjergvej 3, DK-2100 Copenhagen, Denmark

*mfha@dtu.dk

We present on-chip implementation of an isothermal amplification assay with optomagnetic (OM) detection. Isothermal rolling circle amplification (RCA) was designed for the 100% specific detection of a single point mutation in the sub-sequence of the *katG* catalase peroxidase gene responsible for resistance against the antibiotic rifampicin in Tuberculosis [1]. The assay was performed in a polymer chip with three connected chambers filled with reaction buffers for capture, RCA and the OM detection. The chip was fabricated by laser machining of PMMA layers and bonded using pressure sensitive adhesive foils. Streptavidin coated magnetic microbeads (MMBs) were employed as a movable substrate to transport the synthetic *katG* target and products between the microfluidic chambers. The chip was mounted in a setup integrating (1) temperature control of the chambers using sandwiched heaters, (2) transportation of the enzymatically processed MMBs between chambers using a permanent magnet on a motorized xz-stage, and (3) OM detection (Fig. 1).

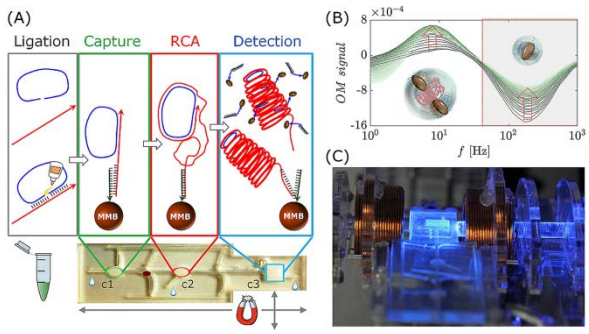


***Fig. 1**: On-chip implementation of RCA with OM detection. A) Off-chip DNA circularization and on-chip capture (c1), RCA (c2), and OM detection (c3). The DNA was transported between chambers c1-c2-c3 using MMBs and an external magnet. B) Real-time OM detection of 60 pM katG-RCP (arrow indicates time). C) Picture of chip mounted in open integrated setup illustrating components for OM measurements: the detection chamber is positioned between two electromagnetic coils with a diode emitting the light through the detection chamber to a photodetector.*

The OM measurements optically detect the ability of magnetic nanoparticles (MNPs) to rotate in response to a magnetic field oscillating at frequency *f* (Fig. 1B). MNPs bound to RCPs experience a significant size increase and a shift of the OM signal to lower frequencies [2]. Chamber c3 contained 100 nm MNPs functionalized with a detection oligo (DO) complementary to a repeating DNA subsequence in the RCA products (RCPs) (Fig. 1A). The detection temperature was chosen to release the targets from the MMBs but below the melting point of the DO-RCP hybrids. In conclusion, we demonstrate strategy for the integration of MMB sample handling with on-chip RCA and OM detection of the antibiotic resistance in synthetic Tuberculosis DNA target with a limit of detection of 4 pM for a total assay time of about 2 h.

[1] A.R. Pavankumar, et al. *Anal.Chem.*, 88, 4277 (2016)
[2] M. Donolato et al. *Biosens.Bioelectron.*, 67, 649 (2015)

The effect of exchange-correlation functional on the ground state properties of $Fe_{2+x}Ni_{1-x}Ga$ Heusler alloys

O. MIROSHKINA[a,*], V. SOKOLOVSKIY[a,b], M. ZAGREBIN[a], V. BUCHELNIKOV[a,b]

[a]Chelyabinsk State University, 454001, Bratiev Kashirinykh 129, Chelyabinsk, Russia

[b]NUST MISIS, 119049, Leninskiy prospect 4, Moscow, Russia

*miroshkina.on@yandex.ru

Heusler compounds became of interest since their discovery and are still under an intensive study due to their extraordinary properties such as shape memory effect, effects of superelasticity and superplasticity, giant magnetocaloric effect, giant magnetoresistance and magnetostrain, etc. The prediction of the composition and properties of such compounds is one of the most important scientific tasks. Density functional theory is the powerful tool for the theoretical study of many-particle systems. The effectiveness of it depends on exchange-correlation functional choice. Nowadays, the generalized gradient approximation (GGA) [1, 2] in the Perdew, Burke, and Ernzerhof (PBE) [3] formulation is the mostly widespread and successful. However, recently proposed meta-GGA [4, 5] strongly constrained and appropriately normed (SCAN) [6] functional presents the next generation of functionals and is already well proven for systems with different types of bonding. Thus, we were interested in the effect of GGA and meta-GGA approximations on the ground state properties of $Fe_{2+x}Ni_{1-x}Ga$ (x = 0, 0.25, 0.5, 0.75 and 1) Heusler alloys.

The first-principles calculations were performed with Vienna *ab initio* simulation package [7, 8]. The uniform Monkhorst-Pack grid with 8×8×8 k-points was used. The following atomic configurations were taken for the projector augmented wave pseudopotentials: Fe ($3p^6 3d^7 4s^1$), Ni ($3p^6 3d^9 4s^1$), and Ga ($3d^{10} 4s^2 4p^1$). Modeling was performed for 32-atom supercells with $L2_1$ and $L1_2$ cubic phases. In case of $L2_1$, the regular ($Fm\bar{3}m$, #225) and inverse ($F\bar{4}3m$, #216) structures were considered. The geometry optimization of structures was performed using both PBE and SCAN functional and included the electronic and ionic relaxation.

The geometry optimization shows that PBE and SCAN predict the same structure as an energetically favourable for the austenitic phase. It was found the increasing of Fe concentration (from x = 0.5) leads to changes in preferable structure. In order to check the stability of found phases, the formation and segregation energies calculations were performed. The lattice parameters calculated with SCAN are underestimated in comparison with PBE and experimental ones. Contrary, the SCAN values of the total magnetic moment are overestimated as compared to PBE values. Both PBE and SCAN predicts no transitions into tetragonal phase.

The analysis of SCAN application to the calculation of $Fe_{2+x}Ni_{1-x}Ga$ ground state properties showed that SCAN is needed in some adaptation for better prediction accuracy.

This work was supported by Russian Science Foundation No. 18-12-00283.

[1] J.P. Perdew, Phys. B 172, 1 (1991)
[2] K. Burke, J.P. Perdew, and M. Ernzerhof, Int. J. Quantum Chem. 61, 287 (1997)
[3] J.P. Perdew, K. Burke, and M. Ernzerhof, Phys. Rev. Lett. 77, 3865 (1996)
[4] J.P. Perdew, S. Kurth, A. Zupan, and P. Blaha, Phys. Rev. Lett. 82, 2544 (1999)
[5] J. Tao, J.P. Perdew, V. N. Staroverov, and G.E. Scuseria, Phys. Rev. Lett. 91, 146401 (2003)
[6] J. Sun, A. Ruzsinszky, and J.P. Perdew, Phys. Rev. Lett. 115, 036402 (2015)
[7] G. Kresse and J. Furthmüller, Phys. Rev. B 54, 11169 (1996)
[8] G. Kresse and D. Joubert, Phys. Rev. B 59, 1758 (1999)

Surface Plasmon for Magnetic Devices

K. NAKAGAWA*, Y. ASHIZAWA

Nihon University, 7-24-1, Narashino-dai, Funabashi city, Chiba, Japan

*nakagawa.katsuji@nihon-u.ac.jp

Surface plasmon polariton (SPP), which is an electric charge density wave combined with an electromagnetic wave at the surface between a metal and air, is a very useful phenomenon to detect a reflective index change, because it is very sensitive for the SPP to be generated depending on its environmental condition [1]. The SPP is also effective to sense a magnetization change, and this effect has been studied as the surface-magnetoplasmon [2, 3]. When it comes to the condition that the metal is very small, the plasmon has another feature, so called localized surface plasmon (LSP). The charges in a small metal or at an edge of metals must be localized in the metal. This localization of electric charges enhances the energy confinement as well as the intensity of the LSP. The spot size can be reduced to a small spot by applying the LSP, even though the evanescent light generated at the surface of the dielectric material which has a high reflective index can be confined in a smaller spot [4], compared to a spot in air. The spot size generated by the LSP is much smaller than that focused by the conventional method using evanescent light. The spot size using such an evanescent light is only submicron, but the spot size of the evanescent light generated by the LSP is around 10 nm. Therefore, the effect by the LSP to make a small spot is very useful and highly effective.

In this paper, it is reported that 1) the application of the LSP for the heat-assisted magnetic recording, and 2) a near-field transducer applying the LSP for all optical magnetic switching (AOS). Examples of studied near-filed transducer models for AOS is shown in Fig. 1. Details of 1) and 2) will be reported at the conference.

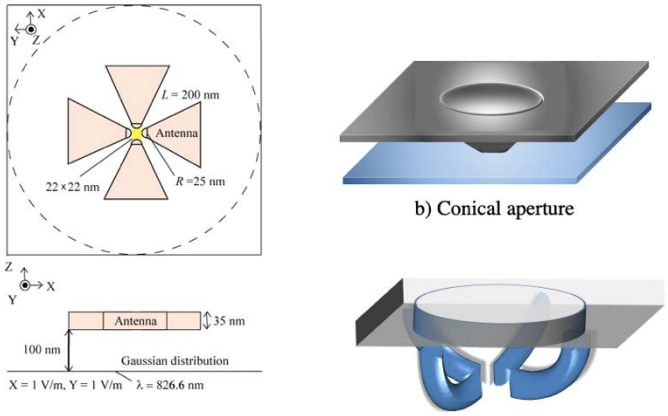


Fig. 1 Examples of studied near-filed transducer models for AOS

[1] E. Kretschmann, Z. Phys. (1971) Vol. 241, 313.
[2] J. B. González-Díaz, A. García-Martín, G. Armelles, J. M. García-Martín, C. Clavero, A. Cebollada, R. A. Lukaszew, J. R. Skuza, D. P. Kumah, and R. Clarke, Phys. Rev. B, (2007) Vol. 76, 153402.
[3] T. Tachikawa, Y. Ashizawa, and K. Nakagawa, J. Magn. Soc. Jpn. (2014) Vol. 38, No. 3-2, 135-138.
[4] S. W. Lee, J. Magn. Soc. Jpn. (1999) Vol. 23, Suppl. S1, 257-259.

Steady-state and ultrafast magnetooptics of profile-tailored all-nickel magnetoplasmonic crystals

I.A.NOVIKOV*, M.A.KIRYANOV, A.YU.FROLOV, V.V. POPOV, T.V. DOLGOVA, A.A. FEDYANIN

Faculty of Physics, Lomonosov Moscow State University, 119991Moscow

*novikov@nanolab.phys.msu.ru

The excitation of surface plasmon-polaritons (SPP) in periodic gratings results in electromagnetic field localization near their surface. Such localization provides an opportunity to significantly enhance optical and magnetooptical response of the structure [1]. This unique feature of SPP may be used in the number of cases – from lowering the threshold of laser fluences for demagnetization [2] and all-optical switching processes [3] to increasing the sensitivity of biosensors. The possibility to tune (shift, change spectral form) the SPP resonance seems to be very attractive for some fundamental and practical needs. The approaches of active plasmonics, that aim to control the process of SPP excitation in real time using external stimulus [4], allow to achieve it.

Here we experimentally study the influence of 1D nickel-based magnetoplasmonic crystal (MPC) surface profile on the value of transverse magnetooptical Kerr effect (TMOKE) enhancement caused by SPP excitation. It is shown that the absolute value of TMOKE in the vicinity of Wood's anomaly is sensitive to the shape of MPC profile characterized mainly by the corrugation depth of its surface. It may be explained by the variation of SPP excitation conditions with the change of the profile, which is qualitatively illustrated by the different Q-factor of plasmonic resonance in optical spectra. The maximal achieved value of TMOKE for the set of studied samples was 2.5%.

The possibilities of active control of SPP resonance in considered MPCsare also studied. Using pump-probe technique, we obtain that laser with moderate fluence (6 mJ/cm^2) is able to produce the modulation of optical and magnetooptical response on the timescale similar to the duration of laser pulse. The physical reason of such modulation is laser-induced heating of the free electrons of nickel and their relaxation through electron-phonon and phonon-phonon interaction processes. The corrugation depth of the sample surface affects the absolute value of modulation and the duration of laser-induced thermalization and relaxation processes. The maximal achieved values for ultrafast modulation of MPCs reflectivity and TMOKE spectra in the vicinity of SPP resonance are equal to 10% and 1% respectively.

Thisresearch wassupportedby theRussian Foundation for Basic Research (Grants No. 17-52-56011, No. 18-52-50021) and MSU Quantum Technologies Center.

[1]A.A.Gruninet.al., App. Phys. Lett.,97, 261908 (2010)
[2] M. Kataja et. al., App. Phys. Lett., 112, 072406 (2018)
[3] D. Bossini et. al., ACS Photonics, 3, 1385 (2016)
[4] N. Jiang et. al., Chem. Rev., 118, 3054 (2018)

Spin-wave Fano resonances in lateral geometry of YIG microstructures

S. ODINTSOV[a,*], A.SADOVNIKOV[a], M. PRECNER[b], E.N.BEGININ[a]

[a]Saratov State University, 410012, 83 Astrakhanskaya Street, Saratov, Russia

[b]Institute of Electrical Engineering, Slovak Academy of Sciences, Bratislava, 841 04, Slovak Republic

*odinoff@gmail.com

Of great interest in past few years is the study of the dynamics of spin waves propagating in magnetic waveguiding structures of nanometer size [1]. Particular attention is paid to the use of spin waves (SW) as carriers of information signals, since there is a possibility of implementing a number of signal processing devices based on magnonics principles, taking into account the possibility of signal coding using both amplitude and phase of spin wave [2].

Fig. 1(a) shows a schematic view of the structure, which consists of two waveguides located laterally or instead S_2 waveguide we can placed S_3 resonator. The width of both waveguides is w = 4 μm, and the thickness t = 200 nm. The distance between waveguides S_1 and S_2 is d = 800 nm. The waveguide length was 40 μm for S1 and S2. The structure was placed in a uniform static magnetic field H = 1200 Oe, oriented along the short axis of each nano-waveguide for the effective excitation of a guided magnetostatic surface wave (MSSW). Fig 1(b,c) shows snapshots of spin wave intensity with frequency f_0 = 5.075 GHz(b) and f_0 = 5.19 GHz(c). It was shown, that using the spatial distribution of spin-wave intensity the calculation of the coupling length and effectiveness is possible in time-domain simulation. Brillouin light scattering technique was used to experimental study of the spin-wave propagation in the fabricated YIG array with focused ion beam. The work was carried out to determine the optimal geometric parameters of the lateral system of magnetic structures based on nanoscale films. It should be noted that the influence of geometrical parameters at the nanoscale has a much stronger effect on the coupling parameter, unlike one in microscales. The variation of spin-wave phase and amplitude in the proposed structure can be performed via the tuning of geometrical parameters, which can be used in planar topology of magnonic networks for neuromorphic computing. The transfer characteristics of the waveguide resonator system and Fano resonance parameter were calculated. The influence of the nonreciprocal propagation of SWs was taken into account in the simulation.

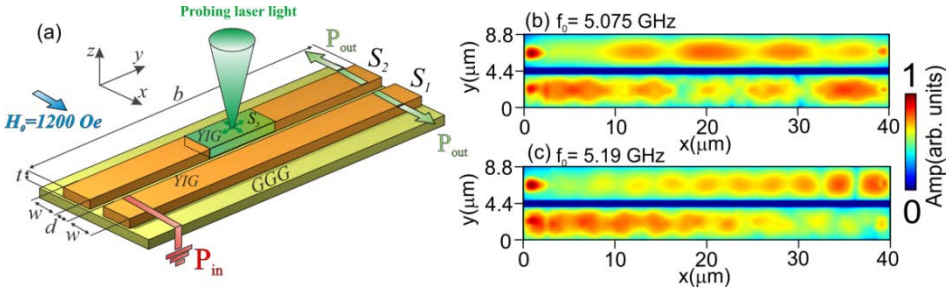


Fig1.(a) Schematic view of investigated structure, snapshots of spin wave intensity with frequency f_0 = 5.075 GHz(b) and f_0 = 5.19 GHz(c)

Micromagnetic numerical simulation of lateral structure is supported by the Grant from Russian Foundation for Basic Research (Project No. 18-37-20005). Development and numerical research of nano-waveguide – resonator are supported by the Russian Science Foundation (No. 16-19-10283).

[1] D. Sander et. al., Journal of Physics D: Applied Physics, V. 50, N. 36, 2017

[2] A.V. Sadovnikov, S. A. Odintsov, E. N. Beginin et al., JETP Letters, V.107:1 (2018), p. 25 – 29, (2018)

Magnetic and magnetothermal properties of materials based on rare-earth metals and doped with hydrogen

M. PAUKOV[a,b,c,*]

[a]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[b]Cold Crucible Laboratory, Research Centre Rez Ltd., 25068, Hlavni 130, Husinec-Rez, Czech Republic

[c]Department of Condensed Matter Physics, Charles University, 12116, KeKarlovu 3, Prague 2, Czech Republic

***** Michael.Paukov@gmail.com

Rare-earth metals (R), their alloys and compoundshave been intensively studiedfor more than a hundred years. The investigation of the properties of these objects is of great practical importance for science and technology.Fundamental characteristics of rare-earth metals, their alloys and compounds are highly sensitive to the atomic substitutions and interstitial absorption of atoms of light elements.In the present work,several samples were studied:

1. Gd and GdH_x single crystals;
2. $TmFe_{11}Ti$ and $TmFe_{11}TiH_x$ single crystals;
3. Tm_2Fe_{17} and $Tm_2Fe_{17}H_x$;
4. $(R,R')_2Fe_{14}B$ and $(Nd,R)_2Fe_{14}BH_x$ (R = Pr, Ho, Erand Tm)

where x is hydrogen concentration ($0 \leq x \leq 5.5$).

In the work was investigated the influence of hydrogen on the magnetic and magnetothermal properties given objects obtained in a single-crystal state and polycrystal state, using both weak and strong magnetic fields.

Particular attention is paid to the methods of obtaining single-crystal hydrogenated samples without breaking the single-crystal.

Samples obtained with different hydrogen content from 0.15 H/f.u. to 5.5 H/f.u. (the maximum possible for the given compound).

The research was done for:

- dependence of the magnetocaloric effect on the direction of the applied field in single crystal after hydrogenation;
- concentration (in hydrogen) dependences of the main structural and magnetic characteristics of the studied R-Fe-H compounds, including the temperature of spontaneous spin-reorientation phase transitions;
- the values of the critical fields of transitions and jumps of magnetization during spin-reorientation phase transitions induced by an external magnetic field;
- investigation of the phenomenon of induced ferromagnetism in R-Fe-H ferrimagnets.

All the results obtained are very important because the materials are studied often function in a hydrogen-containing environment.The observed regularity of changes in the main magnetic characteristics in the studied compositions can be implemented in other systems.

Critical behavior of multilayer magnetic nanostructures

P. PRUDNIKOV[a,*], V. PRUDNIKOV[a], M. MAMONOVA[a], M. BOLDYREVA[a], V. LOZHNIKOV[a], V. BORZILOV[a]

[a] Dostoevsky Omsk State University, 644077, Mira 55A, Omsk, Russia

*prudnikovpv@omsu.ru

A significant interest has been recently focused on non-equilibrium processes in magnetic low-dimensional materials. Thin films and low-dimensional magnets demonstrate the slow critical evolution from a non-equilibrium initial state. Aging, coarsening and memory effects are nontrivial features in the non-equilibrium behavior of such systems with slow dynamics [1]. The magnetic properties of multilayer magnetic systems have been widely investigated over the past years, since they are widely used in magnetic storage devices. The antiferromagnetic coupling was crucial for the discovery of the giant magnetoresistance (GMR). It kickstarted the field of nanomagnetism and spintronics [2]. The nanoscale periodicity in magnetic multilayer structures gives rise to the mesoscopic effects of the strong spatial spin correlation with the slow relaxation dynamics of magnetization accompanying the quenching of the system in the non-equilibrium state.

We performed a numerical Monte Carlo simulation of the non-equilibrium and behavior of the multilayer Co/Cu/Co and Pt/Co/Cu/Co/Pt magnetic structures [3,4]. Properties of ultrathin magnetic films contacted with nonmagnetic spacer can be described by the anisotropic Heisenberg model [5]. Calculation of the magnetoresistance for trilayer structure is carried out for the current perpendicular to plane (CPP) geometry. Experimental study shows that the CPP magnetoresistance is characterized by larger values than the CIP magnetoresistance. Energy and magnetic parameters for multilayer magnetic structures were calculated by ab initio package VASP [6].

This work was supported by RFBR according to the research projects 17-02-00279, 18-42-550003 and grant MD-6868.2018.2 of the Council of the President of the Russian Federation for State Support of Young Scientists. The supercomputer calculations were supported in through computational resources provided by the Shared Facility Center “Data Center of FEB RAS” (Khabarovsk), Supercomputing Center of Lomonosov Moscow State University, Moscow Joint Supercomputer Center of RAS.

[1] V.V. Prudnikov, P.V. Prudnikov, M.V. Mamonova, Phys. Usp. 60, 762 (2017).
[2] R.A. Duine, K-J. Lee, S.S.P. Parkin, M.D. Stiles, Nature Physics 14, 217 (2018)
[3] V.V. Prudnikov, P.V. Prudnikov, M.V. Mamonova, M.M. Firstova, A.A. Samoshilova, J. Phys. Commun. 3, 015002 (2019)
[4] P.V. Prudnikov, V.V. Prudnikov, M.V. Mamonova, N.I. Piskunova, J. Magn. Magn.Mater. 482, 201 (2019)
[5] V.V. Prudnikov, P.V. Prudnikov, M.V. Mamonova, JETP 127, 731 (2018).
[6] V. Borzilov, V. Lozhnikov, P. Prudnikov, et al., J. Phys.: Conf. Ser. 1163, 012059 (2019)

Electro-thermal treatment influenced phase formation in diffusion zone of Fe-Sn reaction crucibles

A. RISUNKOV[a,*], D. KARPENKOV[a]

[a]National University of Technology and Science MISIS, 119991, Leninskiy prospect 4, Moscow, Russia

*vkurichenko@hotmail.com

The main goal of effective rare-earth free magnetic materials development is related to discovering new phases with high values of uniaxial magnetic anisotropy and saturation magnetization. One of the experimental methods for combinatorial analysis, which allows to obtain significant information concerning equilibrium phase diagrams by making single experiment is called “reaction crucibles” technique. In this technique, intermetallic compounds are identified as thermodynamically stable phases, hence plenty of experimental works concerning investigation of various alloy systems were conducted by means of aforementioned method [1-3].

In this work, Fe-Sn system was chosen as an object of our research, as it possesses several metastable uniaxial magnetic phases, such as Fe_3Sn and Fe_3Sn_2, which are considered as perspective substitutional materials for rare-earth free permanent magnets production.

It was discovered that electrical current treatment combined with annealing (electro-thermal treatment) had led to stabilization of novel structure modification of Fe_3Sn_2 phase. Additionally, we estimated the existence temperature range of this phase.

Transmission electron microscopy analysis revealed that sample after electro-thermal treatment consists of two regions with different crystal axes. The first axis is attributed to three-fold rotation axis, whereas the second one is associated with 4-fold rotational symmetry. Such combination of rotational axes corresponds to cubic crystal system. Resulted patterns, presented at Figure 1, are in a good agreement with reference pattern for B2 structural type cubic lattice $Fe_{1.5}Sn_{0.5}$ phase. This data was verified by X-ray analysis.

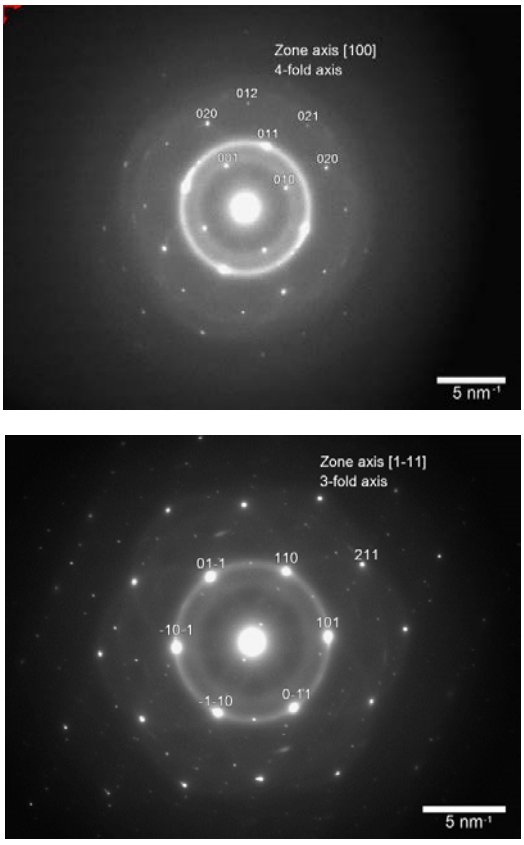


Figure 1. Diffraction pattern obtained by transmission electron microscope analysis

Investigation of magnetic domain structure revealed that obtained phase have easy-plane magnetic anisotropy and demonstrates stripe domain structure.

[1] B. Fayyazi, et al. Acta Materialia 141 (2017): 434-443.
[2] F. Groß, Search for New Permanent Magnetic Phases by Reaction Crucible Analysis and Development of High Throghput Methods, PhD thesis, The University of Birmingham, 2004.
[3] D. Goll, R. Loeffler, J. Herbst, R. Karimi, G. Schneider, High-throughput search for new permanent magnet materials, J. Phys. Condens. Matter 26 (6) (2014).

Properties of metal-dielectric nanocomposites with a high content of magnetic atoms in an insulating matrix

V. Rylkov[a,E,*], A. Sitnikov[a,B], S. Nikolaev[a], A. Emelyanov[a], K. Chernoglazov[a], A. Drovosekov[c], M. Blinov[d], A. Taldenkov[a], V. Demin[a], A. Vedeneev[e], A. Granovsky[d]

[a]National Research Centre ‘‘Kurchatov Institute”, 123182 Moscow, Russia

[b]Voronezh State Technical University, 394026 Voronezh, Russia

[c]Kapitza Institute for Physical Problems RAS, 119334 Moscow, Russia

[d]Faculty of Physics, Lomonosov Moscow State University, 119991 Moscow, Russia

[e]Kotel’nikov Institute of Radio Engineering and Electronics RAS, 141190 Fryazino, Russia

*****vvrylkov@mail.ru

We present results of comprehensive study of properties of M_xD_{100-x}nanocomposite (NC) filmswith x=6-60 at.%based on metallic alloy with amorphizing addition (M=CoFeB, CoNbTa) and dielectrics D=Al_2O_3, $LiNbO_3$ or SiO_2. The films were produced using the ion-beam sputtering of the composite targets onto glass-ceramic substrates and they consist on magnetic nanogranules (2–4 nm in size) embedded into the nonstoichiometric oxide matrix with a large amount of dispersed Fe or Co atoms in it (up to $3x10^{22}$ cm^{-3}). It plays a crucial role both in the ferromagnetic exchange between granules and in transport and magnetic properties below percolation threshold at $x \leq 57$ at.%. The conductivity of the systems follows the ln$T$ law on the metallic side of metal-insulator transition in the wide range of metal content variation x=44-56 at.% that corresponds to the conductivity of array of granules with strong tunnel coupling between them. A hysteresis of the magnetization is observed below the percolation threshold up to $x \approx 33$ at.%, which indicates the appearance of a superferromagnetic order in the nanocomposites [1]. Under this condition sharp minimum in the temperature behavior of the coercive field $H_c(T)$ at ≈50 K close to the blocking temperature ($T_b \approx 70$ K) of the granule magnetic moment has been detected in samples with $x < 42$ at.%.

Negative magnetoresistance (MR) almost saturates with increasing magnetic field but slowly increases or decreases in high magnetic fields. There is an evidence of linear positive contribution to MR above saturation at 65–300 K with the slope (3–9) 10^{-3}%T^{-1} [2]. The resistive switching (RS) effect was studied in details for capacitor-like M/NC/M structures based on $(CoFeB)_x(LiNbO_y)_{100-x}$NC at electric field $>10^4$ V/cm. The number of stable RS exceeds 10^5 at a resistance ratio $R_{off}/R_{on} \sim 50$. The RS effect in such systems could be explained by conductive filaments formation and destruction due to electromigration of oxygen vacancies controlled by the percolation network from granules [3]. We assume also that magnetic Fe (Co) atoms can play a significant role in the stability of the RS, since in this case the formation of conducting channels can be significantly facilitated due to the dispersed atom nucleation during the flow of current. The dispersed atoms can promote also to lowering the tunnel barrier height and manifestation of positive contribution to MR.

The work was supported by the Russian Science Foundation (grant No 16-19-10233).

[1] V.V. Rylkov et al., J. Magn. Magn.Mater.**459**, 197 (2018).
[2] M.I. Blinov et al., J. Magn. Magn.Mater.**469**, 155 (2019).
[3] V.V. Rykov et al., J. Exp. Theor. Phys.,**126**, 353 (2018).

Numerical modelling of a magnetic polymersome under a uniform magnetic field

A.V. Ryzhkov[a,B,*], YU.L. Raikher[a]

[a]Institute of Continuous Media Mechanics, Ural Branch, Russian Academy of Sciences, 1, Academician Korolev Street, 614013 Perm, Russian Federation

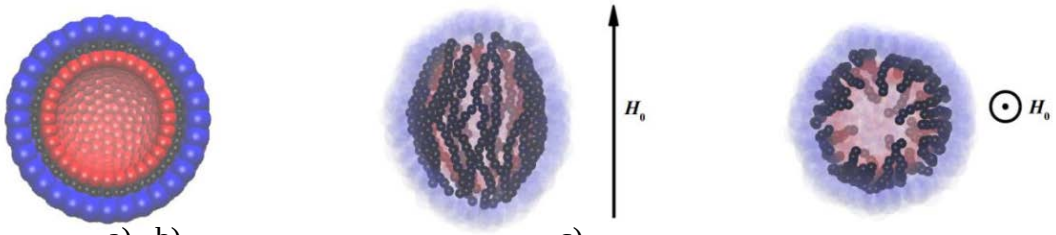
[b]Perm National Research Polytechnic University, 29, Komsomolsky prospekt, 614990 Perm, Russian Federation

*ryzhkovalexandr@gmail.com

Submicron capsules whose double-layer amphiphilic polymer membranes are stuffed with magnetic nanoparticles (MNPs) are known in the literature as *magnetic polymersomes* (MPSs) [1]. Due to the MNPs in their membranes, MPSs could be driven by a field gradient, and this makes them convenient carriers for targeted drug delivery [2] since the inner cavity is available for any necessary chemical cargo. Our work, however, is aimed at the physics of another method of engaging MPSs in cellular medicine. The key point there is the ability of MPSs to deform under a uniform field. The field orients the magnetic moments of MNPs and helps them to unite in chains. Being arc-like due to the confinement, the chains strive to straighten along the field, and this makes the MPS to elongate. Thus, one gets a nanodevice generating localized mechanical forces on the surface of an individual cell. This stimulation opens way to launch mechano-biochemical processes like apoptosis or to drill a hole in the cell membrane for injecting a drug nanodose.

In the model, the MPS membrane is presented as two nested “particulate” (in coarse-grained sense) flexible shells between which a monolayer of magnetic nanoparticles is enclosed [3], see Figure 1(a). The particles interact as soft dipolar spheres, and the membrane boundaries are impenetrable for them. The membrane boundaries are bonded in such a way that they maintain the intramembrane thickness equal to its equilibrium value. The response of an MPS to a quasistatic magnetic field is calculated by integrating equations of motion of all the elements of the system in the framework of coarse-grained molecular dynamics with ESPResSo software [4].

The effect of field-induced MPS elongation illustrated by Figures 1(b) and 1(c) was studied at different filler fractions, intensity of MNPs interaction and strength of coupling between the membrane boundaries.



a) b) c)

Figure 1. (a) – coarse-grained schematization of an MPS: blue and red beads make the boundaries of the membrane, black ones are MNPs; (b) – side and (c) – top view of the model MPS in a uniform field

The work was funded by RFBR in the framework of research project № 18-31-00326.

[1]S. Lecommandoux et al, *Advanced Materials*, 17, 712–718 (2005)
[2]C. Sanson et al, *ACS Nano*, 5, 1122–1140 (2011)
[3]A. Ryzhkov and Y. Raikher, *Nanomaterials*, 8, 763 (2018)
[4]ESPResSo webpage http://espressomd.org/

LASER-INDUCED CONTROL OF SPIN WAVE PROPAGATION IN ARRAY OF MAGNONIC STRIPES

A.SADOVNIKOV[a*], S.NIKITOV

Saratov State University, 410012, 83 Astrakhanskaya Street, Saratov, Russia

*sadovnikovav@gmail.com

In recent years much research has been directed towards the use of spin waves for signal processing at microwave and subterahertz frequencies due to the possibility to carry the information signal without the transmission of a charge current [1,2]. Recent theoretical and experimental studies suggest that strain can be used to engineer energy-efficient complicated 2D and 3D piezoelectric material and heterostructures [3,4].

In the present work we demonstrate the experimental observations of the strain-mediated spin-wave coupling phenomena in different magnonic structures based on the asymmetric adjacent magnonic crystals, adjacent magnetic yttrium iron garnet stripes and array of magnetic stripes, which demonstrates the collective spin-wave phenomena. The voltage-controlled spin-wave transport along bilateral magnonic stripes was demonstrated (Fig.1a,b). The model describing the spin-wave transmission response and predicting its value is proposed based on the self-consistent equations [4-6].

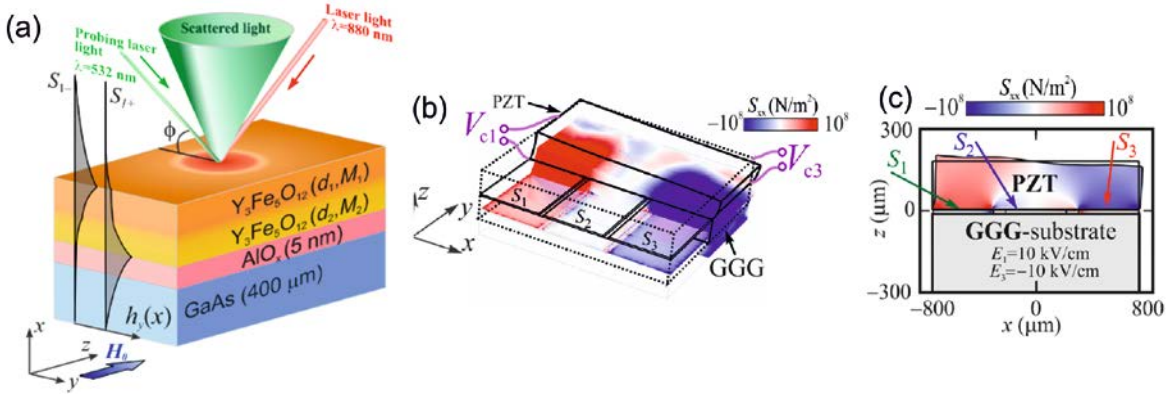


Fig1.(a) Schematic of the BLS experiment (b) Distribution of stress tensor component S_{xx} showing a local deformation of PZT layer; (c) induced stress in the YIG/PZT structures at the applied electric field E_1=10 kV/cm;

Fabrication of experimental samples of functional elements of magnon networks based on laterally and vertically connected magnetic waveguides of micron size is supported by the Russian Science Foundation (Project No. 18-79-00198). Micromagnetic numerical simulation is supported by the Grant from Russian Foundation for Basic Research (Project No. 18-37-20005) and Scholarship (SP2819.2018.5) and Grant (MK-3650.2018.9) of the President of RF.

[1] V. V. Kruglyak, S. O. Demokritov, and D. Grundler, J. Phys. D 43, 264001 (2010).
[2] A. V. Chumak, et.al. Nat. Phys. 11, 453 (2015).
[3] Y. K. Fetisov and G. Srinivasan, Appl. Phys. Lett. 88, 143503 (2006).
[4] A. V. Sadovnikov, Phys. Rev. Lett. 120, 257203 (2018)
[5] A. V. Sadovnikov, et. al., Phys. Rev. B 99, 054424. 2019.
[6] A.V. Sadovnikov, et al , Phys. Rev.B, Vol. 96, p. 144428 (2017).

Spinel Ferrite Nanopaticles as Magnetic Labels in Lateral Flow Immunoassays

M. SALVADOR[a,b*], O. ARRIORTUA[c], A. MOYANO[a,d], J.C. MARTÍNEZ-GARCÍA[a], M. INSAUSTI[c], M.C. BLANCO-LÓPEZ[d], M. RIVAS[b]

[a]Department of Physics & IUTA, University of Oviedo, 33204 Gijón, Spain

[b]Istituto di Struttura della Materia-CNR, 00015 Monterotondo Scalo (RM), Italy

[c]Zientzia eta Teknologia Fakultatea, Euskal Herriko Unibertsitatea, 644 pk, E-48080 Bilbao, Spain

[d]Department of Physical and Analytical Chemistry, University of Oviedo, 33006 Oviedo, Spain

*salvadormaria@ uniovi.es

Lateral Flow Immunoassay (LFIA) is a paper-based architecture whose most popular use is the pregnancy test. They are increasingly being used for determination of biomarkers, allergenic pathogens, drugs and metabolites, biomedical, food safety and environmental settings [1]. Their sensitivity, selectivity, quickness and ease of use make them ideal for *Point-of-Use*(PoU) testing. One of the key points of the LFIAs is the labelling of the biomarker, traditionally with latex or gold nanoparticles, which provides a visible signal. These are essentially qualitative (presence/absence) or semi-quantitative analyses. To add quantification capacities to LFIAs, the use of Magnetic Nanoparticles (NPs) has been proposed [2].

The magnetic LFIAs has to be associated to a magnetic reader that should be itself fast and portable. A radio-frequency inductive sensor has been developed for this purpose which takes advantage of the superparamagnetic character of the NPs [3,4].The purpose of this work was to carry out a systematic study of the effect of different nanoparticles in order to provide insights on the sensing principle. Superparamagnetic metal oxide NPs of spinel ferrites (SFs), with a general formula $M^{2+}Fe_2^{3+}O_4$ where M can be a divalent metal such as Co, Mn, Ni, Zn, etc., are suitable for this study as a result of their multifunctional properties, affordability and fine-tuning capability of their properties by simply chemical manipulations [5]. Three different composition SFs nanoparticles (Fe_3O_4, $Ni_{0.31}Fe_{2.69}O_4$ and $Mn_{0.13}Fe_{2.87}O_4$) have beencharacterisedto find out the optimum properties for LFIAs. Particle size, crystallinity and magnetic properties such as initial permeability and saturation magnetisationwere studied and compared. The results indicate that magnetiteSFs, which have the highest initial permeability, are the most suitable labels yielding the highest quantitative signal.

[1] B. O'Farrel et al. Phys. Rev. B 30 (2015)
[2] Lago-Cachón, D. et al., IEEE Magn. Lett. 8 (2017)
[3]Lago-Cachón, D. et al., Nanotechnol. 24 (2013)
[4] Rivas, M. et al., Sensor Actuar A-Phys. 216 (2014)
[5]Da Silva, F.G. et al. J. Nanosci. Nanotechnol. 19 (2019)

Effect of Fe doping on structural, magnetic and elerctrical characteristics of manganites $La_{0.7}Sr_{0.3}Mn_{0.9}Zn_{0.1-x}Fe_xO_3$

A. BADELIN[a], V. KARPASYUK[a], D. MERKULOV[a], R. EREMINA[b],
I. YATSYK[b], A. SHESTAKOV[*, b], S. ESTEMIROVA[c, d]
[a]Astrakhan State University, 414056, Astrakhan, Russia
[b]Zavoisky Physical-Technical Institute ofFRC "KazSC of RAS", 420029, Kazan, Russia
[c]Institute for Metallurgy UB RAS, 620016, Yekaterinburg, Russia
[d]Ural Federal University, 620002, Yekaterinburg, Russia
*ALEKSEY665@GMAIL.COM

Substituted lanthanum manganites continue to attract the attention of researchers and applied specialists all over the world [1, 2]. The effects of colossal magnetoresistance, giant magnetostriction, electrical switching, high magnetocaloric effects were used in modern technology and medicine.

The aim of this work was to study effect of Fe^{3+} substitution of Zn^{2+} in lanthanum-strontium manganite $La_{0.7}Sr_{0.3}Mn_{0.9}Zn_{0.1-x}Fe_xO_3$ (x = 0; 0.025; 0.075; 0.100) by the microwave absorption by using magnetic resonance method. The electron spin resonance (ESR) spectra were recorded in the X- (9.4 GHz) range on a Bruker ER 200 SRC (EMX/plus) spectrometer in the temperature range from 100 to 300 K and on a Varian E-12 spectrometer in the range of 300 - 600 K.

In samples with high Fe concentration (x = 0.075 и 0.1) over the entire temperature range there is only one exchange narrowed line, caused by the Mn^{3+} and Mn^{4+} ions, at x=0.075, x=0 there is an additional line from ferromagnetic nanoclusters (Fig. 1., Fig. 2.).

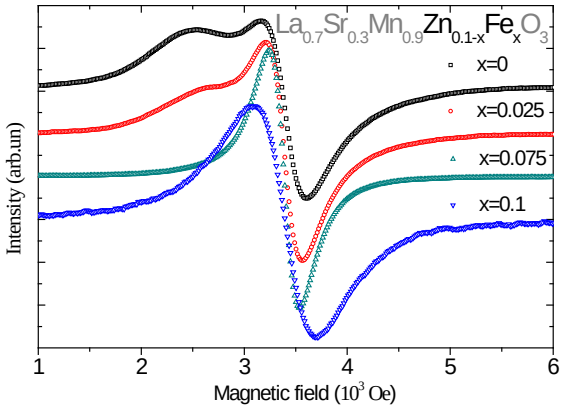


Fig. 1. The EPR spectra at room temperature of the manganites $La_{0.7}Sr_{0.3}Mn_{0.9}Zn_{0.1-x}Fe_xO_3$

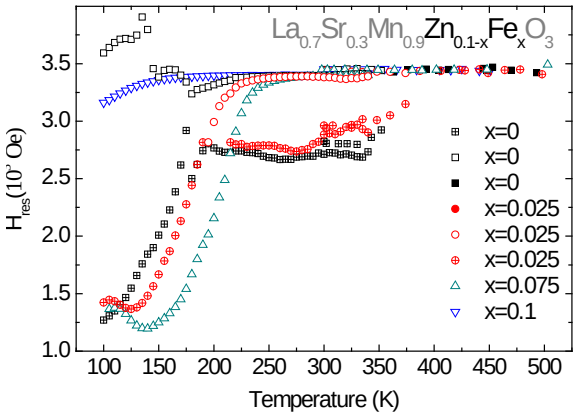


Fig. 2. Temperature dependence of the resonance magnetic field (Hres) of EPR lines in manganites

This work was supported by the RFBR grant № 18-52-06011.

[1] R. Jacobs, J. Booske, D. Morgan, Advanced Functional Materials, 26, 30 (2016)
[2] A. Golenishchev-Kutuzov, V. Golenishchev-Kutuzov, R. Kalimullin, A. Semennikov, Bulletin of the Russian Academy of Sciences: Physics, 79 (11), 1394–1396 (2015)

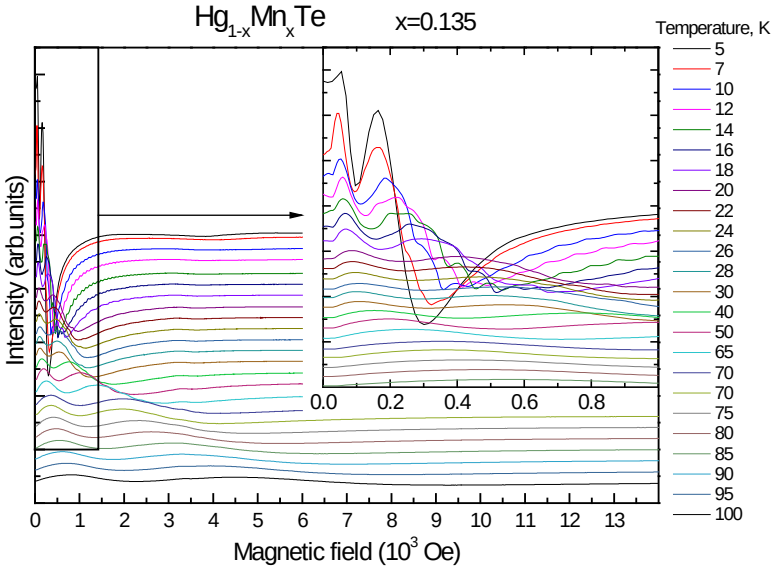
Magneticproperties temperature dependence of $Hg_{0.865}Mn_{0.135}Te$

A. SHESTAKOV*, I. YATSYK, M. IBRAGIMOVA, I. R. EREMINA,

Zavoisky Physical-Technical Institute ofFederal Research Center "Kazan Scientific Center of RAS", 420029, Sibirsky tract 10/7, Kazan, Russia

*ALEKSEY665@GMAIL.COM

In diluted magnetic semiconductors, the strong spin-spin interactions between band electrons and localized magnetic ions lead to a host of entirely new magnetooptical physical phenomena, such as giant Faraday, giant Kerr, photoinduced magnetization effects, which was first demonstrated in monocrystals $Mn_xHg_{1-x}Te$ (MHT) by Krenn [1]. Characteristics of charge carriers can be investigated by the microwave absorption by using magnetic resonance method. The aim of this work was to study the magnetic and transport properties of the $Mn_xHg_{1-x}Te$ (x=0.135) monocrystals by magnetic resonance method. The electron spin resonance (ESR) spectra were recorded using ER 200 SRC (EMX/plus) spectrometer (Bruker) in X-band 9.4 GHz. Measurements were performed at the temperatures 4.2–100 K and at the magnetic fields varying from 0 to $1.4 \cdot 10^4$ Oe. Temperature dependencies of ESR spectra are presented in Fig. 1 for single crystals $Hg_{0.865}Mn_{0.135}Te$. As shown in Fig.1, two lines with strong temperature dependence were observed in X- band spectra due to all Mn^{2+} ions and charge carriers. We obtained the temperature dependencies of resonance fields and linewidths of magnetic resonance lines in $Hg_{0.865}Mn_{0.135}Te$.



Specific heat in different magnetic were measured at a temperature of 5 and 300K on the multifunctional system for measuring physical properties with superconducting magnet PPMS-9. The nature of the exchange interactions between the spins of the charge carriers and the spins of the manganese ions is discussed.

[1]H. Krenn, W. Zawadzki, and G. Bauer, Phys. Rev. Lett. 55, 1510(1985)

Investigation of magnetic properties of $(Cr_{1-x}Mn_x)_2AlC$ MAX-phase

K. SOBOLEV[a,*], A. PAZNIAK[b], V. KOLESNIKOVA[a], A. MIELEWCZYK-GRYŃ[c] AND V. RODIONOVA[a]

[a]Immanuel Kant Baltic Federal University, Kaliningrad, Russia

[b]Institut PPRIME, Département de Physique et Mécanique des Matériaux,Poitiers, France

[c] Faculty of Applied Physics and Mathematics, Gdańsk University of Technology, Gdańsk, Poland

*KSobolev1@kantiana.ru

MAX-phases are the family of layered ternary compounds with general $M_{n+1}AX_n$ chemistry, where M is an early transition metal, A is an A-group element (mostly IIIA and IVA) and X is either C or N. MAX-phases possess the unique set of physical characteristics, combining metallic and ceramic ones which are high values of thermal and electrical conductivity, great oxidation resistance, easy machinability, tolerance to thermal shock and mechanical damages [1]. The major part of MAX-phases is paramagnetic, although the Cr_2AlC compound was anticipated to be an antiferromagnet [2]. Doping of Cr_2AlC MAX-phase with manganese on Cr-site was proposed to enhance the total magnetic response of the compound [3]. However, due to the closeness of ferromagnetic (FM) and antiferromagnetic (AFM) states on an energy scale [4] and the poor quality of samples [5] it's still an actual goal to reliably determine the magnetic response $(Cr_{1-x}Mn_x)_2AlC$ MAX-phase.

Samples of $(Cr_{1-x}Mn_x)_2AlC$ MAX-phase were synthesized using the arc melting technique and characterized by means of XRD and SEM-EDX analysis. Magnetometry measurements were performed on a vibrating sample magnetometer. Magnetization (M) *versus* temperature (T) and magnetic field (H) dependences were obtained in a range of temperatures from 100 K to 300 K and a range of magnetic fields up to 1 T.

XRD and SEM-EDX analysis revealed the sufficient quality of samples and the uniform distribution of Mn in the MAX-phase structure. M vs T dependences demonstrated the jump of magnetization in low temperatures which was attributed to the minor incorporation of Mn-containing FM secondary phases. The magnetic response, seemingly originating from the MAX-phase featured the increment of magnetization accompanying the raise of temperature. This phenomenon was interpreted as a result of canting of AFM sublattices which was previously done here [5]. The obtained results provided deeper insight into the contradictory topic of magnetism in Cr-based MAX-phases and may be used for the further application-oriented investigations.

[1]M. W. Barsoum, Progress in Solid State Chemistry, 28(1-4), p. 201-281 (2000)
[2] J. M. Schneider, Z. Sun, R. Mertens, F. Uestel, R. Ahuja, Solid State Communications, 130, p. 445-449 (2004)
[3] M. Dahlqvist, B. Alling, I. A. Abrikosov and J. Rosen, Physical Review B, 84(2), 220403 (2011)
[4] M. Dahlqvist, B. Alling and J. Rosen, Journal of Physics: Condensed Matter, 27(9), 095601(8pp) (2015)
[5] C. M. Hamm, J. D. Bocarsly, G. Seward, U. I. Kramm and C. S. Birkel, Journal of Materials Chemistry C, 23(5), p. 5700-5708 (2017)

Investigations of rare earth - iron compounds in high magnetic fields: The effect of interstitial and substitutional atoms on exchange interactions

I. TERESHINA[a,*], L. IVANOV[a], , A. GORBUNOV[b], E. TERESHINA-CHITROVA [c], M. PAUKOV[d], A. ANDREEV[c]

[a]Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

[b]Dresden High Magnetic Field Laboratory (HLD-EMFL), Helmholtz-Zentrum Dresden-Rossendorf, D-01314 Dresden, Germany

[c]Institute of Physics, ASCR, 18221 Prague, Czech Republic

[d]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

Fundamental characteristics of rare-earth (*R*) – iron intermetallics are highly sensitive to the atomic substitutions and interstitial absorption of light elements [1]. We studied, mainly, a combined influence of the substitutions in the rare-earth sublattice and hydrogen absorption on the magnetization behavior of $R_2Fe_{14}B$ in magnetic fields up to 60 T.

$(Er_{1-x}Nd_x)_2Fe_{14}B$ and $(Tm_{1-x}Nd_x)_2Fe_{14}B$ (x = 0 and 0.5) were obtained by a modified Czochralski method. Laue patterns confirmed monocrystalline state only for $Er_2Fe_{14}B$. XRD study showed that all samples obtained were single-phase. The structure parameters (lattice constants, unit cell volume and the *c/a* ratio) were calculated. All samples were hydrided with the special equipment.

The high-field magnetization measurements were performed at the Dresden High Magnetic Field Laboratory in pulsed magnetic fields up to 58 - 60 T on free powder samples. The absolute values of magnetization were calibrated using static-field data up to 14 T using a commercial PPMS-14 magnetometer (Quantum Design, USA).

We showed that hydrogenation leads to weak the intersublattice exchange interaction in all the investigated compounds. Hydrogenation of $Tm_2Fe_{14}B$ and $(Tm_{0.5}Nd_{0.5})_2Fe_{14}B$ to the maximum hydrogen content of 5.5 at.H/f.u. allows us to observe a field-induced ferromagnetic state in the compounds, with the transitions from ferri- to the ferromagnetic state occurring gradually over a wide field range. A comparison with other *R*-Fe systems (RFe_2 and R_2Fe_{17}) showed that $R_2Fe_{14}B$ is more susceptive to the exchange interaction change upon volume variation. A combination of light and heavy rare earths allows us to increase the magnetization which, in conjunction with hydrogen absorption, shifts the ferrimagnetic-to-ferromagnetic transition to lower fields.

This work is performed with financial support of the grant of Russian Scientific Foundation (project № 18-13-00135). We acknowledge the support of HLD at HZDR (member of the European Magnetic Field Laboratory) and the Materials Growth and Measurement Laboratory (https://mgml.eu).

[1] I.S. Tereshina, A.P. Pyatakov, E.A. Tereshina-Chitrova, D.I. Gorbunov, Y. Skourski, J.M. Law, M.A. Paukov, L. Havela, M. Doerr, A.K. Zvezdin, A.V. Andreev. AIP Adv.**8**, 125223 (2018).

Electron state hybridization and Curie temperature of $La_{0.7}Ca_{0.3}Mn_{1-x}Sc_xO_3$ (x= 0.0; 0.03, and 0.05) manganites

A.N. ULYANOV[a,*], KI-JEONG KIM[b], HYUN-JOON SHIN[b], DONG-SEOK YANG[c],

A.V. VASILIEV[a], S.V. SAVILOV[a]

[a] Department of Chemistry, Lomonosov Moscow State University, 119991, Moscow, Russia

[b]Pohang Accelerator Laboratory, POSTECH, Pohang, 37673, Republic of Korea

[c]Department of Physics Education, Chungbuk National University, Cheongju, 28644,

Republic of Korea

*a-ulyanov52@yandex.ru

Study of *B* – site substituted perovskite-like ABO_3 manganites is stimulated by their interesting multifunctional properties [1,2]. Substitution of manganese by other transition metals with different electron configurations and ionic radii opens the way for fabrication of manganites with wide variety of properties. At present, some aspects of the features of *B*-site doped perovskites are not studied well.

Here we present the study of electronic and crystal structure, and magnetic properties of scandium doped $La_{0.7}Ca_{0.3}MnO_3$ ceramics. $La_{0.7}Ca_{0.3}Mn_{1-x}Sc_xO_3$ (x=0.0; 0.03, and 0.05) oxides, obtained by nitrate technique, were studied by x-ray absorption spectroscopy (XAS) at Mn *K*– and *L*– edges, and O *K*– edge, combined with x-ray diffraction (XRD) and magnetization measurements. XRD Cu Ka analysis was performed with the diffractometer D/MAX-2500V/PC (Rigaku, Japan). Magnetic susceptibility, χ, was measured in a field of 10 Oe and at a frequency of 27 Hz. XAS measurements were performed in Pohang Accelerator Laboratory (Republic of Korea), operating with an electron energy of 3.0 GeV and the maximum current of 400 mA.

We observed a change of average and local crystal structure which explained by the larger Sc^{3+} than the Mn^{3+} ions and manifested with XRD measurements and Fourier transform of the EXAFS spectra. Curie temperature decreases at substitution of Mn by Sc. This is because the scandium ions do not take part in double exchange (major factor), and because the radii of Sc3+ ion is larger than the Mn3+ one (minor factors), see [2] on this item. Observed position of Mn *K*-edge spectra do not show any essential change displaying no change of average manganese valence, v_{Mn}. ObservedT_C change along with constant v_{Mn} can be explained by the change of level of hybridization of O 2*p* and Mn 3*d* states with x increase. The conclusion is confirmed by the observed change of intensity of Mn *L*-edge spectra and by the shifting of O *K*-edge paralleled with T_C and x.

The reported study was funded by Russian Foundation for Basic Research (RFBR) according to the project No. 18-08-01071 A. The authors are also indebted to N.Yu. Starostyuk for the help at preparing the samples.

[1] D.K. Pandey, A. Modi, K. Dubey, P. Pandey, V. Sharma, G.S. Okram, N.K. Gaur, J. Magn. Magn. Mater. 471, 153 (2019).
[2] A.N. Ulyanov, A.V. Vasiliev, E.A. Eremina, O.A. Shlyakhtin, S.V. Savilov, E.A. Goodilin, Ceram. Int. 44, 22297 (2018).

Colossal magnetoresistense of ferrimagnet dielectric/superconductor hybrid structures caused by spin-orbit interactions.

L. USPENSKAYA*, S. EGOROV, O. SKRYABINA, D. L'VOV, G. PENZYAKOV

Institute of Solid State Physics Russian Academy of Science, 142432, Ac.Ossipiana 2, Chernogolovka, Russia

*uspenska@issp.ac.ru

Control of resistive properties of magnetic hybrid structures by spin-polarized current opens wide possibilities to create new types of spintronics devises [1]. Control of resistive properties of superconductor/ferromagnet hybrid structures by spin-polarized current is important for new electronics branch - cryoelectronics [2]. Recently we have demonstrated the possibility of the ultrafast switching of the magnetization of permalloy/niobium stripes by short current pulses [3].

Herewith we discuss the results of our experimental study of temperature variation of the resistance *R(T)* of magnetic dielectric/superconductor (yttrium iron garnet/aluminum, yttrium iron garnet/niobium) hybrid structures under the electrical current and weak magnetic field. We show the dependence of the shift of superconducting transition temperature T_c on the direction of the electric current and on the value of the current, the change in the shape of the *R(T)* with the rotation of the magnetization direction of the underlay ferromagnet dielectrics. We report over then 1000 % magnetoresistance observed in the weak about 10 Oe magnetic field and followed by its rotation by 90 degree, and 1000 % variation of the resistance under the current strength variation in the range of 1-10 μA or its polarity switching. Finally, we discuss the obtained results in terms of the breaking symmetry for the superconducting layer, one surface of which is covered by magnetic dielectric and another is bordered on the vacuum, and show the role of spin-orbit interactions and spin-dependent electron scattering at the superconductor-magnetic dielectric interface considered in recent publications [4,5]. Important is that the rate of switching of this hybrid structures by magnetic field or current could be as large as 3 GHz.

This work was supported in part by the program Challenging Problems of Low-Temperature Physics of the Presidium of the Russian Academy of Sciences and by the Russian Foundation for Basic Research (projects no. 17-02-01270, 19-02-00316).

[1] M. Eschrig. Rep. Prog. Phys. 78, 104501 (2015).
[2] M G Blamire and J W A Robinson J. Phys.: Condens. Matter 26, 453201 (2014).
[3] S. V. Egorov, A. M. Bobkov, I. V. Bobkova, and L. S. Uspenskaya. JETP Letters, 101, 32 (2015).
[4] D Beckmann. J. Phys.: Condens. Matter 28, 163001 (2016).
[5] A. Cottet. Phys. Rev. B 76, 224505 (2007).

Bistable glass-coated microwires for sensor application.

R. JURC[1,2], D. KOZEJOVA[3], L. FECOVA[3], L. GALDUN[1,3], K. RICHTER[1,4], J. GAMCOVA[1], R. SABOL[1], T. RYBA[1], L. HVIZDOS[1], P. KLEIN[1], R. VARGA[1,3,*]

[1]RVmagnetics, a.s., Hodkovce 21, 04421 Košice, Slovakia

[2]Faculty of Aeronautics, TU Košice, Košice 042 00, Slovakia

[3]Centre of Progressive Materials - TIP, UPJS, Park Angelinum 9, 041 54 Košice, Slovakia

[4]Institute of Physics, Faculty of Science, UPJS, Park Angelinum 9, 041 54, Kosice, Slovakia

*rastislav.varga@upjs.sk

Glass-coated microwires are unique group of material that offer some advantages in practical applications. First of all, it is their extremely high added value due to the very efficient production. It allows to produce up to 100 000 sensors from few gram of iron-based master alloy within 10 minutes. Glass-coating provides insulation from electrical short-circuits, from chemically aggressive environment and provides biocompatibility as well. Their dimensions allow introduction inside almost any material without changing its functional properties. Magnetic nature gives advantage of contactless sensing from the distance. High durability (high elasticity because of amorphous nature) increases their wide range of potential applications.

In the present contribution we offer some examples how bistable microwires can be used to sense internal stress in 3D printed materials or how stress dependence of the switching field can be employed for monitoring osteomalacy in medicine.

Understanding correctly magnetic material science allows for adjustment of chemical composition to obtain high sensitivity to various range of applications from technical (temperature range up to 150°C) to medical (temperature range from 35-45°C) using the onset of superparamagnetism in early stage of nanocrystalline phase. We offer the proof of concept for intracranial temperature monitoring using the personalized titanium implants and other perspective applications.

This work was supported by Slovak Grant Agency VEGA 1/0053/19 and VEGA 1/0185/18, Slovak Grant Agency grant number APVV-16-0079 and APVV-17-0184.

High Content Screening:comprehensive tool to study the side effects ofantibody-conjugated magnetic beads

A. VITOVTOV

Thermo Fisher Scientific Inc., 117485, Obrucheva str., 30/1, Moscow, Russia

anton.vitovtov@thermofisher.com

Magnetic cell separation is a widely used method for many subsequent applications in cell biology.

FDA approval was established in 2017 for treatment of patients suffering from leukemia. The approved method (CAR-T therapy) is based on genetic modifications of T-cells extracted from patient's blood. The treatment workflow utilize antibody-conjugated magnetic beads (Dynabeads™) to capture specific CD4, CD8 and CD25 positive T-cell fractions from blood samples.

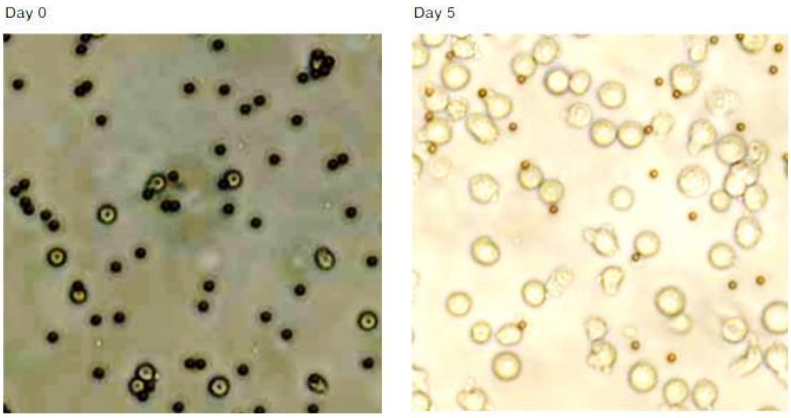


Fig. 1. T-cells coincubated with Dynabeads T-Activator CD3/CD28 showed proliferation from day 0 to day 5. 40x magnification.

Antibody-captured magnetic beads are also used to collect and enrich exosomal fraction from cell culture samples for fundamental research.

Taking into account the growing number of published papers, as well as new approved clinical applications, it is important to highlight the lack of comprehensive studies of antibody-conjugated magnetic beads on cell toxicity, morphology, signaling and gene expression.

High Content Screening (HCS) imaging-based quantitative cell analysis approach is a golden standard to study the effects of different drugs on cellular level, as it allows to investigate:

1. Cell morphology changes. As HCS method is based on microscopy, quantitative analysis of cell morphology could be done precisely.
2. Cell signaling. Kinase cascades and transcriptional factors could be visualized using specific fluorescent-labelled antibodies.
3. Cytotoxicity. There are various fluorescent molecular probes, specially designed to label different biochemical processes in cells.
4. 3D cell models. Spheroids are perfect object for translational research

Cellomics™ research platforms were the first commercially available HCS instruments on the market. They remain the leadership position according to the number of high-impact publications and install-base.

The purpose of this abstract is to highlight the importance and perspectives of HCS studies of antibody-conjugated magnetic beads in cellular models.

Magnetite-gold nanoparticles: from physics to theranostics

M.V. EFREMOVA[a,b], Y.A. NALENCH[b], E. MYROVALI[c], A.S. GARANINA[a,b], V.A. NAUMENKO[b], M.A. ABAKUMOV[b,d], M. SPASOVA[e], M. ANGELAKERIS[c], A.G. SAVCHENKO[b], M. FARLE[e], A.G. MAJOUGA[a,b,f], N.L. KLYACHKO[a,b], U. WIEDWALD[b,e,*]

[a]Lomonosov Moscow State University, Department of Chemistry, Moscow, Russia

[b]National University of Science and Technology «MISIS», Moscow, Russia

[c]Aristotle University of Thessaloniki, Physics Department, Thessaloniki, Greece

[d]Medical Nanobiotechnology, Russian National Research Medical University, Moscow, Russia

[e]Faculty of Physics and Center for Nanointegration Duisburg-Essen, Univ. of Duisburg-Essen, Germany

[f]D. Mendeleev University of Chemical Technology of Russia, Moscow, Russia

*ulf.wiedwald@uni-due.de

The application of magnetic nanoparticles (MNPs) in biomedicine is one of the most dynamic and promising fields of nanoparticles research. Two examples for the use of multifunctional MNPs in theranostics are agents in magnetic resonance imaging (MRI) and magnetic particle hyperthermia (MPH) for the localized treatment of cancer. We designed, synthesized and tested various MNPs like ferrites [1-3], core-shell architectures [4], and magnetite-gold (Fe_3O_4-Au) hybrids [5,6] for optimized properties.

Here, we present pairwise connected Fe_3O_4-Au hybrids with diameters of 6-44 nm Fe_3O_4 and 3-11 nm Au aiming for optimized theranostics response. Figure 1 shows high-resolution transmission electron microscopy (HRTEM) images and corresponding FFT images of 15 nm and 25 nm Fe_3O_4-Au hybrids [6]. With increasing MNPs diameter from 6 to 25 nm in agarose mimicking tissues, MPH revealsthat the specific loss power increases from 12 to 327 W/g, while for MRI, we observe the growth of the r_2-relaxivity from 118 to 612 $mM^{-1}s^{-1}$. These values are significantly enhanced as compared to other Fe_3O_4-Au hybrids due to their octahedral shape and large saturation magnetization. As a practical application, MRI-controlled drug delivery and dual-mode MRI/fluorescent imaging are presented for the optimized MNPs size of 25 nm.

The study was supported by the Russian Foundation for Basic Research 18-33-01232 (fluorescent labeling of NPs) and Increase Competitiveness Program of NUST MISIS K3-2017-022 (magnetic measurements).

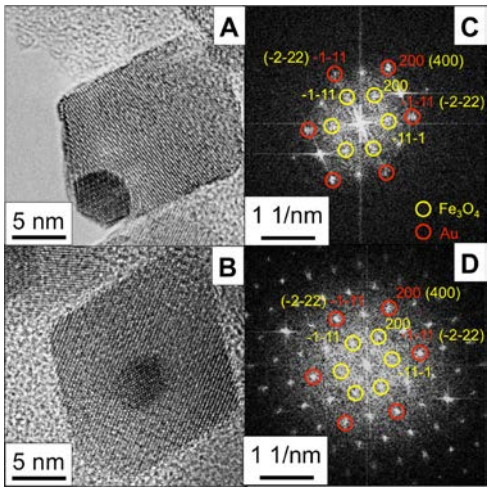


Figure 1: *HRTEM and corresponding FTT images of size-selected magnetite–gold NPs: 15 nm (A, C) and 25 nm Fe_3O_4(B, D). Fe_3O_4 and Au indices are marked yellow and red, respectively. The [111] and [200] crystallographic directions of Fe_3O_4 and Au register to each other. The NPs are viewed along their [011] direction [6].*

[1]S. Liébana Viñas et al., J. Magn. Magn.Mater.**415**, 20 (2016).
[2]K. Simeonidis et al., RSC Advances **6**, 53107 (2016).
[3]E. Myrovali et al., Sci. Rep. **6**, 37934 (2016).
[4]S. Liébana-Viñas et al., RSC Advances **6**, 72918 (2016).
[5]M. V. Efremova et al., Sci. Rep. **8**, 11295 (2018).

POSTERS

Hybrid DFT calculation of ^{47,49}Ti NMR resonances and orbital order in titanates

P. AGZAMOVA[a,b,*], V. CHERNYSHEV[b]

[a]M.N. Miheev Institute of Metal Physics of UB RAS, 620108, S. Kovalevskaya 18, Ekaterinburg, Russia

[b]Ural Federal University, 119991, Mira 19, Ekaterinburg, Russia

*polly@imp.uran.ru

The crystal structure and orbital order of titanates (RTiO$_3$, where R = La, Nd, Sm, Gd, Y) are calculated using a first-principles hybrid density functional theory (DFT) method in the CRYSTAL [1] and VASP [2] packages.

The initial atomic positions in the crystal structure calculations are those refined from diffraction and thermal expansion studies [3]. Fermi contact, magnetic dipolar contributions to magnetic hyperfine field and electric field gradient (EFG) tensor components at ^{47,49}Ti nuclei calculated in the framework of hybrid DFT method are used to obtain NMR resonance frequencies for titanates for a range of external magnetic field directions in relative weak fields.

NMR resonance frequencies of Ti ions show large relative variations with applied field direction owing to anisotropic hyperfine fields from orbital ordered Ti 3*d* electrons.

This work was performed using «Uran» supercomputer of IMM UB RAS in the framework of the State Task of the FASO of the Russian Federation for IMP UB RAS and was supported in part by the RFBR no 18-32-00690.

[1] http://www.crystal.unito.it/index.php
[2] https://www.vasp.at/
[3] A.C. Komarek et al., PRB 75, 224402 (2007).

Magnetic field influence on the self-assembly in the systems of magnetic ellipsoidal nanoparticles

A. Akisheva (Gudkova)[A,*], E. Pyanzina[a]

[a]Ural Federal University, 620000, Lenina51, Ekaterinburg, Russia

*annagudkova94@gmail.com

Recent researches, based on the study of systems with anisotropic magnetic nanoparticles became an important fast-developing branch in the investigation of dipolar soft matter. One can study particles of various shape, among those are spheres, ellipsoids, rods, etc. Also it's possible to change orientation of point magnetic dipole by placing it in the center of particle's mass along or perpendicular to the main axis. Magnetic field presence or its absence also has an influence on system's behavior. So, one can tune and design new smart materials with controllable microstructure and as a result various macroproperties via changing external and internal parameters.

Our work is a complex investigation of the system of magnetic ellipsoidal nanoparticles [1,2] based on different theoretical approaches and computer experiments. We study the influence of magnetic field on the self-assembly in the systems of magnetic ellipsoids with various orientation of dipoles (Fig. 1). We use molecular dynamics to perform computer simulations, calculate initial susceptibility and radial distribution function. Also we made cluster analysis in order to investigate type of clusters, their average size and clusterization [3].

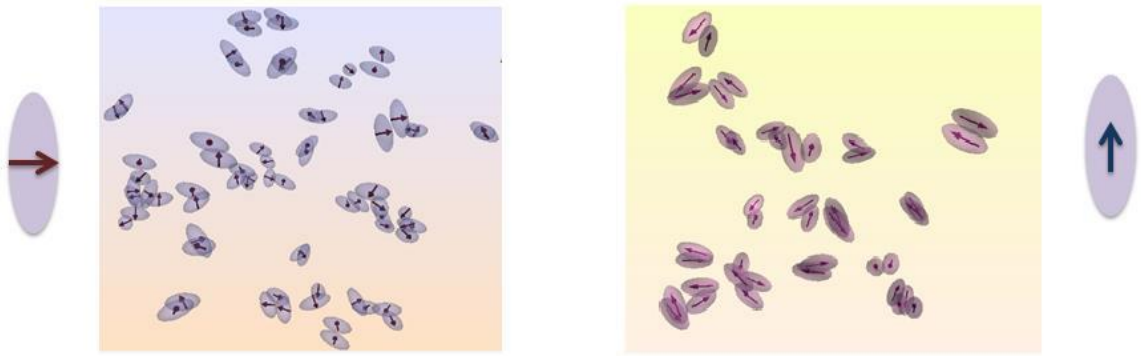


Fig. 1.Self-assembly in the system of magnetic ellipsoidal nanoparticles: comparison of two different orientations. Square of particles magnetic moment is equal to 5.

We can conclude that external magnetic field has an influence on the self-assembly of the system of magnetic anisotropic nanoparticles. Microstructure and macroscopic properties of magnetic soft materials significantly change with modifying particles parameters, such as shape and orientation of the magnetic moment and system characteristics. These results provide recommendations for the development of new systems with magnetic response that can become quite useful in further applications, where the most important one is medicine.

[1]L. A. Trusov et al., Chem. Commun. 50, 14581(2014)
[2]P. Bender et al., JMMM 372, 187 (2014)
[3]S. Kantorovich et al., Soft Matter 9, 6594 (2013)

Magnetoelectric and magnetodeformational effects in multiferroic rheological composites

YU. ALEKHINA[a,*], L. MAKAROVA[a,b], R. MAKARYIN[a], A. KOMLEV[a], N. PEROV[a,b]

[a]Lomonosov Moscow State University, 119991, Leninskie gory 1-2, Moscow, Russia

[b]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

*ya.alekhina@physics.msu.ru

Materials with multiferroics properties have attracted research interest due to the promising prospects of practical applications. Use of such materials allows to increase energy efficiency and reduce the design complexity of various devices. Moreover, the description of coupling mechanisms between magnetic, electric and mechanical properties of such materials is of fundamental scientific importance. Among multiferroics with ferroelectric and ferromagnetic types of ordering, composite structures established themselves as those having larger value of magnetoelectric transformation (change of polarization under the influence of magnetic field and vice versa, change of magnetization under the influence of electric field).

Recently the new type of composite multiferroics based on magnetorheological elastomers (MRE) was proposed [1]. Three-phase multiferroic composite – ferromagnetic and ferroelectric particles embedded in elastic polymer medium – was shown to demonstrate magnetoelectric transformation. Model of the mechanism based on the elastic coupling of ferromagnetic and ferroelectric particles was proposed [2]. It was also shown, that magnetorheological ferroelectric foam filled with the elastomer with iron particles demonstrates reverse magnetoelectric effect [3].

In this work the reverse magnetoelectric effect in four-component composite structures based on ferroelectric foam was investigated. Ferroelectric foam with PZT particles was prepared using PDMS silicone compound. MRE with iron and barium ferrite particles were used as fillers of the foams. Samples of two types of MRE and filled foam without PZT particles were also investigated as reference samples.

Magnetic properties of the samples were investigated using vibrating sample magnetometer LakeShore 7400 Series in the magnetic field range ±16 kOe. For the measurement of magnetoelectric transformation experimental setup was additionally provided with high voltage power supply. Magnetization curves were measured under the applied electric field in the range 0-5kV/mm. Measurements were carried out in parallel and perpendicular mutual orientations of magnetic and electric fields.

Samples of four-component composites demonstrated the magnetoelectric transformation. Rearrangement of ferroelectric particles in the foam under electric field leads to the deformation of pore walls. This deformation induces mechanical stresses in the MRE filling the foam. Then the reverse magnetodeformational effect appears as a change in sample magnetization. Thus, composite structure on the basis of ferroelectric foam demonstrates mulltiferroic properties and can be developed for further improvement of the observed effects.

Financial support of RFBR grant No. 18-32-00354 is acknowledged.

[1] L.A. Makarova et al., IEEE Transactions on Magnetics 99, 2699740 (2017)
[2] L.A. Makarova, et al., JMMM 470, 89–92 (2019)
[3] L.A. Makarova, et al., JMMM 485 (2019)

Magnetism of $TmFe_4CoAl_7$ single crystal

A.V. Andreev[a,*], D.I. Gorbunov[b], J. Šebek[a]

[a]Institute of Physics, Academy of Sciences, Na Slovance 2, 18221 Prague, Czech Republic

[b] Hochfeld-Magnetlabor (HLD-EMFL), Dresden-Rossendorf, D-01328 Dresden, Germany

*a.andreev@seznam.cz

The ternary intermetallic compound $TmFe_5Al_7$ (tetragonal crystal structure) was recently investigated within a systematic study of RFe_5Al_7 (R = rare-earth metal) [1]. It is a highly anisotropic ferrimagnet below the Curie temperature T_C = 193 K. In the ground state, the magnetic moment of the Fe sublattice is slightly higher than that of the Tm one, the spontaneous magnetic moment is M_s = 0.5 m_B at 2 K. It was found for the compounds with R = Dy and Ho that Fe can be partially substituted by Co (Co does not form isostructural compounds RCo_5Al_7) which leads to interesting changes in the magnetic properties, in particular, to an unexpected strong reduction of T_C [2,3]. In the present work, we studied effects of the 20% Co substitution for Fe on the magnetism of $TmFe_5Al_7$ on a single crystal grown in a triarc furnace by modified Czochralski methods.

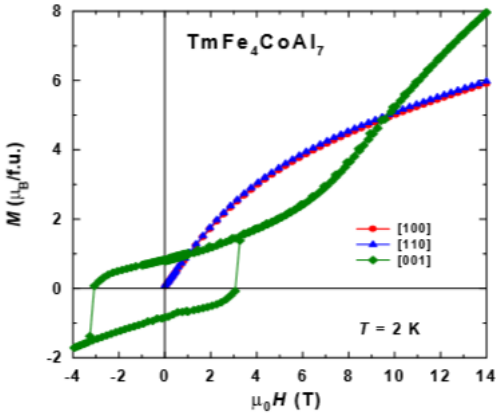


Fig. 1. Magnetization curves along the main axes at 2 K.

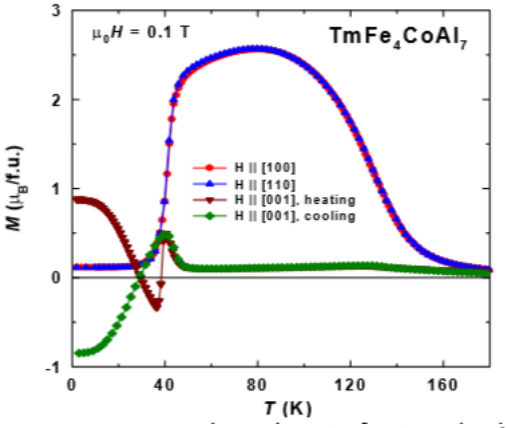


Fig. 2. Temperature dependence of magnetization in 0.1 T field applied along the main axes.

$TmFe_4CoAl_7$ is a ferrimagnet with T_C = 135 K, i.e., the drastic T_C drop observed in the Dy and Ho compounds is confirmed also for R = Tm. The [001] axis is the easy-magnetization direction (Fig. 1). No anisotropy, in contrast to the Dy and Ho systems, is observed within the basal plane. Introduction of Co leads to a decrease of the magnetic moment of the 3d-metal sublattice, the total M_s = 0.5 m_B (at 2 K) is along the Tm sublattice at 2 K. This results in the appearance of a compensation point, T_{comp} = 29 K (Fig. 2), with thermal hysteresis characteristic for RT_5Al_7 ("negative magnetization effect"). The Tm sublattice provides a uniaxial magnetic anisotropy, whereas the Fe sublattice favors an easy-plane anisotropy. A competition between them results in a spin-reorientation transition at 42 K. An antiferromagnetic state observed in $TmFe_5Al_7$ just above the spin-reorientation is not seen in $TmFe_4CoAl_7$.

We will compare also the high-field behavior of $TmFe_5Al_7$ and $TmFe_4CoAl_7$. In both compounds, a field-induced transition is observed for field applied along the [001] axis.

[1] D.I. Gorbunov, S. Yasin, A.V. Andreev, N.V. Mushnikov, E.V. Rosenfeld, Y. Skourski, S. Zherlitsyn, J. Wosnitza, Phys. Rev. B 89 (2014) Art. No. 214417.
[2] D.I. Gorbunov, A.V. Andreev, D.S. Neznakhin, J. Šebek, M.S. Henriques, Y. Skourski, S. Daniš, J. Wosnitza, J. Alloys Compd. 741, 715 (2018).
[3] A.V. Andreev, D.I. Gorbunov, J. Šebek, D.S. Neznakhin, J. Alloys Compd. 731, 135 (2018).

Inhomogeneous magnetic field influence on magnetic properties of NiFe/IrMn thin film structures

CH. GRITSENKO[a], A. BERG[a*], I. DZHUNB[b], N. CHECHENIN[b,c], G. BABAYTSEV[b] AND V. RODIONOVA[a,d]

[a]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[b]Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

[c]Faculty of Physics, Lomonosov Moscow State University, 119991, Leninskie Gory 1/2, Moscow, Russia

[d]National University of Science and Technology MISiS, 119049, Leninsky Prospect 4, Moscow, Russia

*berg.anton007@gmail.com

Exchange coupled thin films performing exchange bias effect are important components of spintronics, sensorics, and magnetic recording devices. Exchange-biased systems can be used to obtain a stepwise hysteresis loop that potentially can give a possibility to increase sensitivity and implement the secure passive magnetic tags [1]. In this application, a rich harmonic spectrum of a signal induced in pick-up coils is required. These features of a spectrum are determined by magnetization reversal processes of a magnetic system.

In this work we use a novel method for achieving a controllable stepwise hysteresis loops by applying an inhomogeneous magnetic field during deposition of exchange coupled NiFe/IrMn thin film structures. For this purpose, we have used two NdFeB permanent magnets of curved shape to create an external magnetic field in the deposition camera of a magnetron sputtering machine.

We demonstrated that presence of an inhomogeneous magnetic field during the deposition leads to dramatic changes in the magnetization reversal process of an exchanged-coupled thin film structures. A low gradient of the magnetic field results in altered values of the exchange bias. A large gradient affects both the magnitude of the exchange bias and a magnetization reversal mechanism of the NiFe/IrMn bilayer thin film. These features provide the ability to expand the field of applications of the exchange bias effect.

[1] Xu, Wei, et al. "New axial laminated-structure flux-switching permanent magnet machine with 6/7 poles." *IEEETransactionsonmagnetics* 47.10 (2011): 2823-2826.

Microwave magnetoelectric effect in layered structures based onferromagnetic metals

M.Bichurin[a,*], O. Sokolov[a], A. Tatarenko[a], V. Lobekin[a], S. Ivanov[a], A. Turutin[b], N. Sobolev[b,C]

[a]Novgorod State University, 173003, Bolshayay Sankt-Peterburgskaya 41, Veliky Novgorod, Russia

[b]National University of Science and Technology MISiS, 119049, Leninsky prospekt 4, Moscow,Russia

[c]Department of Physics and I3N, University of Aveiro, 3810-193 Aveiro, Portugal

*****Mirza.Bichurin@novsu.ru

Development of spintronics has increased interest in the magnetoelectric effect in nanostructures. Recently, the magnetoelectric effect in multiferroics in the terahertz range was studied on the basis of various manganites [1]. It is of interest to investigate the magnetoelectric effect in the FMR region in nanostructures based on ferromagnetic metals [2].

This report presents the results of research of FMR in thin films of nickel, iron and cobalt (thickness of films ~ 50 nm). The calculated values of the resonant magnetizing field for frequencies 3, 10, 30 GHz at different orientations of this field are given. Cases are considered when the magnetizing field is perpendicular to the plane of a thin metal film and is also directed in the plane of a thin metal film along or perpendicular to the axis of easy magnetization. The main attention is paid to the theoretical study of two-layer magnetoelectric composites, in which PZT, PMN-PT or PZN-PT disks with a thickness of 0.5 mm are used as piezoelectrics, on which Ni, Fe or Co thin films are deposited. When exposed to such magnetoelectric composites of a constant electric field, directed perpendicular to the disk plane, the FMR resonance line in a thin metal film is shifted as a result of the microwave magnetoelectric effect [3].

As a result of the calculation, it was found that the maximum shift of the FMR line in an iron film in an electric field of 10 kV/cm was 855 Oe for a PZN-PT piezoelectric. In the case of cobalt and nickel films, the shift under the same conditions was 783 Oe and 446 Oe, respectively. The studied effect can find practical application in the development of spintronic microwave devices.

[1]A.A. Mukhin, et al., Phys. Usp. **52**, 851 (2009)
[2]E.A. Karashtin, A.A. Fraerman, Phys. Solid State **58**, 2228 (2016)
[3]M.I. Bichurin, V.M. Petrov, R.V. Petrov, A.S. Tatarenko, Magnetoelectric Composites, Pan Stanford Publ., 2019, 280p.

Internal Structure and Stability of Skyrmions in Heavy Metal/Ferromagnet Multilayers

K. CHICHAY[a,*], J. BARKER[b], O. TRETIAKOV[c]

[a]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[b]School of Physics and Astronomy, University of Leeds, Leeds, United Kingdom

[c]School of Physics, The University of New South Wales, Sydney 2052, Australia

*ks.chichay@gmail.com

Magnetic Skyrmions are one of the fascinating and promising objects because of their small size and stability to perturbations such as electric currents and magnetic fields [1-4]. The major mechanism to stabilize small Skyrmions in ferromagnet/heavy metal bilayers is the presence of Dzyaloshinskii-Moriya interaction (DMI). In thin films, the DMI arises at the interface of ferromagnetic material and heavy metal due to the presence of spin-orbit interaction and broken inversion symmetry [4, 5].

In this work we investigate the stability and internal structure of an isolated Skyrmion in bilayer (ferromagnet/heavy metal) and trilayer (heavy metal 1/ferromagnet/heavy metal 2) nanodisks. We study the static properties of the Skyrmions and obtain the phase diagrams of the Skyrmion existence depending on the thickness of the ferromagnetic layer and the DMI strength. We demonstrate the importance of fully taking into account the dipolar interaction even for a few atomic layers thin nanodisk and that together with DMI it has the stabilizing effect and defines the Skyrmion configuration. For the trilayer structures with two heavy-metal interfaces (corresponding to two interfacial DMIs), we show that the type and configuration of the Skyrmion can be controlled by the thickness of ferromagnetic, and interplay of two interfacial DMIs can lead to formation of magnetic structures with higher winding number.

[1] N. Nagaosa and Y. Tokura, Topological properties and dynamics of magnetic skyrmions, Nat. Nanotechnol. 8, 899-911 (2013),
[2] A. Hoffmann, S. Bader, Opportunities at the Frontiers of Spintronics, Phys. Rev. Applied 4, 047001 (2015),
[3] A. Fert, V. Cros, J. Sampaio, Skyrmions on the track, Nat. Nanotechnol. 3, 152-156 (2013),
[4] J. Sampaio, V. Cros, S. Rohart, A. Thiaville, A.Fert, Nucleation, stability and current-induced motion of isolated magnetic skyrmions in nanostructures, Nat. Nanotechnol. 8, 839-844 (2013)
[5] S. Heinze, et al. Spontaneous atomic-scale magnetic skyrmion lattice in twodimensions, Nature Phys. 7, 713–718 (2011)

Formation of ferromagnetic semiconductor GaAs:Mn by ion implantation with subsequent pulse laser annealing

YU. DANILOV[a,*], R. KRYUKOV[a], A. KUDRIN[a], A. PARAFIN [b], O. VIKHROVA[a], M. DOROKHIN[a]

[a]N.I. Lobachevsky State University, 603950, Gagarine av. 23/3, Nizhny Novgorod, Russia

[b]Institute for Physics of Microstructures RAS, 603950, GSP-105, Nizhny Novgorod, Russia

*danilov@nifti.unn.ru

Ferromagnetic semiconductors (FMS) are materials with semiconductor and ferromagnetic properties simultaneously. Such combination of the parameters is achieved by heavy doping of the common semiconductors (elementary or III-V compounds) with transition element atoms. A standard FMS is $Ga_{1-x}Mn_xAs$ ($x \approx 0.05$) fabricated by the molecular beam epitaxy at a low (~ 250°C) temperature (LT-MBE). This FMS has a temperature of ferromagnetic/paramagnetic transition (Curie temperature, T_C) about of ≤ 110 K. Other method of Mn heavy doping GaAs is ion implantation. However, there is a serious problem of radiation defect annealing, necessary also for electrical activation of implanted Mn atoms as acceptors. The use of rapid thermal annealing (RTA) at the temperatures above 700°C has undesirable effect in Mn ion-implanted GaAs related with formation of ferromagnetic MnAs and GaMn clusters. This means appearance of the second phase inclusions in single crystal GaAs and causes a degradation of some (for example, optical) properties as compared with the initial semiconductor. The effect is conditioned by decomposition of Mn solid solution in the GaAs lattice because of low ($\leq 10^{18}$ cm^{-3}) equilibrium solubility of Mn atoms.

We used the technique of Mn^+ ion implantation with subsequent annealing by excimer laser pulse for fabrication of single phase FMS GaMnAs. The irradiation with Mn^+ ions was performed at room temperature into i-GaAs(100) wafers. The ion energy was 50 or 200 keV, and fluences were varied from 10^{13} to 5×10^{16} cm^{-2}. The excimer KrF laser LPX-200 generated a beam with area of ≈1.5 cm^2, a wavelength of 248 nm, pulse duration of ≈ 30 ns and a pulse energy density up to 0.5 J/cm^2. The layers, irradiated by Mn^+ ions even at the fluence of 5×10^{13} cm^{-2}, were amorphous. Depth distribution of implanted Mn atoms, determined by X-ray photo-electron spectroscopy, on the whole corresponded to SRIM code calculation taking into account high (~7 at/ion) sputtering coefficient. The pulse laser annealing (PLA) with the energy density of 125 mJ/cm^2 and above caused recrystallization of Mn^+ ion irradiated layer. It was found that there is a threshold ion fluence of ~1×10^{15} cm^{-2} for p-type conductivity formation upon PLA with 0.2 – 0.3 J/cm^2. The dependences of sheet resistance for fluences from 1×10^{16} to 5×10^{16} cm^{-2} contain a characteristic peak, which associated with T_C. The T_C value increases up to ≈ 110 K with Mn^+ ion fluence. Galvanomagnetic measurements shown anomalous Hall effect with hysteresis loop up to T_C. Also, the negative magnetoresistance was observed up to 120 K. It was also made a comparison of the electrical and magnetic properties of GaAs layers irradiated by Mn^+ ions and annealed by PLA and RTA methods. The absence of ferromagnetic signal at room temperature with high-sensitivity (~10^{-8} emu) magnetization measurements by alternating-gradient method testify that GaMnAs, formed by ion implantation and PLA, is single-phase FMS. The Curie temperature of this material is not below than that for the LT-MBE material. We assume that non-equilibrium recrystallization with superfast cooling at short laser pulse promotes the effective incorporation of implanted Mn atoms into Ga sites, that leads to a high concentration of holes and magnetic moments, causing ferromagnetic ordering in laser-annealed Mn implanted GaAs layers.

This work was supported by the Russian Science Foundation (grant № 19-19-00545).

Influence of Sc-Substitution on Crystal Structure, Magnetic and Electrical Properties of Barium Hexaferrite

M.A. Darwish[a*], V.G. Kostishin[a], I.M. Isaev[a], A.T. Morchenko[a], V.V. Korovushkin[a], K.A. Astapovich[b], S.V. Trukhanov[a,b,c], A.V. Trukhanov[a,b,c], L.V. Panina[a]

[a] National University of Science and Technology MISiS, Moscow, Russia

[b]SSPA "Scientific and Practical Materials Research Centre of NAS of Belarus", Minsk, Belarus

[c]South Ural State University, Chelyabinsk, Russia

*mostafa_ph@yahoo.com

Strongly correlated complex oxides attract substantial interest due to fundamental and practical aspects. This concerns the variety of magnetic and electric properties and their strong correlation with chemical composition and the features of crystal and magnetic structures. M-type barium hexaferrite is a promising material for practical applications as permanent magnets, for high-frequency applications and absorption of electromagnetic radiation. As a rule, diamagnetic substitution of the iron ions leads to changes in the magnetic and electrical properties of hexaferrites due to frustration of magnetic structure (deviation from collinearity of magnetic vectors). Particular changes in the magnetic structure are critically depended on the distribution of the diamagnetic ions in the M-type crystal lattice. Thus, Sc^{3+} -ion localization can have a great impact on the intensity of exchange interactions and, as a consequence, on the spin ordering in the hexaferrite structure.

Polycrystalline $BaFe_{12-x}Sc_xO_{19}$ hexaferrites ($x \leq 1.2$) were produced using a ceramic technology. To carry out a precision investigation of the features of the crystal structure and appearance of a noncollinear spin structure the neutron powder diffraction was used. As a rule, the diamagnetic substitution does not induce any deviations from strict collinearity at low concentrations. In the case of Sc^{3+} - substitution, a non-linear change in the magnetic parameters with concentration was detected. A non-linear behavior of the saturation magnetization is a result of the peculiarities of Sc^{3+}-ion distribution over the non-equivalent oxygen coordinations and some deviation from strict collinearity in the direction of the magnetic vector. We noted a sharp decrease of the coercivity in the concentration range $x \geq 0.6$. It could be explained by a rapid frustration of the magnetic structure (destruction of long-range magnetic ordering due to weakening of the intra-sublattice exchange interaction in Fe^{3+}-O^{2-}-Fe^{3+} in the first and second coordination spheres). Mossbauer studies show that the high sensitivity of the magnetic parameters of polycrystalline $BaFe_{12-x}Sc_xO_{19}$ ferrites is caused by several factors: 1) ordered location of Sc^{3+} ions in positions 2*b* and $4f_2$, and also the ordering of cation vacancies at the boundary of the spinel and hexagonal blocks; 2) transfer of spin density from iron ions localized at position 12*k* to 3*d* orbitals of Sc^{3+} ions; 3) weakening of the indirect exchange interactions between 2*b*, $4f_2$, , and 12*k* sublattices; 4) the presence of a non-collinear structure for *x* above 0.6.

Acknowledgment

The work was support by the Russian Science Foundation (Agreement No. 19-19-00694 of 06 May 2019).

Properties and spintronic applications of CoPt ferromagnetic films

P. Demina[a,*], M. Dorokhin[a], A. Zdoroveishchev[a], O. Vikhrova[a], A. Kudrin[a],Kalent'eva[a], M. Temiryazeva[b], A. Temityazev[b]

[a]Nizhniy Novgorod State University, 630090, Gagarin avenue 23/3, Nizhniy Novgorod, Russia

[b]Fryazino Branch of IRE RAS, 141190, Vvedensky square 1, Fryazino, Russia

*demina@phys.unn.ru

The paper describes the physical, micromagnetic, magneto-optical properties of CoPt films fabricated by the method of electron beam evaporation. This method of film deposition is more productive and technologically precise than the currently widely used ultrahigh vacuum magnetron sputtering systems. In addition, the lower-energy of deposited materials allows decreasing the surface defect generation, which is promising for fabrication of Schottky contacts to A^3B^5-based light-emitting heterostructures.

The results of our studies were aimed at application of CoPt films as a tool for magnetic force microscopy and as basic spintronics devices [1]: a spin light-emitting diode and a detector of circularly polarized radiation. The main advantages and disadvantages of using different compositions of ferromagnetic films for the electronic device technology are analyzed.

The most important features of magnetic films for magnetic force microscopy are perpendicular magnetic anisotropy, small thickness and corrosion resistance. CoPt material has a high corrosion resistance and is not susceptible to etching in most of the known acids. CoPt films have perpendicular magnetic anisotropy at small, up to 10 nm, film thickness [2]. Magnetic field dependences of magnetization for CoPt films in the case of a magnetic field direction perpendicular to the surface of the structure are of hysteretic character with a magnetization yield to saturation in 350 to 500 Oe. In the demagnetized state, they exhibit a domain structure with a characteristic domain size of 100°-°200 nm. In addition, CoPt films allow "remembering" the single domain restructuring due to the effect of the magnetic field of the probe. This makes such films a very convenient object for express testing of the performance of the MSM probe.

Spin-emitting diodes (SLED) based on A^3B^5 semiconductors are one of the key elements of spintronics [3]. Magnetic field dependences of the degree of circular polarization of a diode with a CoPt injector demonstrate a non-zero degree of polarization of electroluminescence up to room temperature. The maximum degree of circular polarization in magnetization saturation mode for these diodes was 2%, a slight decrease in the coercive field was observed with increasing measurement temperature.

Using the CoPt film, we proposed technical solutions for a detector of circularly polarized emitting. We have proposed a planar design of a detector of circularly polarized light based on a MIS-structure with a ferromagnetic CoPt layer, which is based on the use of the magnetic-circular dichroism effect. Such a detector, demonstrating the relationship between an electrical signal (current or voltage) and the sign and degree of incident light polarization, can be applied in optical communication systems.

This work supported by the Governmental project no. 8.1751.2017/PCh of the Ministry ofEducation and Science of the Russian Federation, and the Russian Foundation for Basic Research (project 18-29-19137).

[1]R. Jansen, Silicon spintronics, Nature mat. 11, 400 (2012)
[2]A.V. Zdoroveyshchev, M.V. Dorokhin, O.V. Vikhrova, et al. PSS 58, 2267 (2016)
[3]M. Holub, P. Bhattacharya, J. Phys. D: Appl. Phys. 40, R179 (2007)

Magnetoelectric Effect In Bilayer Piezoelectric – Magnetostrictive Fiber Composite Structure

L.Y. Fetisov*, D.V. Chashin, D.V. Saveliev, D.A. Vyunik

MIREA - Russian technological university, 119454, Vernadskogo 78, Moscow, Russia

e-mail: fetisovl@yandex.ru

The direct magnetoelectric (ME) effect is manifested as a change of a sample polarization in an external magnetic field. The largest value of ME effect is achieved in layered composite structures consisting of alternating ferromagnetic (FM) and piezoelectric (PE) layers. The effect arises due to combination of magnetostriction of FM layer and piezoeffect in PE layer through mechanical coupling between the layers [1]. Various lead-based piezoelectric ceramics such as PZT and PMN-PT are the traditional PE materials for such composite structures. Recently it was shown that use of piezofiber composite structures (PCS) as PE layer significantly increase the value of ME effect [2]. Similar composite materials based on magnetostrictive fibers [3], can also be used as FM layers in ME composite structures [4].

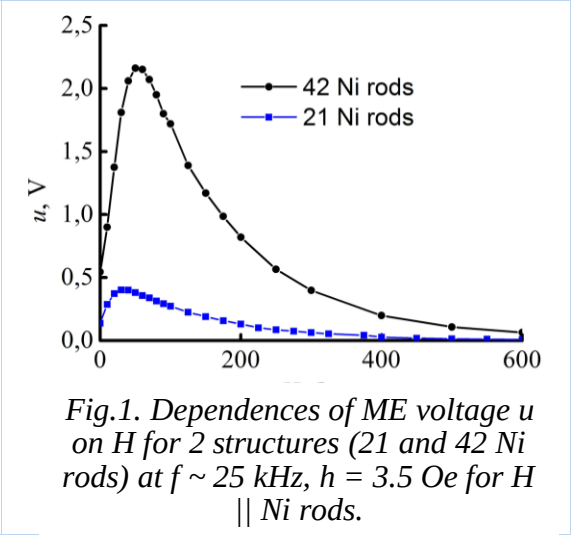


Fig.1. Dependences of ME voltage u on H for 2 structures (21 and 42 Ni rods) at f ~ 25 kHz, h = 3.5 Oe for H || Ni rods.

The present work describes investigation of ME effect in two layered FM-PE structure with Ni based MFC. Piezoelectric ceramic plate (PZT - 19) with dimensions 10 mm × 10 mm × 200 μm was used as PE layer. Ferromagnetic layer was made of magnetostrictive fiber composites (MFC) consisted of 21 or 42 parallel Ni fibers 100 μm in diameter each. The wires were placed in a polymer matrix. Magnetic and magnetostrictive characteristics of MFC were measured, so as frequency and field dependences of ME voltage *u*, generated by the structures. Dependences of ME voltage on the constant magnetic field *H* for two structures with 21 and 42 Ni rods are shown on figure 1. Magnetic field*H* was appliedparallel to fibers in MFC. The maximum on the curve at *H* ~ 40 Oe corresponds to the maximum of the MFC piezomagnetic coefficient. As it follows from the measurements, an increase in the number of wires by 2 times leads to an increase in the ME voltage by ~ 5.4 times. Nonlinear ME effects were also investigated in these structures.

Nonreciprocal light scattering by toroidal magnetic systems

O.G.Udalov, M. V. Sapozhnikov,E. A. Karashtin, B. A. Gribkov, S. A. Gusev, E. V. Skorohodov, V. V. Rogov, A. Yu. Klimov,A.A. Fraerman*

Institute for physics of microstructures RAS, GSP-105, Nizhny Novgorod 603950, Russia

** andr@ipm.sci-nnov.ru*

It is well known that time reversal symmetry of the any particle (for example, neutron or photon) motion equations leads to the following equality for the elastic scattering cross section $\sigma(\vec{k},\vec{k}',\vec{B})$

$$\sigma(\vec{k},\vec{k}',\vec{B}) = \sigma(-\vec{k}',-\vec{k},-\vec{B}),(1)$$

where $\vec{k}$ and $\vec{k}'$ are wave vectors of the incident and scattered particles, and $\vec{B}$ is the magnetic field in the system. For systems without the center of inversion, the scattering cross section may contain the term

$$\sigma = \ldots+\acute{\alpha}(\mathbf{k} + \mathbf{k}')\ \mathbf{C} + \ldots, \quad (2)$$

where**C** is a polar vector that also changes its sign under the time reversal. For a magnetic scatterer of centrosymmetrical shape made of a centrosymmetrical material, **C** can be chosen in the simplest form $\mathbf{C} = \alpha\langle[\mathbf{r} \times \mathbf{M}(\mathbf{r})]\rangle$, which is a toroidal moment of the particle associated with the magnetic vorticity(the square brackets mean the spatial averaging over the scatterer). It follows from the above that the scattering of unpolarized light by a particle with the vortex magnetization distribution is nonreciprocal, its contribution being dependent on the vorticity. We carried out experimental investigations of light diffraction by two different systems with toroid moment. First of them is mulilayer structure, containing two ferromagnetic layers separated by some nonmagnetic spacer. If coercive forces of the films are different we can obtain, after some magnetization process, anti parallel orientation of magnetic moments in the layers. So, the system in the state is characterized by toroid moment aligned in plane of the sample. Second example is lattice of triangle ferromagnetic particles with vortex distribution of magnetization. In this case, magnetic toroid moment lies perpendicular to the sample plane [1].

This work was supported by the Ministry of Education and Science of the Russian Federation (Grant No. 8565) and the Russian Foundation for Basic Research (Grant No. 11-02-00294-a, 11-02-00589-a).

[1]. O. G. Udalov et al,Phys. Rev. B **86**, 094416 (2012)

Magnetooptical spectroscopy of $(CoFeB)_x$-$(Al\text{-}O)_{100-x}$ nanocomposites: Evidence of superferromagnetism

E. GAN'SHINA[a,*], A. GRANOVSKY[a], D.SHEVYAKOV[a], A.SITNIKOV [B], E. LäHDERANTA[c], V. RYLKOV [D]

[a]Faculty of Physics, Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

[b]Voronezh State Technical University, 394026 Voronezh, Russia

[c]Lappeenranta University of Technology, 53851, Finland

[d]National Research Centre "Kurchatov Institute", 123182 Moscow, Russia

*eagan@mail.ru

We present results of magnetooptical investigations of $(CoFeB)_x$-$(Al\text{-}O)_{100-x}$ film nanocomposites in the transverse Kerr effect (TKE) geometry in the spectral range 0.5-4.0 eV and magnetic field up to 3.0 kOe. Nanocomposites were deposited onto a glass–ceramic substrate by the ion-beam sputtering. The details of their structural and transport properties are given in [1,2]. Accordingly to the data obtained from resistivity measurements the percolation threshold is about $x_{per}\approx 56$ at.% and the critical concentration for metal-insulator transition is about $x_c \approx 47$ at.%. Low temperature magnetic measurements clearly indicate on a large amount of magnetic ions located in insulating barriers between ferromagnetic or superparamagnetric granules that favors superferomagnetic ordering in the vicinity of x_c . The TKE response at room temperature strongly depends on the wavelength of light, applied magnetic field H and metallic fraction. The TKE field dependence is almost linear up to H=3.0 kOe and identical for 1.57 and 3.06 eV at $x\leq 30$ at.%. It means that at $x\leq 30$ at.% nanocomposites consist of only superparamagnetic granules. With increasing x the TKE field dependence for 3.06 eV becomes more and more similar to the field dependence of ferromagnetic material but it is not the case for 1.57 eV. For example, the TKE signal for x=43 at.% measured at 3.06 eV saturates at H=100 Oe, that indicates on the presence of large ferromagnetic regions below x_c. But for the same composition the TKE field dependence measured at 1.57 eV does not saturate and resembles more superparamagnetic response. The same difference is observed also at x=49 and 56 at.%. The presence of large ferromagnetic regions in completely insulating samples together with separate superparamagnetic granules can be considered as an evidence of superferromagnetic ordering in the vicinity of x_c. Magnetooptical spectral measurements confirm that with increasing x separate superparamagnetic granules at $x< x_c$ approach each other, part of them form superferromagnetic regions in the vicinity of x_c, then they touch each other forming ferromagnetic entities but some of them at $x_c<x< x_{per}$ are still in superparamagnetic and superferromagnetic states. In spite of overwhelming majority of granules are in contact at $x> x_{per}$ there are still some amount of superparamagnetic granules.

Support of Russian foundation for basic research (grants № 18-52-50021 and № 19-07-00471) is acknowledged.

[1] V.V. Rylkov, S.N. Nikolaev, K.Yu. Chernoglazov et al., Phys. Rev. B **95,** 144202 (2017).
[2] V.V. Rylkov, A.V. Sitnikov, S.N. Nikolaev et al., Journ. Magn.Magn.Mater.**459**, 197 (2018).

Orbital ordering of Jahn-Teller manganites as a way to magnetic frustration.

L.E. GONCHAR[a,b*]

[a]Ural Federal University, 620002, Mira 19, Ekaterinburg, Russia

[b]Ural University of Railway Transport, 620034, Kolmogorova 66, Ekaterinburg, Russia

*l.e.gonchar@urfu.ru

The orthorhombic manganite crystals $R_{1-x}A_xMnO_3$ (where R^{3+} is a rare earth ion or Bi^{3+}, A^{2+} is an alkaline earth ion, and x is a doping rate) are known as smart materials with strong correlation between crystalline, charge, orbital, and magnetic subsystems' orderings because of Jahn-Teller (JT) ions Mn^{3+} sublattice [1]. The influence of this correlation give rise to low-dimensional, incommensurate and frustrated magnetic structures.

The frustration of magnetic structure in manganites is of two kinds. The firs type of frustrated magnetic structure is found in the pure hexagonal manganite crystals with R=Sc, Y, Ho, Er, Tm, Yb, Lu with triangular magnetic cell. The competition of nearest-neighbor antiferromagnetic superexchange interactions is due to geometrical reason [2]. Another type of magnetic frustration in JT orthorhombic manganites is the competition between different direction of nearest-neighbor superexchange interaction in $BiMnO_3$ and in charge-ordered compound with x=2/3. The reason of this type of frustration is the dependence of superexchange interaction upon orbital ordering [3]. The current investigation is devoted to theoretical description of such kind of magnetic frustration.

The sign and value of superexchange interaction considered to be dependent upon orbital states of interacting manganese ions and upon superexchange bond parameters (direction, length, Mn–O–Mn angle). The final magnetic ordering is forming due to single-ion anisotropy, which also depends upon orbital states.

The model Hamiltonian of manganites is [4]

$$\hat{H}_{mag} = \sum_{i>j} J_{ij}(\Theta_i, \Theta_j)\left(\mathbf{S}_i \cdot \mathbf{S}_j\right) + \sum_{i,\alpha,\beta} D_i^{\alpha,\beta}(\Theta_i) S_i^{\alpha} S_i^{\beta} + \mu_B \sum_{i,\alpha,\beta} H_{\alpha} \mathbf{g}_{a\beta}^{i}(\Theta_i) S_i^{\beta}, \qquad (1)$$

where first sum is superexchange interaction, second one is single ion anisotropy and the third one is Zeeman interaction. All terms are dependent upon total manganese spins $\mathbf{S}_i$, $\mathbf{S}_j$ and orbital structure parameters Θ_i, Θ_j.

In the current study, the role of orbital ordering in magnetic competition is emphasized. The magnetic field dependences of complicated magnetic structures are discussed. The conditions of ordered state's destruction are estimated. The ranges of orbital structure mixing angles to form frustrated or low-dimensional magnetic structures are determined.

The support by Act 211 Government of the Russian Federation, contract № 02.A03.21.0006 is acknowledged.

[1] N.G. Bebenin, R.I. Zainullina, V.V. Ustinov, Phys. Usp. 61, 719–738 (2018)
[2] Th. Lottermoser, JMMM 226–230, 1131–1133 (2001)
[3] L.E. Gonchar, JMMM 465, 661–669 (2018)
[4] L.E. Gonchar, Physics of the Solid State, 61, 728–734 (2019)

Spin-Wave Transport In Multi-Channel Lateral YIG Structure

A. GRACHEV[a,*], A. SADOVNIKOV[a,b], E. BEGININ[a], S. SHESHUKOVA[a], S. NIKITOV[a,b]

[a]Saratov State University, 410012, Astrakhanskaya 83, Saratov, Russia

[b]Kotel'nikov Institute of Radioengineering and Electronics, RAS, 125009,Mokhovaya 11, Moscow, Russian Federation.

*Stig133@gmail.com

The study of the transfer of magnetic moment or electron spin instead of charge transfer opens up new possibilities for using spin waves to build the elemental base of devices for processing, transmitting and storing information in the microwave and terahertz range [1,2]. Ferrite films, for example, yttrium iron garnet (YIG), exhibiting record low attenuation of spin waves (SW), are used as media suitable for these purposes [3].

Here we report on numerical and experimental study of the dynamics of spin waves propagating in a multi-channel side-coupled magnonic structure.

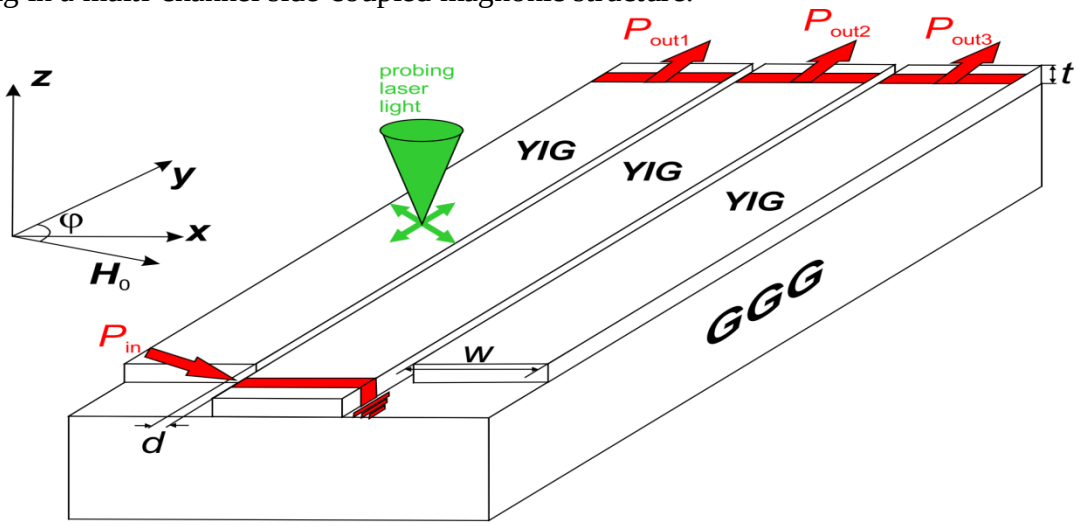


Fig. 1 The scheme of the considered structure.

The considered structure is shown in Fig. 1 and consists of three parallel oriented magnetic stripes, which form three spin-wave channels. The structure was created using a laser scribing method made of YIG film, thickness t = 10 μm width of each magnetic stripe is w = 500 μm, the structure is placed on a gallium-gadolinium garnet substrate with 500 μm thickness. The distance between the magnetic stripes is d = 40 μm. The structure is placed in an external static magnetic field H_0 = 1200 Oe and varying at an angle φ.

Using Brillouin light scattering spectroscopy we experimentally demonstrated spin-wave transport along bilateral magnonic stripes. We identified the spin-wave routing between the magnetic channels by varying the bias angle of the magnetic field.

This work was supported by the Grant from Russian Foundation for Basic Research (projects № 18-29-27026, 18-37-20005) and Scholarship (SP2819.2018.5) and Grant (MK-3650.2018.9) of the President of RF.

[1] A.V. Sadovnikov et.al, Phys. Rev. Lett. 120, 257203 (2018)
[2] A.V. Sadovnikov et.al, Physical Review Applied, 7, 014013 (2017)
[3] A.V. Sadovnikov et.al, IEEE Magnetics Letters, 8, 1 (2017).

Micromagnetic study of hysteresis properties in hexagonal antidot lattices with perpendicular magnetic anisotropy

Z. GRININA [a,b,*], A. BOLYACHKIN [a], N. KULESH [a,c], V. LEPALOVSKIJ [a], V. VAS'KOVSKIY [a], M. VÁZQUEZ [a,c]

[a]Ural Federal University, 620002, Ekaterinburg, Russia

[b]Institute of Metal Physics, 620108, Ekaterinburg, Russia

[c]Institute of Materials Science of Madrid, CSIC, 28049, Madrid, Spain

*zlatagrinina@ya.ru

Searching for new ways of tailoring magnetic properties of thin films is important for applications in magnetic sensors, spintronics and MRAM. Introduction of artificial defects with well-controlled parameters is one of the most effective methods. Ordered defect lattices can be introduced by various techniques: lithography, ion beam etching, depositing magnetic material onto the array of polysterene spheres or porous anodic alumina [1, 2]. In the last case, the substrate has a self-organized hexagonal ordering of pores. The distance between pores and their diameter can be controlled by selecting the appropriate anodizing parameters. Structural order of anodic alumina substrates is replicated by the deposited thin magnetic film. At the moment, more attention is paid to the study of nanostructured films with in-plane magnetic anisotropy [1]. Fewer articles are devoted to antidot films with perpendicular magnetic anisotropy [2]. Coercivity of such films depends on the distance between the holes and their diameter. Studying such dependence for antidot films with strong perpendicular magnetic anisotropy was the purpose of this work. To consider widest possible range of antidot diameters and lattice parameters, we employed micromagnetic simulation. As a reference system we used $Tb_{29}Co_{71}$ antidot films with perpendicular magnetic anisotropy, which were synthesized and studied experimentally [2].

For simulations we used the following set of material parameters corresponding to the $Tb_{29}Co_{71}$ film: exchange interaction constant $A = 6.2 \cdot 10^{-7}$ erg/cm, magnetic anisotropy constant $K = 6 \cdot 10^5$ erg/cm^3, and saturation magnetization $Ms = 150$ emu/cm^3. The simulation was carried out in the OOMMF micromagnetic package [3]. Periodic boundary conditions were taken into account. Out-of-plane hysteresis loops were simulated for different antidot diameters and distances between neighboring holes. As a result, two-dimensional map of coercivity on the two parameters was calculated. To explain the difference between the shapes of simulated and experimental hysteresis loops we also considered the influence of the specific magnetic material distribution in the proximity of the nanoholes.

This work was supported by RFBR (research project No. 18-32-00220) and the President of Russian Federation grant for young scientists (Contract 14.Y30.18.1891-MK).

[1] P. Gawronski, EPL 100, 1700 (2012)
[2] N. Kulesh, Nanotechnology 29, 065301 (2018)
[3] M. Donahue and D. Porter, OOMMF User's Guide (http://math.nist.gov/oommf/)

Nanosized ferrites NiFe2O4, synthesis and biomedical applications.

M.S. GRYAZNOVA[a,*], E.A. BELYA[a], D.A. Kalganov[a]

[a]Chelyabinsk State University, 454001, Br. Kashirinykh 129, Chelyabinsk, Russia

*masha_gryaznova@mail.ru

Nanosized nickel ferriteis a spinel structure compound, which is applied in medicine as X-ray contrast, sorption and vehicles, as well as a major component for the magnetic tapes and magnetic ferrimagnetic materials production.

To obtain samples of nanodispersed $NiFe_2O_4$, cation-exchange synthesis was used[1]. Solution of iron chloride and nickel nitrate was added to the synthesized cation-exchange material in various molar ratios. To complete the ion exchange, this mixture was left for half an hour. The obtained samples were dried overnight on air and calcined in a muffle furnace at various temperatures for an hour. During calcination, the cation exchange matrix was burned, and the sample was a spinel of a specified composition. Powders with the expected composition of $NiFe_2O_4$ were a brown color. X-ray patterns of nickel ferrite samples calcined on air at the different temperature are shown in Fig. 1,***a***. At a calcination temperature of 400-500°C, the formation of the spinel phase begins, and ends at a temperature of 700°C.

Morphology of samples was studied with use of scanning electron microscopy. As can be get from Fig. 2,***b*** for a nickel ferrite sample calcined at 500°C, the particle size does not exceed 20 nm. Microwave properties of the samples were measured at various values of the external DC magnetic field (Fig. 1,c) using short coaxial line reflection method [2].

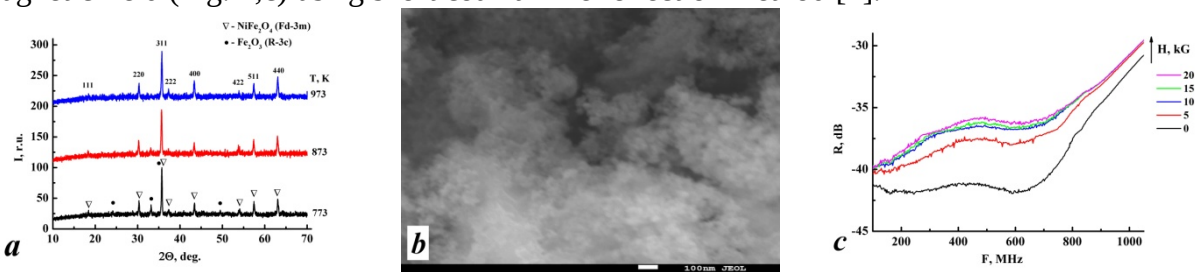


*Figure 1. X-Ray diffractograms – **a**, morphology – **b** and microwave properties – **c** of samples nanodispersed $NiFe_2O_4$*

[1] E.A. Belaya, M.S. Gryaznova, V.V. Victorov, I.N. Kovalev, D.A. Zherebtsov, Butlerov Communications 52, 10 (2017)

[2] V. Radonić, N. Blaž and Lj. Živanov, Acta Physica Polonica A. 117, 5 (2010)

Influence of Grain Boundary Restructuring on Mechanical Properties of TbDyFe Alloy

ZHIGUANG ZHOU[a], XUEXU GAO[a,*], JIANPING HE [a], HONGWEI GU [b]

[a] State Key Laboratory for Advanced Metals and Materials, University of Science and Technology Beijing, Beijing 100083, China

[b] Institute of electrical engineering, Chinese academy of sciences, No.6 Beiertiao, Zhongguancun, Beijing, 100190, China

*gaox@skl.ustb.edu.cn

Terfenol-Dhave been regarded as a giant magnetostrictive material and plays an important role in applications such as actuators and sensors [1]. However, the brittleness of Laves phase in Terfenol-D, resulting in the fracture failure during machining operations, and the cracking failure for the material in service, significantly decreases its engineering design and applications. This study aims to investigate the effect of restructuring the grain boundary of Terfenol-D by diffused the low-melting-point alloys. The toughness phase has been produced by diffused the low-melting-point alloys to substitute for RE-rich phase in grain boundary. DyCu alloy was diffused to Terfenol-D ingot in different heat treatment. The microstructure, magnetostrictive properties, tensile strength and bending strength were studied systematically. The results indicated that magnetostrictive properties declines slightly by grain boundary diffusing DyCu alloy. The mechanical properties improve significantly, attributed to the formation of a (Tb, Dy) Cu phase in grain boundary. Compared with the original sample, the bending strength(S) increases 1.5~2 times, and the tensile strength increases 2 times respectively with diffusing DyCu alloy. The Terfenol-D ingot diffuses DyCu alloy after annealing at 1020℃ for 3h, and the best bending strength increase to 93MPa. Compare with these diffused samples, the Terfenol-D by grain boundary diffusing DyCu alloy after annealing at 980℃ for 3h, shows the best combination property between the magnetostriction and mechanical properties.

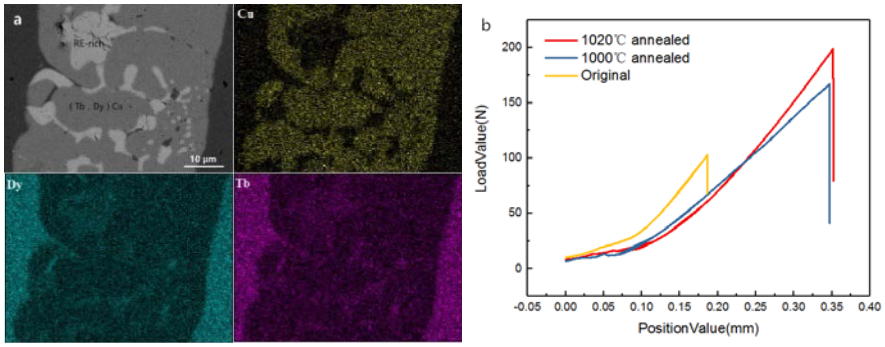


Figure1. *The DyCu diffused TbDyFe alloy (a) Cu, Dy and Tb element mapping images, (b) The bending strength curves annealed at different temperatures.*

[1] Olabi AG, Grunwald A. Mater Des. 29,469(2008).

Recrystallization and magnetostrictive properties in the rolled Fe-Ga alloy sheets

QINGLI QI [A], HONGWEI GU [B, *], GUANGHUA YU [C], XIAOQIAN BAO [A],JIANPING HE [A]

[a]State Key Laboratory for Advanced Metals and Materials, University of Science and Technology Beijing, Beijing 100083, China

[b] Institute of electrical engineering, Chinese academy of sciences, No.6 Beiertiao, Zhongguancun, Beijing, 100190, China

[c] School of Materials Science and Engineering, University of Science and Technology Beijing, Beijing 100083, China

*guhw@mail.iee.ac.cn

Magnetostrictive materials exhibit large magnetostriction at low fields [1] and are becoming widely used in actuators and sensors. The flexible flow sensors do not need too high power and frequency, but requiring good flexible performance. To achieve a degree of elastic bending deformation, Fe-Ga sheet is adopted. because the preparation of single-crystal Fe-Ga alloy is difficult, strong textured polycrystalline sample is firstly considered. However, the sheet obtained by directional solidification is high-cost and the size of the sheet is limited. The preparation of strong textured polycrystalline Fe-Ga alloy may be a good way to obtain large magnetostriction. In this work, the $(Fe_{83}Ga_{17})_{99.9}(NbC)_{0.1}$directional solidification ingot was rolled to ~1.0 mm. The sheets were enclosed in quartz ampoules using Ar as protecting gas, or with additional elemental S. Firstly, they were employed from 900 to 1080 °C without dwell at 1080 °C, and finally were annealed at 1200 °C for 6 h under Ar/H_2 mixed atmosphere.

Fig.1 (a) shows no obvious abnormal grain growth (AGG) of Goss texture was found. Due to the S-induced surface energy effect and the dispersion of NbC particles, notable Goss grains of AGG were observed In Fig.1 (b). The corresponding magnetostriction was 133.4 and 194.5 ppm after the final annealing at 1200 °C for 6 h, respectively, as shown in Fig.1 (c). This result may be related to the thickness of the sheets, the surface energy as well as the inhibition of NbC particles.

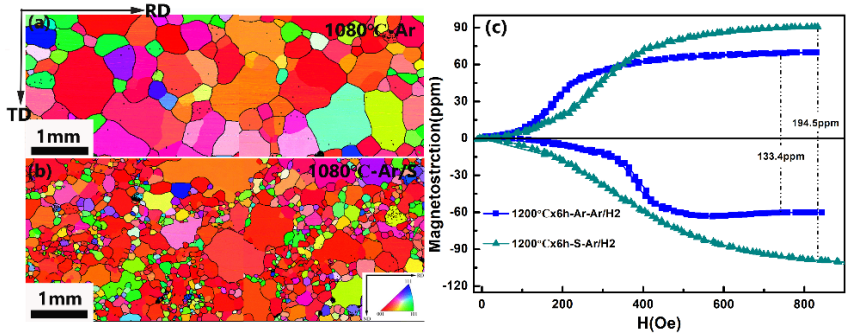


Fig. 1 the IPF images along the RD on the sheets surface after 1080 °C annealed (a) Ar-annealed and (b) S-annealed. And (c) the corresponding magnetostriction.

[1] K.S. Kumar, V. Murthy, K. Balasubramaniam, Insight. 54 (2012) 217-220.

Structural properties of magnetic polymers mixtures

M. Gupalo[a,*], E. Novak[a]

[a]Department of Theoretical and Mathematical Physics, UrFU, Ekaterinburg, Russia

*marinakashpurova@list.ru

Nowadays, a design and an application of co-called smart materials - materials that are sensitive to changes in their environment such as rise or decrease of temperature, turning on and off an external magnetic fields, light, etc - take attention of scientists from all over the world. According to the recent research, [1] one of the promising building blocks to design them are magnetic filaments - semiflexible polymer-like chains of magnetic nanoparticles permanently crosslinked with polymers.

In the present study, we focused on dispersions of magnetic filaments which are composed of monodisperse particles with spherical shape. Linear, ring, X- and Y-shapes of filaments are used as these configurations are prevalent in systems of dipolar fluids when the temperature is low [2].

The main goal of the work is an investigation into structural properties of magnetic polymers of different shapes.

We used the simulation package ESPResSo [3] to perform molecular dynamics computer simulations. All parameters were reduced. We vary the concentration of filaments and the strength of magnetic interparticle interaction. To get full information about structural properties of the system we analyze the behaviour of initial susceptibility and radial distribution function. Also we performed cluster analysis using graph theory. All these results were compared with the same ones but for pure ferrofluid.

[1]Sánchez et al., Magnetic filament brushes: tuning the properties of a magnetoresponsive supramolecular coating, Faraday Discuss. 186, 241 (2016).
[2]S.Kantorovich, A.O. Ivanov, L. Rovigatti, J.M. Tavares, F. Sciortino, Nonmonotonic magnetic susceptibility of dipolar hard-spheres at low temperature and density, Phys. Rev. Lett. 110 (2013).
[3]H.J. Limbach et al., ESPResSo – an extensible simulation package for research on soft matter systems, Comput. Phys. Commun. 174 (9) (2006).

Ferromagnetic Microwire Systems as a High-Gradient Magnetic Field Source for Magnetophoresis

A. A. GUREVICH[a,b,*], A. V. BEKLEMISHEVA[a,b] ,S. E. PSHENICHNIKOV[c], A. S. OMELYANCHIK[c],K. LEVADA[c], V. RODIONOVA[c],L. V. PANINA[a,c]

[a]National University of Science and Technology (NUST MISIS), Moscow, 119049, Russia

[b]Institute for Design Problems in Microelectronics RAS, Moscow,124365 ,Russia

[c]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

*gurevich-anastasia@yandex.ru

The influence of high-gradient magnetic field (HGMF) on paramagnetic [1] and diamagnetic [2] objects are widely studied and have a large range of application in biomedicine [3]. This paper proposes in a new system of micro magnetsbased on amorphous microwires of Co-rich composition in a glass biocompatible shellto create magnetic fields with gradients in the range of 10^3-$10^5 T/m$. Depending on the wire magnetization and their spatial arrangements, a number of magnetic energy profiles are realized, which are characterized by 2D minima located in the vicinity of wires.A camel-like energy minimum forms in the central plane between two microwires magnetized along a diameter (x-axis). In this case, a stable diamagnetic trap is possible at the height of about the wire radius as demonstrated in Fig. 1a.The microwires can be used as magnetic tweezers: two or more microwires located towards each other and magnetized along the length generate magnetic fields with strong spatial distribution. Thus, the magnetic energy of two wires located along their axis (z-axis) has a minimum in the central plane along the radius as shown in Fig. 1b. Thedesigned magnetic field sources are interesting for cell sorting and manipulation. A minimally invasive non-contact magnetic trapping method is proposed for controlling cell movement and targeted drug delivery, which may be used in cell therapy [4].The authors have obtained preliminary data on the potential use of permanent magnetic fields together with nanomaterials for cell death induction inJurkatcell line, without human peripheral blood mononuclear cells viability inhibition.

a) b)

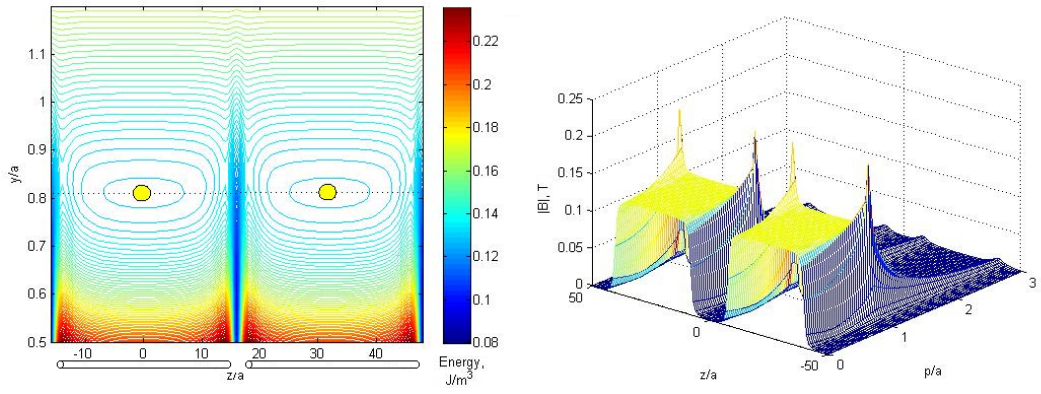


Fig.1. (a): Equipotential curves of the total energy (magnetic andgravitational)for a diamagnetic cell with the susceptibility $\chi = -10^{-5}$in the plane (x = 0) for a periodic system of microwires magnetized along a diameter. Parameters for calculation: wire radius $a = 7\ \mu m$, distance between the wires$d = 2a$,wire length $L = 16a$. The cell is captured by a magnetic trap over the micro wires. (b): The distribution ofmagnitude of magnetic field induction | B | from a pair of micro wires, with longitudinal magnetization.

[1]Yu X., He R., Li S. et al //Small 2013.9. No. 22. 3895–3901
[2] Wang H., Zhang X.// International Journal of Molecular Sciences2017. 18. № 2175
[3] Nguyen H. P., Vy T. H. // British Journal of Applied Science & Technology 2017. 7. № 10798
[4] M. Rubio Ayala, et al//Th. Simmet. Biomaterials. (2018) 163, 174

Level anti-crossing and transfer ofspin polarization in diamond

A. T. HALIKOV[a,*], A. I. IVANOV[a]

[a]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Ru

*ahalikov12@mail.ru

The nitrogen-vacancy (NV^-) centers in diamond have been a focus of recent research due to their promise as sensors of magnetic and electric fields, qubits that can be optically initialized and readout, fluorescent markers for biological systems. The NV^- center is uniquely suited for these applications due to its atom-scale spatial resolution and exceptional optical and spin properties over a wide range of operating temperatures. The optical transitions of the NV^- allow a high degree of spin polarization at room temperature via optical pumping. Recently [1], optically-pumped nuclear polarization of a diamond containing a high concentration of the NV^- centers has been demonstrated, however, the electron-nuclear transfer mechanism is not well understood. Through the combination of nuclear magnetic resonance(NMR) and optically detected magnetic resonance (ODMR) in ref. [1] shows that ^{13}C nuclei are polarized through multi-spin processes involving the electronic spin of the NV^-center and electronic and nuclear spins of the P_1 center.In ref.[1]it was noted that the field-dependence of the signal exhibits a non-trivial behavior. For example, it was found that even with a small change in the magnetic field, the sign of spin polarization changes.We investigate the effect of a NV- center and P1 center on the hyperpolarization of the nearest ^{13}C nucleus in a diamond single crystal placed in a magnetic field of ≈50 mT. The basis of the study is the calculation of the energy levels of the spin system in a magnetic field. To obtain eigenvectors and eigenvalues of the spin-hamiltonian, a method based on a complete set of commuting operators (CSCO) is used. This method is well known in quantum mechanics for a long time, but until recently [2] it has never been used in spectroscopy. In our approach, the spin-hamiltonian is considered as a CSCO operator. The CSCO eigenvectors are constructed using the principles of the quantum theory of angular momentum. Most of these vectors describe entangled spin states. It was possible to obtain analytical expressions for all the energy levels of the spin system under consideration. Within the framework of this approach, the properties of spin states are uniquely determined by CSCO, and each spin eigenvector is determined by a unique set of CSCO values. In a magnetic field of ≈50 mT, the ground state level anti-crossing (GSLAC) plays an important role in analyzing the ground state of the system under consideration. The change in the properties of the spin states of the system at GSLAC is considered as a possible cause of the experimentally observed change in the polarization sign of the spin of the 13C isotope in diamond with an insignificant (0.2-0.3 mT) change in the magnetic field.

[1]. D. Pagliero *et all*, Phys. Rev. B 97, 024422 (2018).
[2]. A. A. Talatay, A. I. Ivanov, A. T. Halikov.IEEE Xplore, **19 F,** 3086 (2018).

3D printing of NdFeB bonded magnets

FANG YANG [a], ZHIMENG GUO [a, *], JUNJIE HAO [a], XUEXU GAO [b], YANLI SUI [b]

[a]Institute for Advanced Materials and Technology, University of Science and Technology Beijing, Beijing 100083, China

[b]State Key Laboratory for Advanced Metals and Materials, University of Science and Technology Beijing, Beijing 100083, China

*zmguo@ustb.edu.cn

Due to their excellent advantages in minimizing post-manufacturing processing wastes while using smaller quantities of the RE materials [1,2], demands for NdFeB bonded magnets are expected to substantially increase in the clean energy industry. Nevertheless, there are still some drawbacks of the conventional fabrication techniques used for bonded magnets, such as specific tooling requirements for each design and limitations in shape flexibility and complexity [3,4]. Therefore, additive manufacturing (AM), also known as 3D printing, is well-suited to fabricate NdFeB bonded magnets [5]. To date, AM printing of magnets is still in its infancy. Although some related studies have been carried out [6-7], the as-printed magnets exhibit relatively low density. Besides, poor thermal stability still limits their further applications at elevated temperatures. Therefore, it is of interest to 3D print hybrid bonded magnets with a mixture of NdFeB and $SrFe_{12}O_{19}$. Due to the positive coercivity temperature coefficient β of pure $SrFe_{12}O_{19}$ magnets, the hybrid magnets exhibit considerably lower β compared with pure NdFeB magnets [8].

In this study, complex-shaped NdFeB bonded magnets with $SrFe_{12}O_{19}$ addition have been prepared by 3D printing. The prepared NdFeB slurries with ferrite addition were deposited to form shaped parts using a 3D printer. Highly loaded pseudo-plastic printing slurries were employed to print bonded magnets with 98% of theoretical density.In the printed magnets with 20 wt.% $SrFe_{12}O_{19}$, good dimensional accuracy and surface quality were obtainedwith a relatively low surface roughness of ~6 μm. In addition, good coalescence without obvious defects or pores was observed, and the ultimate tensile strength was 12 MPa. The magnetic properties of the hybrid magnets decreased with the increase of $SrFe_{12}O_{19}$ content due to a lower volume fraction of the NdFeB powder and lower magnetic performance of the $SrFe_{12}O_{19}$ powder. Nevertheless, the β value increased from -0.4%/°C to -0.2%/°C with the $SrFe_{12}O_{19}$ content increase to 20 wt.%, indicating better thermal stability of hybrid magnets. The proposed method of fabricating NdFeB bonded magnets significantly reduces the manufacturing cost of complex-shaped magnets, enables efficient utilization of rear earth elements and broadens elevated operating temperature applications.

[1] J. Ormerod, J. Appl. Phys. 81, 4816 (1997)
[2] I.C. Nlebedim, J. Magn. Magn.Mater. 422, 168 (2017)
[3] L. Li, Sci. Rep. 6, 36212 (2016)
[4] M.P. Paranthamn, JOM. 68, 1978 (2016)
[5] L. Li, Scr. Mater. 135, 100 (2017)
[6] B.G. Compton, Mater. Manuf. Process. 33, 109 (2018).
[7] L. Li, J. Magn. Magn.Mater. 438, 163 (2017) 163
[8] M. Dospial, J. Magn. Magn.Mater. 330, 152 (2013)

Grain growth and magnetic properties of HDDR Nd-Fe-B strip cast

BIN MA [a], XIAOQIAN BAO [a,*], GUANGHUA YU [b], ZHIMENG GUO [c], JUNJIE HAO [c]

[a]State Key Laboratory for Advanced Metals and Materials, University of Science and Technology Beijing, Beijing 100083, China

[b] School of Materials Science and Engineering, University of Science and Technology Beijing, Beijing 100083, China

[c]Institute for Advanced Materials and Technology, University of Science and Technology Beijing, Beijing 100083, China

* bxq118@ ustb.edu.cn

The coercivity of Nd-Fe-B magnet is deeply influenced by various microstructural features, such as grain size and Nd-rich grain boundary (GB) layers, that rely heavily on the memory of Nd-Fe-B magnetic powders. Hydrogenation- disproportionation-desorption-recombination (HDDR) is a process to prepare Nd-Fe-B particles with ultrafine equiaxed $Nd_2Fe_{14}B$ grains. So it is a practicable method to enhance coercivity from the viewpoint of improving Nd-Fe-B magnetic powder by taking advantage of equiaxed grain of HDDR process[1]. However, the grain size of HDDR equiaxed grain, less than 1um, is too small for the preparation of sintered Nd-Fe-B magnets.

We investigated the grain growth and magnetic properties of $Nd_{30.17}Fe_{68.87}B_{0.96}$ (wt%) SC alloy after HDDR process. Fig.1 presents SEM images of (a) fractured surface of HDDR alloy, (b) hydrogen decrepitated powders and (c) corresponding J-H curve. Seen from Fig.1 (a), the HDDR alloy exhibits uniform microstructure of equiaxed grain with average grain size of 2.03μm that reaches the maximum ever reported. In Fig.1 (b), hydrogen decrepitated powders are intergranular fractured and Nd-rich grain boundary phase presents on the surface. The residual magnetization (Mr) and coercivity (H) of corresponding Nd-Fe-B SC alloy is about 71.8 emu/g and 4730 Oe according Fig.1 (c). One reason for the decreasing coercivity is the incomplete cover of Nd-rich grain boundary layers that makesexchange coupling between $Nd_2Fe_{14}B$ grains.

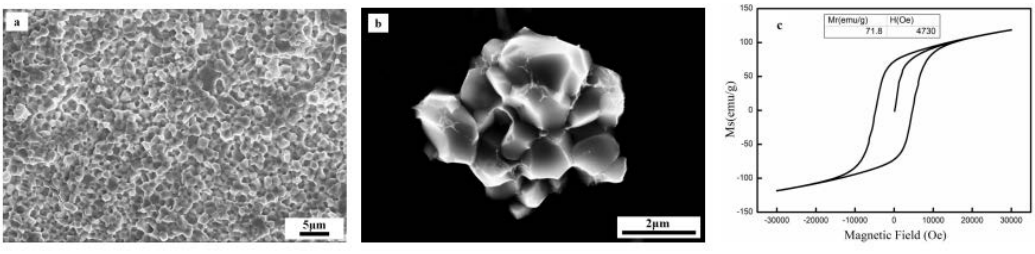


Fig 1. SEM images of (a) fractured surface of HDDR SC alloy, (b) hydrogen decrepitated powders and (c) corresponding J-H curve.

[1] M. Nakamura, M. Matsuura, M. Sagawa, et al, Appl. Phys. Lett.103(2013) 022404.

Hydrostatic pressure effects on magnetic transition andmagnetocaloric effect in $Ho_{0.6}Er_{0.4}Co_2$ alloys

J.Z. Hao[1,2], J. He[*1], F.X. Hu[2,3], J. Wang[2.3], J.R. Sun[2,3], and B.G. Shen[2,3]

[1]Division of Functional Material Research, Central Iron and Steel Research Institute, Beijing 100081, China

[2]Beijing National Laboratory for Condensed Matter Physics & State Key Laboratory of Magnetism, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, P. R. China

[3]School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100049, P. R. China

*hejun@cisri.com.cn

A large magnetocaloric effect (MCE) and negative thermal expansion behavior have been observed in compounds of RCo_2 (R: rare earth) recently [1, 2], evoking a far reaching interest. For $HoCo_2$ compounds, the magnetic ordering transition is accompanied by a volume change of -0.27% on heating due to the magnetic-structural coupling at T_C . The variation of interatomic distances could affect the intersublattice exchange coupling between Ho and Co.

Here, we investigate the effect of hydrostatic pressure on magnetic transitions and MCE in $Ho_{0.6}Er_{0.4}Co_2$ compound. Fig.1a presents M-T curves measured at 0.5T under different pressures. A spin reorientation transition (T_{SR}=44 K) and a successive transition from ferrimagnetic to paramagnetic phase (T_C=59 K) are observed on heating at ambient pressure. T_{SR} keeps almost unchanged because the cell volume maintains during the spin reorientation. The thermal hysteresis around T_C broadens with increasing pressure but the magnetic hysteresis remains almost zero even a high pressure was applied (Fig.1c, d). This interesting result implies novel mechanism. The calculated magnetic entropy change (ΔS_M) based on magnetization data exhibits an increase of maximum ΔS_M from 22.1 to 25.7 J/kg K with the pressure increasing from 0kbar to 11.08kbar (Fig. 1b), which is mainly due to the increase of pressure-induced lattice entropy. Furthermore, the effective refrigerant capacity (zero hysteresis loss) increases by 12%, from 299.7 (0kbar) to 334.8 J/kg (11.08kbar)

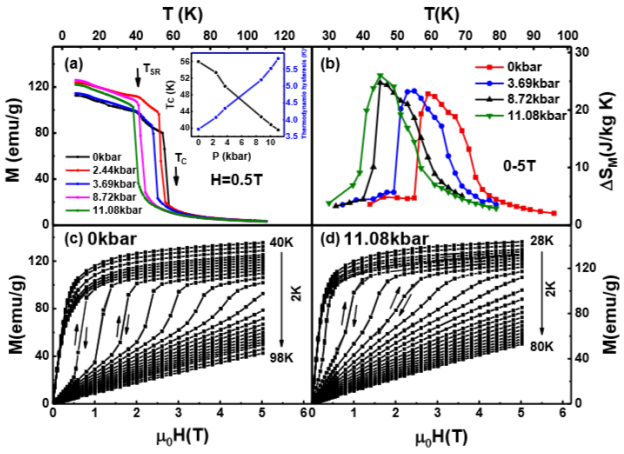


Fig.1. (a) M-T for $Ho_{0.6}Er_{0.4}Co_2$ under 0.5T. The inset shows the pressure dependent T_C and thermal hysteresis (b) ΔS_M-T under different pressures; Magnetization isotherms around T_C under pressure of References:(c)0kbar and (d)11.08kbar

[1]Herrero-Albillos, J. et al. Phys. Rev. B. **73**, 134410 (2006)
[2]Song, Y. et al. JACS. **140**, 602–605 (2018)

Enhancement of magnetocaloric effect driven by hydrostatic pressure in HoCuSi compound

J.Z. Hao[1,2], F.X. Hu[1,3], J. He[*2], N.Tang[1], X.Y. Yin[1], J.R.Sun[1,3] and B.G. Shen[1,3]

[1]Beijing National Laboratory for Condensed Matter Physics & State Key Laboratory of Magnetism, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, P. R. China

[2]Division of Functional Material Research, Central Iron and Steel Research Institute, Beijing 100081, China

[3]School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100049, P. R. China

*hejun@cisri.com.cn

The hexagonal Ni_2In-type HoCuSi is an attractive candidate for low temperature magnetic refrigerant. Previous neutron powder diffraction (NPD) studies demonstrated that HoCuSi undergoes a magnetic transition from AFM to PM states at T_N=7 K, accompanied by a positive lattice expansion, but the AFM coupling is not robust and transforms into ferromagnetic ordering at 0.2T [1]. NPD also revealed that the small change in atomic distribution of Cu/Si atoms.

Here, we study the effect of hydrostatic pressure on magnetic properties and MCE in this compound. Fig.1a displays M-T curves at 0.2T field under different pressures. One can see that the magnetization at low temperature increases greatly with increasing pressure, indicating a pressure-induced magnetic ordering conversion. Similar behavior is also observed in isothermal magnetization measurements at 5K (Fig.1b). The magnetization at 5T increases significantly after applying pressure to 8.97 kbar, indicating a remarkable enhancement of the ferromagnetic coupling between Ho moments. The magnetic entropy change (ΔS_M) was also calculated according to Maxwell relation (Fig.1d) at different field changes.

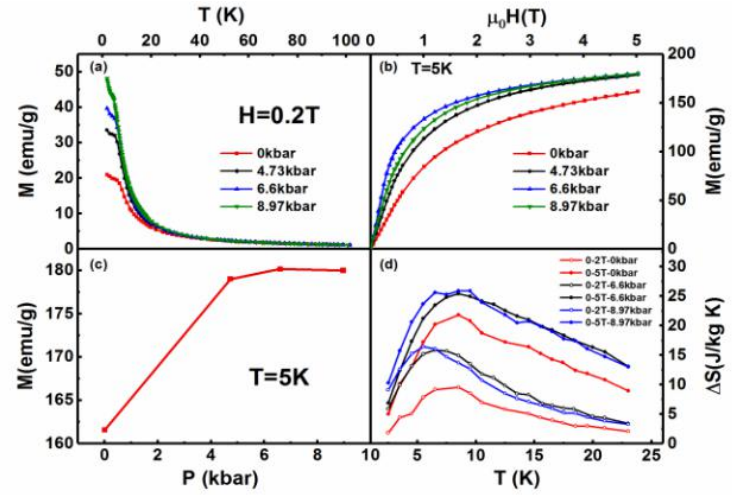


Figure1(a) M-T for HoCuSi under 0.2T (b) M-H measured at 5K under different pressures (c) Pressure dependence of magnetization at 5T (d) Temperature dependences of ΔS_M under different pressures for the field changes of 0-2T and 0-5T

[1]. Chen, J., et al. Appl. Phys. Lett. 96, (2010).

Magnetic particles in biological objects and the possibility of their non-invasive registration

L.P. ICHKITIDZE[a,b*], M.V. BELODEDOV[c], S.V. SELISHCHEV[a], D.V. TELYSHEV[a,b]

[a]National Research University of Electronic Technology, Zelenograd, Moscow, 124498 Russia

[b]I.M. Sechenov First Moscow State Medical University, Moscow, 119435 Russia

[c]Bauman Moscow State Technical University, Moscow, 105005 Russia

*ichkitidze@bms.zone

Weak magnetic fields in the human body are indicated by life processes in the body, as well as by ferromagnetic particles that are captured or intentionally introduced into it. Indeed, micron-, submicron and nanoscale magnetic particles (MP) are widely used in medical practice, for example, to: improve the contrast of magnetic resonance imaging (MRI), diagnose and treat cancer, targeted drug delivery to certain organs, etc. In particular, spherical MPs coated with active substances are used to isolate DNA and RNA from biological materials. In this case, the nucleic acid is stored with MP much longer than in their absence. The magnetization *J* of the MP is more than ten million times greater than the *J* of the medium in the MRI method, so the MP will create a new type of tomograph, the so-called MPI. Apparently, it will work with a small magnetic field several mT [1].

We conducted estimates of the minimum concentration and the minimum size of magnetic particles, within which modern ultra-sensitive magnetic field sensors (MFS) can register them.

Calculations showed that magnetite MPs with a specific magnetization $100\,\mathrm{A\times m^2/kg}$ with characteristic dimensions of 50 nm and concentration $C_V \geq 0{,}1\,\mathrm{vol.\%}$ can be detected at a distance of ≤ 0.1 mm from the magnetoresistive MFS type HMR1001 (Honeywell) [2]. It is assumed that the MFS type HMR1001 has a low threshold sensitivity $\delta B \geq 10^{-9}$ T. However, it is very likely that the same MPs will be detected using SQUID or combined MFS with an operating temperature of ~ 4 K. These sensors are assumed to be $\delta B \geq 10^{-15}$ T and will be at a distance of $\leq$ 1cm from MP. These sensors also have the potential to record individual MPs of spherical shape with micron sizes.

It is noted that superparamagnetic particles of iron or carbon nanotubes (CNTs) can also be detected only with SQUIDs or combined magnetic field sensors [3-5]. It is believed that CNTs may contain particles of catalytic iron, or encapsulated nanoparticles in nanotubes.

Thus, modern supersensitive magnetic field sensors with $\delta B \geq 10^{-15}$ T will allow magnetic particles to be recorded in nano-, submicron- and micron sizes in biological objects. They can be used for non-invasive control of organs, implants, prostheses and vector drug delivery in the right parts of the body. Particularly important is the non-invasive control of carbon nanotubes in functional biocompatible nanomaterials, which have good prospects for widespread use in medical practice [6,7].

[1] E.U. Saritas, P.W. Goodwill, L.R. Crofr et al. J. Magn. Reson. **229**, 166 (2013)
[2] https://www.terraelectronica.ru/product/41270
[3] D. Robbes. *Sensors and Actuators A*, **129(1),** 86 (2006)
[4] M. Pannetier-Lecoeur, C. Fermon, H. Dyvorne, et al. J. Mag. Magnet. Materials., **322,** 1647 (2010)
[5] L. P. Ichkitidze, A.N. Mironyuk. Physica C, **472(1)**, 57 (2012)
[6] A.Yu. Gerasimenko, L.P. Ichkitidze, A.A. Pavlov, et al. Biomed. Engin., **49(6),** 344 (2016)
[7] A.Yu. Gerasimenko, L.P. Ichkitidze, V.M. Podgaetsky, S.V. Selishchev. Biomed.l Engin., **48(6),** 310 (2015)

Fractal Dimension of Infinite Normal Clusters in Ceramic Superconductors

L. ICHKITIDZE[a,b*], S. SELISHCHEV[a], D. TELYSHEV[a,b]

[a] National Research University of Electronic Technology, 124498, MIET, Zelenograd, Moscow, Russia

[b] I.M.Sechenov First Moscow State Medical University,119435, Moscow, Russia

***** ichkitidze@bms.zone, leo852@inbox.ru

The pattern of the penetration of an external magnetic field and the formation of a resistive state in high-temperature ceramic superconducting (HTSC) materials is rather complicated and, apparently, has not been fully investigated. For its better understanding of separate interest may be the investigation of the resistive state in high-temperature ceramic superconducting (HTSC) materials when they contain both superconducting and normal phases as fractal normal clusters in the form of open pores. Ceramic HTSC materials have a granular structure and can contain numerous inhomogeneities, in particular, at the boundaries of the granules in the form of Josephson junctions, inside the granules as various inclusions of normal or low-temperature superconducting phases, or inside the granules or in the space between the granules in the form of open and closed pores. The pores in the space between the granules can connect, i.e. they can become the open ones and form fractal normal clusters. In this regard, this paper deals with the effect of fractal normal clusters on the resistive state in ceramic HTSC materials.

The objects studied were massive and thick-film samples of ceramic HTSC material of composition Bi-2223. They were obtained according to the classical ceramic technologic conditions: annealing temperature - 850°C, annealing time – 40 h. The dependence $U(I)$ (U is the measured voltage, I is the transport current) was recorded by the standard four-probe method in the mode of a given current. The samples had guide massive dimensions: length (distance between potential contacts) l ~ 6.0 mm, width w ~ 1.5 mm, thickness d ~ 0.5 mm; thick films l ~ 3.0 mm, w ~ 1.5 mm, d ~ 0.05 mm, respectively. The values of critical current density and resistivity were determined with due regard to geometrical dimensions (l, w, d) of the samples.

The proposed method and algorithm for determining the fractal dimension D of the surfaces of porous ceramic materials is implemented on a PC in Borland C ++ Builder environment and tested while processing raster electron microscopic pictures of surfaces of the ceramic Bi-2223 material. The method was more precise and effective in calculating of D as compared with other procedures.

The following D values were measured for infinite normal clusters: a massive sample ~ 1.47; thick film sample ~ 1.73. Apparently, higher values of D in thick-film than those in massive samples may be attributed to technological circumstances and the formation of numerous pores in it. The $U(I)$ curves had nonlinearity characteristic for ceramic HTSC materials. The nonlinearity parameter $\alpha = \Delta(\ln(U))/\Delta(\ln(I))$ varied from I and assumed the highest value for a massive sample α ~ 6.1, whereas for a thick-film sample – α ~ 1.5. The differential resistance $R_d = dU/dI$ in the vicinity of the critical state (i = 1) differs: in the case of i > 0.85 it decreases and in the case of i < 0.85 the value of R_d increases depending on D.

The result obtained is to be used to develop a sensor of an ultra weak magnetic field sensor based on the magnetoresistive effect, when the material with high α and R_d values is required. It is expected that such magnetic field sensors will have a threshold sensitivity of ≤100 pT and will be promising in biomedical diagnostics.

This study was supported by the Russian Science Foundation, project No.18-79-10008.

Surface Magnetic Barrier Clusters in Superconducting Niobium Films

L. ICHKITIDZE[a,b]

[a] National Research University of Electronic Technology, 124498, MIET, Zelenograd, Moscow, Russia

[b] I.M.Sechenov First Moscow State Medical University,119435, Moscow, Russia

***** ichkitidze@bms.zone, leo852@inbox.ru

The free penetration of magnetic field B into the interior of the superconductor is impeded by the magnetic barrier that exists on its boundary. A typical barrier is the so-called Bin-Livingstone magnetic barrier (MB) arising due to the interaction between the Abrikosov magnetic vortex located near the boundary of a type II superconductor and its mirror image located near the outer boundary of a superconductor. The type II film superconductors have a boundary MB arising either on their surface (SMB) in a parallel magnetic field $B_{\|}$, or on the edges (EMB) in a perpendicular magnetic field. Both SMB and EMB can strongly influence the value of the critical current I_c and its dependence on the external magnetic field $I_c(B)$.

In this connection, the dependence of I_c on B, parallel to the surface of niobium (Nb) films, having different degrees of structural perfection and width w, has been studied.

Samples were monocrystalline (heteroepitaxial layers, HEL) and polycrystalline (PC) Nb films on sapphire. Films were deposited by condensation from molecular beams in an oil-free 5×10^{-5} Pa vacuum onto sapphire substrates with electron beam evaporation of Nb. The thickness of the films was ~ 80 ÷ 85 nm. The change in the superconducting parameters of the original HEL Nb films was achieved by irradiating the samples with helium ions (HEL/He^{2+}) or krypton (HEL/Kr^{3+}) with the energy of 36 keV at different doses.

It has been found that under certain conditions in a parallel magnetic field the magnitude of I_c is determined by the existence of SMB, as a result of which non-monotonic regions appear on the $I_c(B)$ dependences. They are recorded when coal between the surface of the film and $B_{\|}$ is in the region of 0÷8°.

It has been established that for all films, regardless of the degree of their structural perfection, the value of w is one of the parameters determining the possibility of the dominant influence of SMB on the type of $I_c(B)$ curves. For Nb films the upper limit of this possibility is the width $w \leq 250$ μm, at which the influence of SMB on $I_c(B)$ is reflected.

The presence or absence of MB traces (non-monotonic sections) on the $I_c(B)$ curves and their length also depends on the degree of structural perfection of the films and, as a consequence, on the degree of development of the growth microroughness of their surface.

This conclusion has been confirmed experimentally: in the films irradiated with He^{2+} and Kr^{3+} ions traces of the influence of MBs on $I_c(B)$ completely disappear despite the fact that they were strongly pronounced when they were not exposed to irradiation. At the same time, both in the HEL and in the PC, the I_c values did not change significantly.

The possibility of creating a high sensitive angle sensor (resolution $\leq$ 0.1 angular seconds, measurement dynamic range $\geq 10^5$ dB) based on the effect of a surface magnetic barrier in niobium films has been estimated.

The considered angular displacement sensor is promising for use in many systems, for example, in aerospace navigation or neurosurgical operations.

Magnetoelectric effect simulation in layered composites based on magnetic elastomers

D. ISAEV [a*], L. MAKAROVA[a,b], YU. ALEKHINA[a], M. KHAIRULLIN[a], N. PEROV[a,b]

[a]Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

[b]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

*isaev.danil@gmail.com

We present the computer model of the magnetoelectric effect in two-layer structure based on magnetorheological elastomer and piezoelectric PVDF layer. The effect is based on the assumption about the displacement of magnetic particles inside the elastic matrix under the external gradient magnetic field and the formation of chain-like structures. Such displacement causes magnetorheological layer deformation. This deformation leads to corresponding bending of PVDF layer, which results in induced voltage from the sample.

To calculate particle redistribution and corresponding bending of the system molecular dynamic approach was used. To calculate particles positions Verlet integration [1] was used. We considered dipole-dipole model for particle-particle interaction and “springs” [2] model for particle-matrix elastic interaction.

In the model the magnetorheological system consists of around 1000 iron particles which are considered as isotropic and anisotropic samples varying with concentration of magnetic filler, size and space distribution of particles, elastic properties of the matrix, linear dimensions of the sample.

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

Presented model can be used to study these novel functional materials, analyze their features and predict the optimal composition of such composites for further profound experimental study.

The reported study was funded by RFBR and Moscow city Government according to the research project No 19-32-70027

[1] Verlet, L. Computer "Experiments" on Classical Fluids. I. Thermodynamical Properties of Lennard-Jones Moleculess. Phys. Rev. 1967, 159, 98–103. doi:10.1103/PhysRev.159.98.
[2] Sánchez, P.A.; Gundermann, T.; Dobroserdova, A.; Kantorovich, S.S.; Odenbach, S. Importance of matrix inelastic deformations in the initial response of magnetic elastomers. Soft Matter 2018, 14, 2170–2183. doi:10.1039/c7sm02366a.

Magneto-optical images of the field of magnets under the action of an external field.

V. IVANOV

Ural Federal University, 620002, Mira street 19, Ekaterinburg, Russia

vladimir.ivanov@urfu.ru

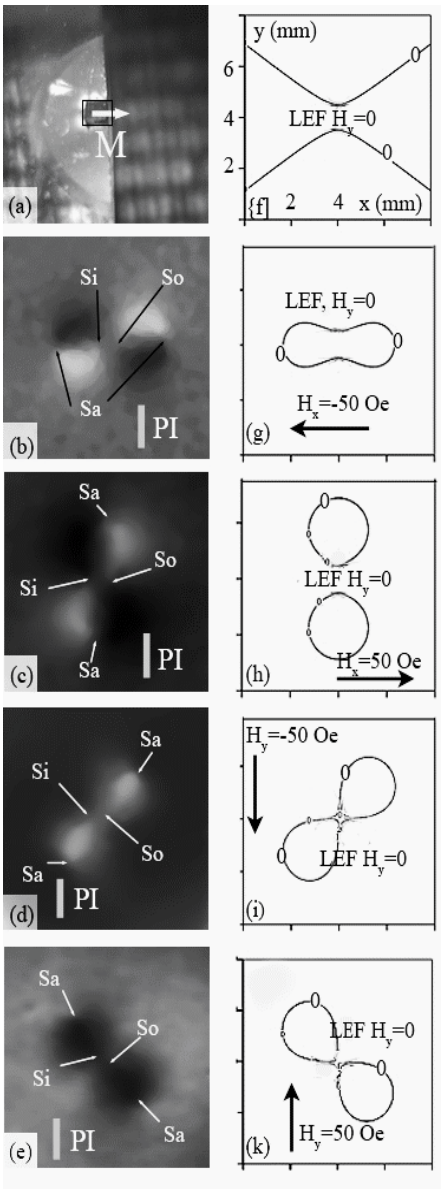


Fig.1. Top view of the magnet (a) and MOI in longitudinal sensitivity with different orientation of the external field in the plane (b, c, d, e). (f-k) lines of equal force (LEF). On LEF, H_y = 0. The orientation of the plane of incidence of light is shown by the line PI.

Simulation has shown that magneto-optical images (MOI) of the in-plane components of the inhomogeneous magnet field of magnets have characteristic features that reflect the mutual orientation of magnetic moment and the external uniform field [1].]. In this paper, it was proposed to conduct mapping of the plane component of the field by fixing the coordinates of the singular points of the MOI.

In our work, characteristic configurations of MOIs of the inhomogeneous field of the magnets in the geometry of the longitudinal Kerr effect are determined when an external uniform field is applied. FAINMET films with low coercive force and anisotropy field were used as the magneto-optical medium.

МОИ of fields of a magnet with imposing an external uniform field have a structure similar to a graph (lines of equal force, on which H_y=0 (Fig. 1). The singular points of the MOI correspond to the special points of the superposition of the plane field of the magnet and the external homogeneous field. They are implemented at the intersection of the LEF H_x = 0 and H_y = 0.

In the absence of an external field, singular points of the “source” (So) and “sink” (Si) type are realized. The imposition of an external field leads to the appearance of singular points of the saddle type (Sa) (Fig. 1b, e).

The field action along the X axis (parallel to the magnet texture axis) forms the MOI in the form of a two-petal eight lying on its side (Fig. 1b). A change in the sign of this field forms a figure eight whose axis is oriented perpendicular to the texture axis (Fig.1c). An external field oriented perpendicular to the texture axis forms two-lobe figures with axis orientation at an angle to the texture axis (Fig. 1 d, e).

[1] V. E.Ivanov, Journ. Magn.Magn.Mater.**401,** 200 (2016)

Colloid-SEM method for the investigation of magneticdomain structures

A.I. Ivanova*, R.M. Grechishkin, E.M. Semenova, O.V. Zhdanova,

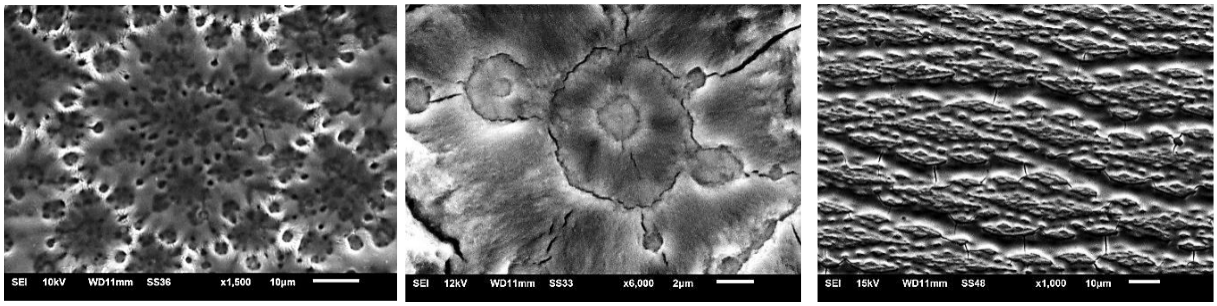
T.V. Rostova

Tver State University, 170100, Zhelyabova st. 33, Tver, Russia

*alex.ivanova33@yandex.ru

In this paper we present colloid-SEM method for study of the domain microstructure of massive and thin-film magnetic materials. It is known that magneto-optical methods of visualization of magnetic domains have certain advantages in comparison with the Bitter-pattern technique. In the case of the study of magnetic domains by the colloid -SEM method, it is possible to visualize small domains that are not resolved by optics and obtain an image of the magnetic structure on unpolished samples. The results of this method and its modifications are described in the works of D.J.Craik, K.Goto, J.Simsova and W.Szmaja [1-4]. We present new version of colloid-SEM technigue.

At the first we made a colloid based on magnetic fluid (diameter of magnetite particles - 10 nm) and sodium carboxymethylcellulose for creating a homogeneous, thin and durable film that doesn□t destroys by the electron beam in the microscope. Next, we dried the colloid on the sample surface and observed domain boundaries by a scanning electron microscope (SEM) in the secondary and backscattered electron mode. Figure 1a shows domains like stars visualized in the basal plane of single crystal Y_2 $(Fe_{0,5}Co_{0,5})_{17}$. Within the large domains there are microdomains 1-2 □m in diameter. Figure 1b shows the domains at higher magnification; the shape of the domains is characteristic of hexagonal crystals.The SEM-image of rhombic domains characteristic of the basal plane of FeB orthorhombic crystal is presented in Figure 1c.



a *b* *c*

Figure 1. SEM-images of domains

As a result of research, the domain structure of such samples as polycrystalline alloys$Nd_2Fe_{14}B$, Co_3B,$DyFe_{11}Ti$ and $HoFe_{11}Ti$, single crystals$Y_2(Fe_xCo_{1-x})17$, SmCo, bismuth-substituted ferrite–garnet films is visualized. The experiment was carried out with the help of magnetic fluids based on water and kerosene basis. Using the colloid-SEM method allows to complement and develop experimental magneto-optical studies of the magnetic domain structure.

DJ. Craik, J. Appl. Phys. 38, 931 (1967)
K.Goto, T.Sakurai, Jap.J.Appl.Phys. 19,1339 (1980)
J.Simsova, M.Simeckova, R.Gemperle, Czech. J.Phys. 35, 1282 (1985)
W.Szmaja, J.MMM. 301,546 (2006)

Features of the surface morphology and magnetic properties of the (Sm,Gd)Fe_2 with Laves phase structure

T. KAMINSKAYA [a], G. POLITOVA [b,c*], A. KARPENKOV[d], M. GANIN[b]

[a]Lomonosov Moscow State University, 119991, Moscow, Russia

[b]BaikovInstituteofMetallurgyandMaterialsScienceRAS,119334Moscow,Russia

[c]PetertheGreatSt.PetersburgPolytechnicUniversity,195251St.Petersburg,Russia

[d] Tver State University, 170002, Tver, Russian Federation

*gpolitova@gmail.com

In recent years, the interest of the world scientific community to the study of alloys with the structure of Laves phases of the RFe_2 type (where R is a rare earth metal) has resumed [1,2]. These alloys are an important family of magnetic materials that exhibit large values of anisotropic magnetostriction and are used in devices such as drives and sensors operating in different environments and in a wide temperature range.

In this work, we studied the alloys $SmFe_2$ and $GdFe_2$, obtained in the single-phase state of high purity by the method of induction melting. Magnetic studies were carried out in the temperature range from 100 to 320 K. The magnetization of the polycrystalline $SmFe_2$ and $GdFe_2$ samples were investigated by the induction method in magnetic fields up to 1.8 T, while the magnetostriction was investigated by the strain gauge method in magnetic fields up to 1.2 T. Atomic force and magnetic force microscopy methods was used to study the surface features of the alloy. The studies were carried out on the polished surface of the samples using a SMENA-A scanning probe microscope (Solver platform, NT-MDT CJSC, Russia) at room temperature. The presence of heterogeneous granular structure was revealed, the main structural elements were determined. The average diameter of the structural elements was determined from the image obtained by the phase contrast method using the Nova_Px_2.0 Grain Analysis program and was 0.52 μm. The large structural elements are made up of smaller grains (40 to 60 nm).

It is known that the presence of stresses in a sample due to the growth conditions of single crystals, their mechanical processing or the inclusion of foreign phases can lead to changes in the magnetocrystalline anisotropy in different parts of the samples, in particular, in a thin surface layer. Thus, several types of domain structure were observed on the surface of polished $GdFe_2$ section. In some areas revealed the absence of a magnetic structure. Studies of the surface of the polished $SmFe_2$ section show the presence of a pronounced domain structure of a rather complex shape, consisting of islands with sizes from 6 to 12 μm and stripes ranging from 3 to 5 μm wide [3].

The study was supported by the Russian Foundation for Basic Research (project no. 18-03-00798_a).

[1] N.J. Wang, Y. Liu, H.W. Zhang, X. Chen, Y.X. Li. China Foundry. 13, 2 (2016) 75- 84.
[2] W.J. Ren, Z.D. Zhang. Chin. Phys. B. 22, 7, (2013) 077507.
[3] G.A. Politova, A.Yu. Karpenkov, T.P. Kaminskaya, M.A. Ganin, Ravi Kumar, A.V. Filimonov, St. Petersburg Polytechnical State University Journal. Physics and Mathematics. 12 (1) (2019) 28–38.

Optical spectroscopic study of 2D frustrated magnet $Cu_3Er(SeO_3)_2O_2Cl$

S.A. KLIMIN[a,*], E.S. Kuznetsova[b], P.S. Berdonosov[b]

[a]Institute of Spectroscopy RAS, 108840, Fizicheskaya5, Troitsk, Moscow, Russia

[b]Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

*klimin@isan.troitsk.rul

Natural mineral francisite $Cu_3Bi(SeO_3)_2O_2Cl$ have been recognized to be an interesting model compound for studying two-dimensional (2D) magnetismwith frustrated interactions inside copper layers [1]. Its synthetic rare-earth (RE) counterparts, $Cu_3RE(SeO_3)_2O_2Cl$,has demonstratedinteresting interplay between magnetic anisotropies of copper and RE magnetic subsystems, leading to spin-reorientation transitions in the cases of *RE* = Sm and Yb [2,3]. In this work, another member of the family, $Cu_3Er(SeO_3)_2O_2Cl$, is studied by the optical spectroscopy of *f-f* transitions.

The transmission spectra were measured using BRUKER IFS125HR spectrometer. Colling of KBr+$Cu_3Er(SeO_3)_2O_2Cl$ pelletswas performed with the helium closed-cycle optical cryostat with CRYOMECHPT403pulse tube system.

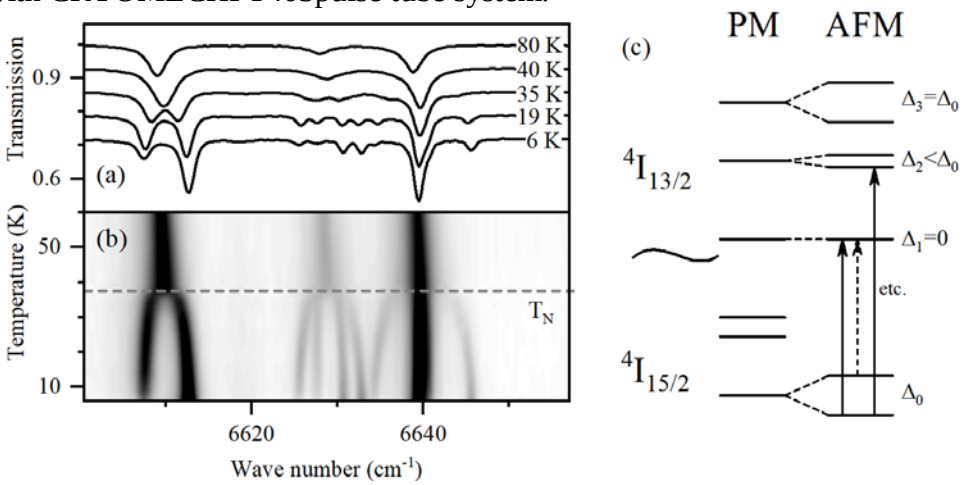


Fig. 1. (a) Transmission spectra of $Cu_3Er(SeO_3)_2O_2Cl$ in the region of the lower-frequency part of the $^4I_{13/2}$multiplet of Er^{3+} ion at various temperatures and (b) corresponding black-white map. (c) Energy level scheme for paramagnetic (PM) and antiferromagnetic (AFM) states.

The transmission spectra of $Cu_3Er(SeO_3)_2O_2Cl$ are shown in Fig. 1 together with a black-white map. Three low-energy crystal field transitions of the $^4I_{13/2}$multipet of Er^{3+} ion are shown. At the temperature T_N=37 K spectral lines split due to the magnetic ordering of a sample. The effective magnetic field acting on Er^{3+} ions splits their Kramers doublets according to the scheme given at Fig. 1c. The analysis of the data obtained enabled us (i)to conclude that the single-ion anisotropy of Er^{3+} ion reinforces magnetic structure of the copper magnetic subsystem, (ii) to extract the splitting of the ground Kramers doublet $\Delta_0(T)$ as a function of the temperature, (iii) to evaluate the erbium contribution into the heat capacity and magnetic susceptibility of $Cu_3Er(SeO_3)_2O_2Cl$.

The support of RFBR (grant № 19-02-00251) is acknowledged.

[1]Pregelj M.; et. al., *Phys. Rev. B***2012**, 86, 144409.
[2] Zakharov K.V.et. al.,*Phys. Rev. B***2016**, 94 (5), 054401.
[3] Markina M.M.; et. al.,*Phys. Rev. B***2017**, 96 (13), 134422.

Features of the magnetization reversal processes of amorphous microwire ensembles

A. KOMLEV[a,*], N. PEROV[a], V. BAUTIN[b], N.Usov[b]

[a]Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

[b]National University of Science and Technology "MISiS", Leninskiy Prospekt 4, Moscow, 119049, Russian Federation

*alkomlev98@yandex.ru

Amorphous microwires are of great interest from the point of view of practical applications. Due to the amorphous structure, the magnetoelastic anisotropy and magnetic anisotropy of the shape are considered as the main factors determining their hysteresis magnetic properties. Microwires have a number of effects that are used in various areas. These effects include magnetic bistability used in coding, logic, and memory systems, magnetoimpedance effect used in high-performance sensors shape memory and magnetocaloric effects for magneto-mechanical actuators [1-3].

The proximity of several microwires to each other can lead to the appearance of a magnetostatic connection between them. This fact can significantly affect the magnetic response of the arrays of wires, since their properties will be determined not only by the contributions of individual wires, but also by their interaction. In this case, their total magnetic response will depend on the magnetic field created by each element.

In this work, we considered the arrays of microwires, which consisted of elements of different composition (Fe-, CoFe-based), diameter and differed in their distribution in the composite. The process of magnetization reversal of the bundle of microwires was compared with the process of magnetization reversal of a single wire.

Experimental data were obtained using a VSM LakeShore 7404 vibration sample magnetometer. Hysteresis loops were obtained for samples in different magnetic field ranges (maximum field - 500 Oe, 5 kOe, 16 kOe) and for different orientations of the magnetic field relative to the sample axis (0, 15 ˚, 30˚, 45˚, 60˚, 75˚, 90˚).

Based on the data obtained for each sample, the dependences of the coercive force on the orientation of the microwires relative to the magnetic field were obtained. The experimental data were compared with the theoretical dependence for the case of the magnetization reversal of a single-domain ellipsoidal particle. Based analysis of the results of the magnetization reversal processes in various samples, it was concluded that there are various magnetostatic bonds in the samples Fe- and Co-based. It is interesting to note that in the process of magnetization reversal of the arrays of microwires, a bistable behavior was not observed, in contrast to a single microwire.

It is assumed that the study of the influence of the configuration of a bundle of microwires on its magnetic properties will allow the composite to be compiled in accordance with predetermined parameters.

The authors wish to acknowledge the financial support of the Ministry of Science and High Education of the Russian Federation in the framework of Increase Competitiveness Program of NUST «MISIS», contract № K2-2019-012.

[1] I. Baraban et al., The role of structural properties on magnetic characteristics of glass-coated microwires , Journal of Magnetism and Magnetic Materials 459, 61–65, (2018)

[2] V. Rodionova et al., Tailoring of Magnetic Properties of Magnetostatically-Coupled Glass-Covered Magnetic Microwires, Supercond Nov Magn, 24, 541–547, (2011)

[3] V. Rodionova et al., Spectral properties of electromotive force induced by periodic magnetization reversal of arrays of coupled magnetic glass-covered microwires, J. Appl. Phys., 07E735, 111, (2012)

SPIONs covered with enzyme substrates for fluorescent tracking of nanoparticles distribution

I. KOZENKOV[a,*], S. JOVANOVIC[b,c], M. VUKOMANOVIC[b], M. A. SHEVCHENKO[a], V. SKRIPSKAIA[a], E. KOZENKOVA[a], A. OMELYANCHIK[a], D. VENGUST[b], V. RODIONOVA[a]

[a]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[b]Advanced materials department, Jožef Stefan Institute, Ljubljana, Slovenia

[c]Laboratory of Physics, Vinca institute of nuclear sciences, University of Belgrade, Belgrade, Serbia

* IKozenkov@kantiana.ru

Superparamagnetic iron oxide nanoparticles (SPION) were synthesized by solvothermal method. SPIONs size distribution, morphology and phase composition was studied using transmission electron microscopy (TEM) and X-ray diffraction (XRD). According to results of analysis the magnetite phase formation was confirmed with size of crystallites smaller than 10nm. Magnetic properties were investigated by vibration magnetometry (VSM) at room temperature and an absence of the remanence and the coercivity was found that confirmed the superparamagnetic behavior of nanoparticles.

The magnetic core was covered with different organic compounds for specific activity as enzyme substrates (Fig.1). Coatings compounds were chosen so that the target substance was either represented in the cellular matrix or was a substrate for cell cycle enzymes for the purpose of low cytotoxicity [1]. The composition and temperature of destruction of the SPIONs shells were determined by the methods of FTIR spectroscopy, differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA).

These structures show tendency to agglomerate in culture mediums at physiological pH, however, are suitable for fluorescence tracking of SPIONs distribution on the bacterial cell wall due to enzymatic activity against substrates of the NP shell.

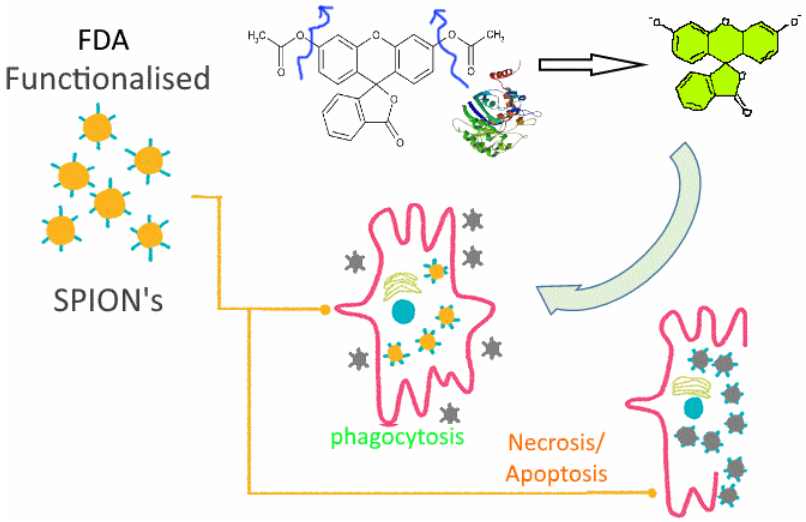


Figure 1. Fluorescein diacetate functionalized SPION's for specific esterase activity in live cell, from [2].

[1] L. Zhang, Chem. Res. Toxicol. 28, 1961-1974 (2015)
[2] O. Ptashnik, https://biomolecula.ru/specials/metody

Synthesis, characterization and antibacterial properties of Au-Fe_3O_4 heterostructed nanoparticles

E. Kozenkova[a,*] I. Kozenkov[a], M. A. Shevchenko[a], V. Skripskaia[a], Y. Nalench[b], M. Abakumov[b], K. Levada[a] , S. Pshenichnikov[a], A. Zyubin[a], I. Samusev[a], A. Omelyanchik[a], C. Sangregorio[c], C. Innocenti[C], V. Rodionova[a]

[a] Immanuel Kant Baltic Federal University, 236041, Kaliningrad, Russia

[b] National University of Science and Technology «MISiS», 119049, Moscow, Russia

[c] Institute of Chemistry of Organometallic Compounds – C.N.R., 50019 and Dept. of Chemistry, Univ. of Florence, Sesto Fiorentino, Italy

*ekozenkova@kantiana.ru

Heterostructed nanoparticles of gold and iron oxide (Au-Fe_3O_4) with dumbbell-like structure were synthesized by thermal decomposition method using different types of solvents [1]. The particles size and morphology were observed by Transmission Electron Microscopy (TEM) and ranged from 11 to 16 nm.

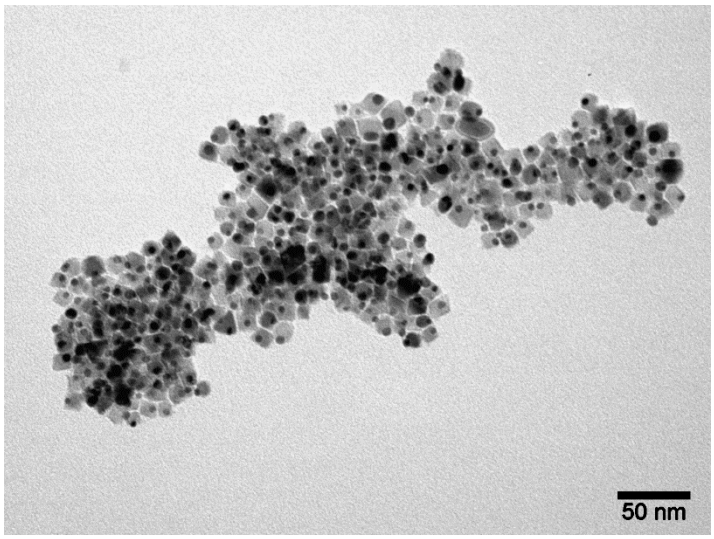


Fig. 1: TEM image of Au-Fe_3O_4 nanoparticles

The structure of the surface of particles was investigated with Raman spectroscopy, which showed it consisted of magnetite (Fe_3O_4) and hematite (α-Fe_2O_3). Magnetic properties were studied with a vibrating sample magnetometer (VSM). The temperature dependence of the magnetization in a small field of 50 Oe was measured for sample in two different initial states: 1) zero-field cooled (ZFC); 2) field cooled (FC). Observed maximum of ZFC curve and merging of FC and ZFC curves at ~130 K confirm transition from blocked to superparamagnetic states. The saturation magnetization of Au-Fe_3O_4 heterostructures was about 31 emu/g at 5 K and 24 emu/g at 300 K.

Nanoparticles were tested for the antibacterial activity in bacterial culture E coli. Additionally, the cytotoxic effect of nanoparticles was investigated in human hepatic cell line (Huh7). Cytotoxicity was assessed by WST-1 assay. Nanoparticles induced cell death in time and concentration dependent manner. However, the difference in cell death activation was not significant in basic working concentration (10 ug/ml).

[1] H. Yu, at al., Nano Letters. 5(2), 379 (2005)

Magneto-Polymer Coatings with a Magneto-TunableSurface Relief

E.YU. KRAMARENKO[a,b*], G.V. STEPANOV[a,c], B.O. SOKOLOV[a], S.A.KANTOROVICH[d,e], P.A. SANCHEZ[d], E.S. MININA[d],

[a]Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

[b]A.N. Nesmeyanov Institute of Organoelement Compounds of Russian Academy of Sciences, Moscow 119991, Russia

[c]State Scientific Research Institute of Chemistry and Technology of Organoelement Compounds, 105118, Moscow, Russia

[d]University of Vienna, Sensengasse 8, 1090, Vienna, Austria

[e]Ural Federal University, Lenin av. 51, 620000, Ekaterinburg, Russian Federation

*****kram@polly.phys.msu.ru

Development of materials with tunable surface properties is an important task of modern materials science.It is known that controlling the surface wettability and, in particular, achieving the effect of superhydrophobicity is associated with the formation of a hierarchical relief on the surface. In this work, we explore the possibility of creating tunable hydrophobic and superhydrophobic coatings based on the so-called magnetoactive elastomers (MAEs) whose structure and properties can be controlled by external magnetic fields [1].

MAEs consist of a soft polymer matrix filled with magnetic microparticles. When a magnetic field is applied to a MAE, magnetic particles within a soft matrix tend to form chain-like aggregates aligned with the field lines. It is some restructuring of the magnetic filler that causes considerable changes of MAE physical properties [1].Not only bulk but also surface properties of MAEs can be tuned by external magnetic field. If the magnetic field is perpendicular to the MAE film surface the magnetic chains can grow from the bulk material to its surface producing some mountain-type surface relief [2,3]. Magnetic-field induced roughness defines rather high values of the water contact angles on a MAE surface [2].

In this talk an introduction into the field of MAEs is first presented with a short review of MAE synthesis, composition, bulk properties being sensitive to external magnetic field as well as possible practical applications. Then the results of complex experimental and theoretical studies on the structure and wettability of thin layers of magnetoactive elastomers in external magnetic fields are shown. The main focus is on the effects of magnetic filler concentration and polymer matrix modulus on the surface structure and wettability in magnetic fields.

Acknowledgements: Financial support of the Russian Foundation for Basic Research (grant No. 16-29-05276) is gratefully acknowledged.

[1]M. Shamonin and E. Y. Kramarenko, Highly responsive magnetoactive elastomers. In: Novel Magnetic Nanostructures, Elsevier, 2018, pp. 221–245.
[2] V.V. Sorokin, B.O. Sokolov, G.V. Stepanov, E. Yu. Kramarenko, Journal of Magnetism and Magnetic Materials 459, 268-271 (2018).
[3] P.A. Sanchez, E.S. Minina, S.S. Kantorovich, E.Yu. Kramarenko. Soft Matter,15, 175 (2019).

Design of Novel Highly Elastic Matricesfor Magnetoactive Elastomers

E.YU. KRAMARENKO[a,b*], S.F. KOSTROV[a,b], V.V. GORODOV[c], A.M. MUZAFAROV[b,c]

[a]Lomonosov Moscow State University, Leninskie gory 1/2, 119991Moscow, Russian Federation

[b]A.N. Nesmeyanov Institute of Organoelement Compounds of Russian Academy of Sciences, Vavilova 28, 119991Moscow, Russian Federation

[c]N. S. Enikolopov Institute of Synthetic Polymer Materials, Russian Academy of Sciences, Profsoyuznaya 70, 117393 Moscow, Russian Federation

*****kram@polly.phys.msu.ru

Magnetoactive elastomers (MAEs) consisting of soft polymer matrices filled with magnetic nano- or microparticles belong to a class of so-called smart materials being able to change their physical properties in response to various external stimuli. In case of MAEs such stimulus is a magnetic field. When a magnetic field is applied to MAEs magnetic filler particles start to interact and if the matrix is soft enough these interactions can cause particle restructuring leading to a change in a number of physical properties of MAEs. In particular, MAEs demonstrate a huge increase of their elastic modulus [1].

To obtain a highly responsive MAE, one has to decrease the elastic modulus of the polymer matrix or to increase the saturation magnetization of magnetic filler because larger matrix deformations will be required to equilibrate the elastic and magnetic forces acting between magnetic particles. To make softer elastomers with a modulus lower than 10kPa solvents are usually employed. In case of silicone elastomers the solvent or plasticizer is silicone oil, in case of hydrogels it is usually water.

In this work we developed a new type of silicone-based elastomers whose modulus can be considerably decreased by using specially designed cross-links containing dangling chains.The presence of dangling chains dilutes the matrix causing a decrease of its elastic modulus without any low-molecular-mass additives. MAEs of various compositions (various concentrations of cross-linking agent and magnetic filler) were synthesized and their rheological properties have been studied depending on the strength of the external magnetic field. It has been shown that the initial modulus of the composite can be varied in the range of 2-50 kPa and the magnetic response of the obtained materials can reach two orders of magnitude in relatively low magnetic fields. The effect of the dangling chains on the viscoelastic behavior of both unfilled matrices and composites is discussed.

Acknowledgements: Financial support of the Russian Science Foundation (grant No. 19-13-00340) is gratefully acknowledged.

[1]M. Shamonin and E. Y. Kramarenko, Highly responsive magnetoactive elastomers. In: Novel Magnetic Nanostructures, Elsevier, 2018, pp. 221–245.

Magnetic and structural properties of $GdFe_{1-x}Ti_xSi$

A.G. KUCHIN[a,*], S.P. PLATONOV[a], V.S. GAVIKO[a,b], M.YU. YAKOVLEVA[a]

[a]M.N. Miheev Institute of Metal Physics of Ural Branch of Russian Academy of Sciences, 620108, 18 S. Kovalevskaya Str., Ekaterinburg, Russia

[b]Ural Federal University named after First President of Russia B.N. Yeltsin, 620002, 19 Mira Str., Ekaterinburg, Russia

*kuchin@imp.uran.ru

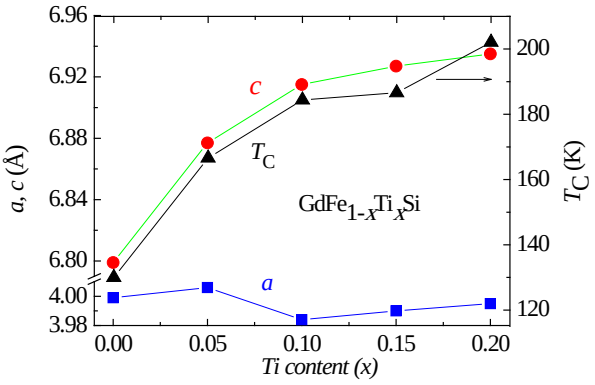


Figure 1. Concentration dependences of lattice parameters a (■), c (●) and Curietemperature T_C (▲) of $GdFe_{1-x}Ti_xSi$.

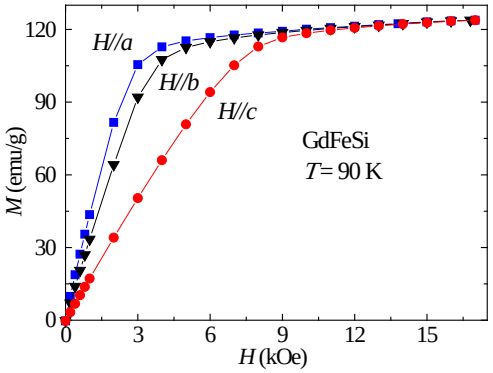


Figure 2. Magnetization curves measured along the a (■), b (▼), c (●) axes of the GdMnSi single crystal at T = 90 K.

The hybridization between Si *p* states and Fe 3*d* states causes the absence of the magnetic moment of Fe in the GdFeSi compound [1]. From this point of view, it is interesting to study magnetic properties of $GdFe_{1-x}Ti_xSi$ with Ti having lower concentration of the 3*d* electrons.

The $GdFe_{1-x}Ti_xSi$compounds with$x$=0-0.2 were prepared by arc-melting. A diffractometer of Empyrean Series 2 (PANalytical) DRON-4 and CuKα radiation were used for structure analyzing. MPMS and 7407 VSM devices were used for magnetic study.

The alloys crystallize in the tetragonal CeFeSi-type structure (*P4/nmm*) with some amount of Gd_5Si_3 phase. The content of the main phase in the alloys decreases with increasing amount of Ti and is approximately 60% for the composition x=0.2. As one can see from Figure 1, the increase of Ti content in the $GdFe_{1-x}Ti_xSi$ system results in an increase in lattice parameter *c*, while the change of parameter *a* is negligible. As a result, the Gd-Gd, Gd-Fe, Fe-Si interatomic distances increase. The Curie temperature T_C should decrease due to the Gd-Gd distance increase and insertion of non-magnetic Ti ions. On the contrary, there is a significant increase in T_C in Figure 2 that can be explained by assuming the itinerant magnetism of these compounds. The decrease of number of the 3*d* electrons in the system leads to the increase of polarization of delocalized 3*d* electrons and contributes to the growth of T_C. The magnetic measurements carried out on the $GdFe_{1-x}Ti_xSi$ single crystals show the high magnetic anisotropy of these compounds. The easy direction of magnetization lies in the basal plane as is presented for GdFeSi in Figure 2. The anisotropy field in the $GdFe_{1-x}Ti_xSi$ system increases with Ti content.

The work has been supported by RSF (Project No. 18-72-10098).

[1] P. Wlodarczyk, L. Hawelek et al., Materials Chemistry and Physics 162, 273(2015)

Crystal structure refinement of PbMnTeO6 magnetic by neutron diffraction data

M.D. Kuchugura [a,b*], A.I. Kurbakov [a], V.B. Nalbandyan [c]

[a]NRC «Kurchatov Institute» -PNPI, 188300, mkr. Orlova roshcha 1, Gatchina, Russia

[b]St.Petersburg State University, 199034, Lieutenant Shmidt Emb. 11, St. Petersburg, Russia

[c]Southern Federal University, Faculty of Chemistry, 344058, Zorge st. 7, Rostov-on-Don, Russia

*mariya_kuchugura@mail.ru

Antiferromagnetic PbMnTeO6, also known as mineral kuranakhite (space group P-62m), was reported recently to have all three cations in trigonal prismatic coordination [1], extremely unusual for both Mn^{4+} and Te^{6+}. We have discovered and synthesized a compound PbMnTeO6, which was reproduced with the same XRD pattern and lattice parameters. However, powder neutron diffraction study unambiguously determined octahedral (trigonal antiprismatic) coordination for all cations within chiral space group P312. The alternative model was considered based on the PbSb2O6 (rosiaite) type. It has the same arrangement of cations, but with different oxygen positions, resulting in octahedral (trigonal antiprismatic) coordination of all cations.

The combination of chirality with magnetic order makes PbMnTeO6 a promising material with possible multiferroic properties.

The appearance of additional reflections related to the antiferromagnetic ordering organization of the PbMnTeO6 sample below *T*N=20 K is clearly visible on the low-temperature neutron powder diffraction patterns measurement by the DMC neutron powder diffractometer at Villigen, Switzerland.

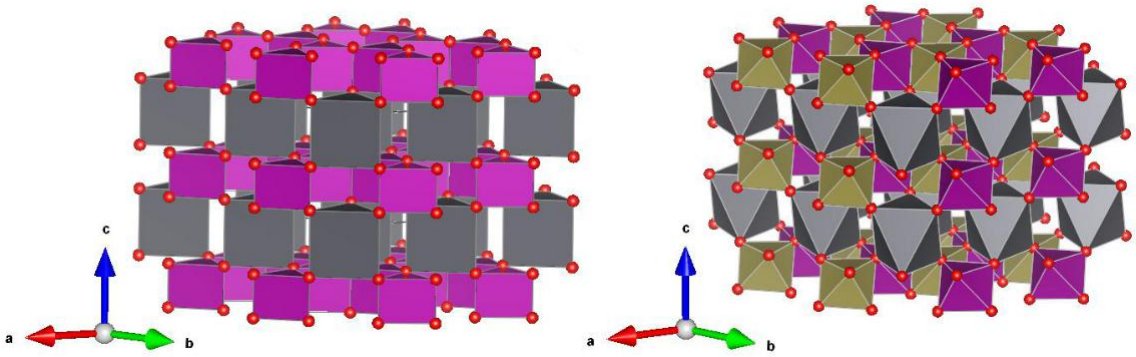


Fig. 1. Comparison of the two structural models for PbMnTeO6: previously published (a) and revised (b) in polyhedral (left).

[1]Sun Woo Kim et all., Inorganic Chemistry, 55, 1333−1338 (2016)

Structure and magnetic properties of microwires with low Curie temperature

V. Bashev[a], N. Kutseva[a,*],V. Larin[b], A. Zhukov[c], V. Zhukova[c]

[a]Oles Honchar Dnipro National University, Gagarina av. 72, Dnipro, Ukraine

[b]MicroFir Tehnologii Industriale, Kishinev, Moldova

[c]Departamento de Física de Materiales, UPV/EHU, 20018, San-Sebastián, Spain

*kutseva.nataliya@gmail.com

Amorphous and nanocrystalline glass-coated magnetic microwires (MW), which are characterized by the excellent combination of soft magnetic properties, GMI effect, stability of amorphous state with small dimension, are promising in sensor applications. As well known, suitable heat treatment, leading to the creation of a nanocrystalline structure, can dramatically change the magnetic properties of MW. The aim of this work is to study the structure and its change near the ferro-paramagnetic transition in amorphous glass-coated MW with low Curie temperature that can be used as temperature sensors.

Initial MW of nominal composition $Fe_{20}Co_{43.3}B_{11}Si_{12.7}Cr_8Mo_2C_2$(metallic nucleus diameter 40 μm and coating thickness 9 μm) was obtained by the Taylor-Ulitovsky technique.

The structure examination showed that the initial MW has amorphous structure (fig.1). The size of coherent scattering region was approx. 4.5 nm. The structure factors and the total radial distribution functions were calculated to describe short-range order of atoms in amorphous MW. From these data it was found that the most probable distance between atoms and average number of nearest neighbor atoms in initial MW were approx. 2.52 Å and 10, respectively. These parameters are closed to the corresponding one of the Fe-Fe, or Fe-Co interatomic distance (~2.49-2.52 Å). Coercivity and saturation magnetization of initial MW were 20 A/m, and 0.4 T, respectively.

Fig. 2 presents the temperature dependence of magnetization (fig.2). As can be seen from fig. 2, T_c of MW was 110°C. It was carried out X-ray analysis at the heating of MW at the temperature 130°C. It was found that the size of coherent scattering region of treated MW at this temperature decreased to 3 nm. Annealing of MW in temperature range 110 – 400°C did not change the structure and magnetic behavior of MW.

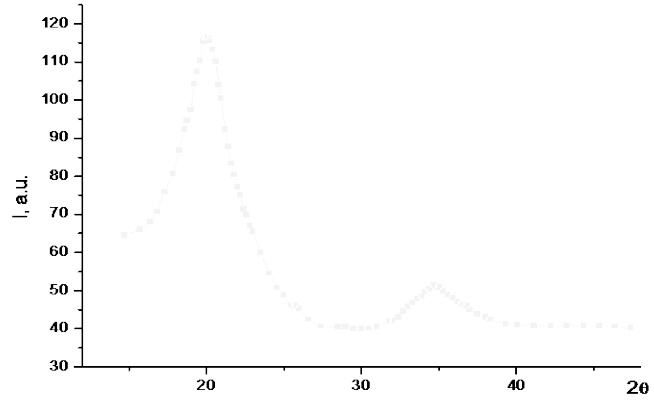


Fig.1 X-ray diffraction patterns of initial MW

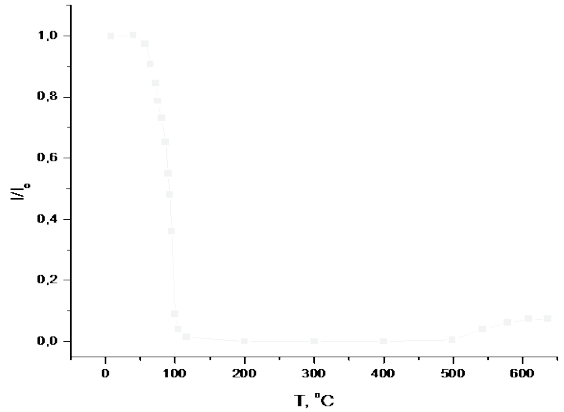


Fig.2 The temperature dependence of magnetization

Anomalous Nernst-Ettingshausen effect in thinferromagnetic films

M.V. DOROKHIN[a], YU.M. KUZNETSOV[a], A.V. KUDRIN[a], V.P. LESNIKOV[a]

Physical Technical Research Institute of Lobachevsky State University, 603950, Gagarina av. 23a,N.Novgorod.

Thermomagnetic phenomena are attracting much attention both for analyzing the properties of semiconductor and metallic materials, and for constructing the sources of electrical energy. Measurement of the Nernst-Ettingshausen effect (NE) is used to analyze electrical properties [1]. In addition, along with the "ordinary" effect of NE, anomalous effect of Nernst-Ettingshausen (AENE) can be registered in ferromagnetic structures (by analogy with the anomalous Hall effect - AHE) [2]. The parameters of the AENE, in particular its sign, give information about the nature of carrier scattering mechanism in ferromagnetic materials above and below the Curie point and, in some cases, about the mechanisms of ferromagnetic ordering. The Nernst-Ettingshausen U_{NE} and Hall U_H voltage arising in the transverse magnetic field is determined by the expression [3]

$$\begin{aligned} U_{NE} &= Q_0 B\Delta T + Q_M M(B)\Delta T, \\ U_N &= R_0 BI + R_M M(B)I, \end{aligned} \quad (1)$$

whereQ_0 is the ordinary Nernst-Ettingshausen constant, Q_M is the anomalous Nernst-Ettingshausen constant, T is the temperature gradient, M is the magnetization, B is the external magnetic field induction, I is the Hall current constant, R_M is anomalous Hall constant. The subject of research in this work is diluted magnetic semiconductors based on GaFeSb and InFeSb compounds, which were obtained by pulsed laser deposition in vacuum at a temperature of 250C and 300C, respectively. These semiconductor layers deposited on a substrate of semi-insulating GaAs(100), show ferromagnetic properties up to room temperature [4], which allows us to consider them as a promising material for fabricating spintronics devices. In this work, magnetic field measurements of Hall and Nernst-Ettingshausen voltages were carried out simultaneously in a wide temperature range (0-300) K in a Janis CCS-300S / 202 closed-loop cryostat.

The experimentally obtained magnetic field dependences were nonlinear with the saturation at high field, which indicates the presence of spin-dependent scattering in the structures under study. It is noteworthy that the magnetic field dependence of the Nernst-Ettingshausen voltage replicates the magnetic field dependence of the Hall voltage, which confirms the similar nature of these two, seemingly at first glance, different effects. The mechanism for spin-dependent scattering and it's influence on Hall and Nernst- Ettingshausen effects is discussed.

This study was supported by the Russian Science Foundation (project 17-79-20173 – NE measurements). and (project 18-79-10088 – sample fabrication and AHE measurements).

[1]Campbell I. // J. Phys. F.-V.6.-N.5.-P.849 (1976)
[2]M. Tanaka, S. Ohya, P.N. Hai. Appl. Phys. Rev. 1, 011102 (2014)
[3]Z. Zhu // Nature Phys., 6, 26 (2009)
[4]A. Kudrin // Phys. Rev. B 90, 024415 (2014)

Phase formation in $Ag_2O–Sb_2O_3–MO_3$ (M – Mo, W) system

Y. LUPITSKAYA*, H. BOZOROV

[a]Chelyabinsk State University, 454001, Br. Kashirinykh 129, Chelyabinsk, Russia

*lupitskaya@gmail.com

Analysis of advances in the development of novel functional materials possessing high ionic and protonic conductivity indicates that a relatively small number of compounds with tailored proper-ties have been discovered in recent years. In this context, research concerned with the ability to modify previously synthesized substances is of particular practical importance. Among widespread materials modification techniques, it is worth noting defect formation in the crystal lattice of a host compound through doping with heterovalent impurities. The synthesis of such materials in the form of ceramic samples makes it possible to use them as key components for the fabrication of ion-exchange and ion-conducting membranes capable of operating at elevated temperatures in fuel cells. At the same time, when heated in air the compounds in question turn out to be chemically unstable: they undergo dehydration and the reduction of pentavalent antimony ions, accompanied by the formation of phases of various compositions and structures. This paper presents a detailed study of phase formation processes in the $Ag_2O–Sb_2O_3–MO_3$ (M – Mo, W) system during heating in air. The compositions of the solid-state reaction products have been deter-mined using thermogravimetry and qualitative X-ray diffraction. The results demonstrate that, at a final heat treatment temperature of 1023 K, synthesis yields a range of $Ag_{2–x}Sb_{2–x}M_xO_6$ (M – Mo, W) compounds with the pyrochlore structure and $0.0 \leq x \leq 2.0$. Based on the X-ray diffraction data, we have proposed a model for the ion distribution over the crystallographic sites of space group Fd-3m: the framework of the pyrochlore structure is formed by positions 16c and 48f, which are occupied by the Sb^{5+}, Mo^{6+}, W^{6+}, and O^{2-} ions at random; position 16d is partially or fully occupied by the Ag^{+}; and position 8b remains vacant. It has been shown that heterovalent substitution of Mo^{6+}, W^{6+} for Sb^{5+} in antimony oxide compounds produces defects in the pyrochlore structure and that doping of such compounds with monovalent metal ions improves their cation-conducting properties. According to our results, the highest conductivity is offered by the $AgSbMO_6$ phase, in which ion transport occurs through channels formed by positions 16d and 8b in the ⟨111⟩ directions of the crystal lattice.

The reported study was funded by RFBR according to the research project No 18-33-00269.

Magnetodeformation and electrodeformation as source ofmultiferroic properties in elastomers

L.A. MAKAROVA[a,b,*], A.S. KOMLEV[a], YU.A. ALEKHINA[a], M.F. KHAIRULLIN[a], A.S. OMELYANCHIK[b], V.V. RODIONOVA[b], O.V. MALYSHKINA[c], N.S. PEROV[a,b]

[a]Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

[b]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[C]Tver State University, 170100, Zhelyabova 33, Tver', Russia

***** la.loginova@physics.msu.ru

Magnetorheological and electrorheological composites, particularly elastomers, attract the researcher attention due to their tunable properties and ease in utilization. The huge magnetodeformation and electrodefromation effects, correspondingly, lead to great opportunities for the development of new composite materials based on them with promising properties.

Composite materials based on silicone, ferroelectric (FE) and ferromagnetic (FM) components were investigated. To determine the contribution of FE component to the properties of composite sample there were used two types of FE particles – PZT microparticles and BFO nanoparticles. PZT particles were obtained by ball milling of bulk ultrasonic element. BFO particles were prepared via sol-gel method with annealing at the temperature of 650 C during 2 or 12 hours. To determine the FM particle moveability in the silicone two types of particles were used – iron microparticles (Fe) and cobalt ferrite nanoparticles (Co-Fe). Co-Fe particles were also prepared via sol-gel method with annealing at the temperature range 300-500 C during 1 h.

The following samples were prepared from silicone and above mentioned components for the investigations: 1) pressed tablets from FE particles with average diameter 6 mm and thickness 1 mm; 2) composites based on silicone and one type of FE or FM particles – magnetorheological (MRE) of electrorheological (ERE) elastomers; 3) composites based on silicone and some mixture of FM and FE particles – multiferroic rheological elastomers (MfRE); 4) composites based on FE porous structure (based on ERE) filled with MRE – multiferroic rheological foams (MfRF).

The sizes of the particles were determined by TEM. The magnetic properties were measured by VSM LakeShore (model 7400) at the fields up to 16 kOe at the temperature range from 80 K to 300 K. The temperature investigations allow to find out the contribution of FM particle movement to magnetic properties of MRE. The ferroelectric hysteresis loops were investigated by Soyer-Tauer method with modifying cell with DC magnetic field.

The contribution of FE particles to the polarization properties of the samples, the moveability of FM and FE particles in silicone matrix under magnetic or electric field, the mechanisms of magnetoelectric transformations in MfRE and MfRF are discussed in the work. Such mechanisms differ for multiferroic elastomers and multiferroic foams. In the first case the magnetoelectric coupling is associated with movements of FE and FM particles in uniform silicone matrix. In the second case this coupling is associated with deformations of silicone pore walls with FE particles and filling MRE with FM particles.

The proposed research allows to improve the existing and to find new properties of composite materials based on rheological elastomers for their further prospective applications.

Financial Support of RFBR Grants No. 18-32-00354, 18-32-20219 is acknowledged.

Magneto-ellipsometry for controlling properties of perspective magnetic materials

O.A. MAXIMOVA[a,b*], S.A. LYASCHENKO[a], I.A. YAKOVLEV[a], D.V. SHEVTSOV[a], S.N. VARNAKOV[a] AND S.G.OVCHINNIKOV[a,b]

[a]Kirensky Institute of Physics, Federal Research Center KSC SB RAS, 660036, Akademgorodok 50, bld. 38, Krasnoyarsk, Russia

[b]Siberian Federal University, 660041, Svobodny 79, Krasnoyarsk, Russia

***** maximo.a@mail.ru

As far as magnetic materials, in particular magnetic nanoparticles, revealed their efficiency in medical applications [1-5], the ways of synthesizing them and controlling their properties are of huge scientific interest. This work is focused on applying a well-known ellipsometry technique to controlling magneto-optical properties of magnetic particles during the process of synthesis inside an ultra-high vacuum chamber.

This report presents:

- The scheme of magneto-ellipsometry setup that is used both for synthesis and investigation of new materials [6];
- The process of synthesis of Fe-based superparamagnetic nanoparticles on NaCl substrates;
- The method of processing magneto-ellipsometry data which provides the researcher with dielectric function tensor spectrum in a range of 1.2-3.5 eV, including diagonal and, what is more important, non-diagonal tensor elements [7]. Much attention is paid to mathematic modeling of the experimental data, integrating and minimization procedures;
- The advantages of magneto-ellipsometry technique including its non-destructiveness and high precision;
- The variants of our nanoparticles application for cancer treatment.

This work is supported by the Ministry of Education and Science of the Russian Federation and by Siberian Branch of the Russian Academy of Sciences (Project II.8.70) and Fundamental research program of the Presidium of the RAS no. 32 «Nanostructures: physics, chemistry, biology, basics of technologies».

[1] Liqin Xie et al., Journal of Biomedical Nanotechnology 15(2), 215 (2019).
[2] M. Latorre-Esteves et al., Puerto Rico health sciences journal 28(3), 227 (2009).
[3] Yu Gao, Yi Liu, Chenjie Xu, Magnetic Nanoparticles for Biomedical Applications: From Diagnosis to Treatment to Regeneration, Springer London, (2014)
[4] Nhiem Tran, Thomas Webster, J. Mater. Chem., 20, 8760 (2010).
[5] Qu. Pankhurst et al., Journal of Physics D-applied Physics, 42 (2009).
[6] D.V., Shevtsov, S.A., Lyaschenko, S.N. Varnakov, Instruments and Experimental Techniques 60, 759 (2017).
[7] O.A. Maximova, et al., SibFU Journal. Mathematics & Physics 10, 223 (2017).

Structural distortion and magnetic properties for LaPbMnSbO6 Compounds

J. MENG[a,*], Y.BAI[a], F.Z.MENG[b], X.J. WU[a],X.C.GAO[c], L.P.LI[a]

[a]State Key Laboratory of Rare Earth Resource Utilization, Changchun Institute of Applied Chemistry,

Chinese Academy of Sciences, 5625 Renmin Street, Changchun 130022, PR China

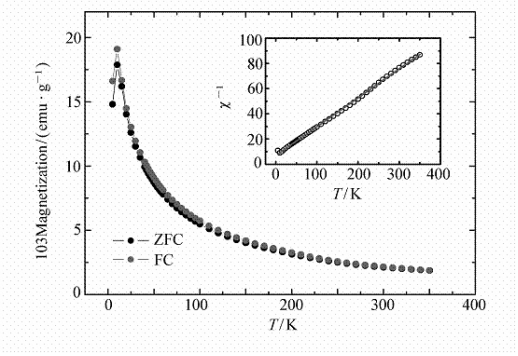
[b]Changchun University of Science and Technology, 130022, PR China

[c]Changchun University of Cjinesemedicine, 130117, PR China

*jmeng@ciac.ac.cn

The B-site ordered double perovskite oxides $LaPbMnSbO_6$ was synthesized via the modified Sol–Gel method. Owing to the cooperative Jahn–Teller effect of Mn3+ and Pb^{2+} ions, the Mn-related compound exhibits almost complete Mn^{2+}–Sb^{5+} order.

The magnetic moment versus magnetic field (M–H) curves under the temperature of 5K for $LaPbMnSbO_6$ show that the paramagnetic (PM) character at room temperature. At low temperature,an antiferromagnetic (AFM) feature with almost no remanence(Mr) and coercive field (Hc) is noticed. Based upon the results of the M–H measurement, two points should be summarized: (1) the unconventional AFM behavior is predominated which should be understood as a consequence of extended super-exchange AFM interaction; and (2) the faint FiM behavior from $LaPbMnSbO_6$ could be interpreted as a kind of spin canted AFM interaction which might be derived from a strong magnetic frustration. The temperature dependence of the field cooled (FC) and zero field cooled (ZFC) magnetizations are shown in Fig.1.



The no clear discrepancy between FC and ZFC curves is seen until a steep kink occurs at ~ 10K. Besides, the Néel temperature(TN), estimated to be 9K, is obviously higher than 8Kof $LaSrMnSbO_6$. This suggests a significant field-dependent effect and further confirms the existence of strong magnetic frustration. From the C–W fitting results, the effective magnetic moment(μeff) of $LaPbMnSbO_6$ is 5.90 μB/f.u. which is not only strongly deviated from the theoretical value of 5.92 $\mu B/Mn^{2+}$ for high-spin (HS) state with spin-only consideration but also larger than the experimental data of 6.01$\mu B/Mn^{2+}$ with spin–orbital coupling consideration. These abnormally large μ_{eff} values indicate a significant orbital contribution from the 3d-shell electrons. After the substitution of Pb^{2+} ion, the extent of structure distortion within the ab plane is more remarkable comparing to the other crystallographic directions. Considering the t_{2g}^5 e_g^2 electronic configuration of Mn^{2+} (HS) cation, both d_{xy} and d_{2x_y} orbitals can participate in spin coupling so the extended AFM super-exchange(AFM-SE) interactions, formed by d–p π bond and d–p σbond, are able to coexist. However, due to the small bond angles of Mn–O1–Sb (142.3(8)°), O1–Mn–O2 (76.7(7)°) and O1–Sb–O2 (72.4(7)°) from $LaPbMnSbO_6$, the π-bond connected extended AFM-SE coupling seems to be more energetically preferable. As a result, a higher frustration factor(F=8.0) is observed. So in the ionic ordered $LaPbMnSbO_6$ DPO systems, lattice distortion could induce strong competition of multiple magnetic coupling paths and further result in a large extent of magnetic frustration. By the analysis of metastable magnetic structure, the intrinsic factor of 3d electric structure of Mn ion plays the major role.

Adiabatic excitation for NMR spectroscopy in magnetic materials

I. MERSHIEV[a,*], S. WURMEHL[b]

[a]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[b]Leibniz Institute for Solid State and Materials Research, 01069, Helmholtzstraße 20, Dresden, Germany

*IMershiev@kantiana.ru

Nuclear magnetic resonance spectroscopy is a well-established method for surveying the structural properties of matter. One of the applications of NMR is spectroscopy in internal magnetic field of magnetic materials. It has a few differences in comparison to conventional NMR methods: the measurements are usually performed in a gradient of hyperfine field of several Tesla, and broad spectra are acquired by spin-echo frequency sweeping. NMR is widely used for the research of nanostructures and spin-polarized materials as a tool that allows probing a local environment of the nuclei [1].

In magnetic materials, excitation of nuclear spins depends of the local magnetic susceptibility of the nuclei. Coupling of the nuclear spins and magnetic moments of electrons in the domain walls of ferromagnetic materials provides an enhancement for both local excitation field and NMR signal by the $\eta \approx 10^3$. The enhancement factor in magnetic domains is several orders smaller, and usually all NMR signal comes from domain walls. In the same time, NMR signals depend on many different factors, as the distribution of enhancement factors in domain walls, effects of averaging in polycrystalline samples, and the displacement of domain walls under the action of external magnetic field [2]. Under these conditions, it is impossible to achieve a spin inversion, as in conventional NMR. In addition, the dispersion of an enhancement factor in domain walls does not allow a uniform rotation of spin magnetization for all nuclei.

The aim of this work is to increase the sensitivity of NMR spectroscopy in ferromagnetic materials by compensation of the dispersion of an enhancement factor in domain walls. The gradient of the enhancement factor in the domain walls result in a gradient of excitation field across the spin magnetization. Broadband radiofrequency pulse with compensation of B_1 field inhomogeneity is able to provide an equal excitation for all the spins in the domain walls. The use of adiabatic excitation pulses [3] allows both limited excitation bandwidth for spin-echo experiments with frequency sweeping and the increase in power for the spin-echo signal. In experiments with polycrystalline sample of Co_2FeGa alloy, more than three times increase in signal power was obtained in comparison with conventional method. The results are applicable to the internal field NMR spectroscopy of nanostructures and samples with low natural abundance nuclei (^{53}Cr, ^{57}Fe, ^{61}Ni, etc).

This work was supported by Russian Ministry of Science and Education, project 3.12718.2018/12.2

[1] S. Wurmehl and J. T. Kohlhepp, “Nuclear magnetic resonance studies of materials for spintronic applications,” J. Phys. D. Appl. Phys., vol. 41, no. 17, p. 173002, 2008.
[2] M. B. Stearns, “Spin-echo and free-induction-decay measurements in pure Fe and Fe-rich ferromagnetic alloys: Domain-wall dynamics,” Phys. Rev., vol. 162, no. 2, pp. 496–509, 1967.
[3] J. Baum, R. Tycko, and A. Pines, “Broadband and adiabatic inversion of a two-level system by phase-modulated pulses,” Phys. Rev. A, vol. 32, no. 6, pp. 3435–3447, Dec. 1985.

Spatial structure characterization of the DNA aptamer to human glioblastoma in solution by X-rays

R.MORYACHKOV[a], A.KICHKAYLO[a,b] , A. NARODOV[b] , Y. GLAZYRIN[a] , G. ZAMAY[a], V.ZABLUDA[a] , F.TOMILIN[a] , I.SHCHUGOREVA[a] , G.PETERS[c] AND A.SOKOLOV[a]

[1]Federal Research Center KSC SB RAS, 660036, Akademgorodok 50, Krasnoyarsk, Russia

[2]Krasnoyarsk State Medical University, Laboratory for Biomolecular and Medical Technologies, Partizana Zheleznjaka 1, Krasnoyarsk, 660022, Russia

[3] NRC ‘‘Kurchatov Institute’’, Akademika Kurchatova pl. 1, Moscow, 123182, Russia

*****mrv@iph.krasn.ru

Glioblastoma is the most frequent and aggressive primary brain tumor, affecting about one million people a year in the world. Complete tumor resection at the first step of glioblastoma treatment is very challenging due to invasive nature of this tumor and blurred boundaries between cancer and normal brain tissues, but it is crucial for increasing patients survival rate. In order to enhance visualization of glial tumor margins during the surgery a DNA-aptamer Gli-233 was selected by tissue-SELEX method.

Aptamers are small DNA or RNA oligonucleotides which specific binding to certain targets is conditioned by the dimensional structure, spatial charges distribution, phosphates and the mismatch of bases, capable of electrostatic and van der Waals interactions and forming hydrogen bonds. Being highly selective to glial tumor tissues, aptamer Gli-233 can quickly distinguish small differences in thousands of proteins and therefore was used for imaging of individual cancerous glia cells, tumor tissues, and in situ for fluorescent visualization of the tumor and its precise microsurgery. The protein binding partner of Gli-233 is tubulin-alpha, with several post-translational modifications, which make it one of the biomarkers of the glial tumor cells.

Spatial structure of the aptamer is crucial for its specific binding but its identification using conventional X-ray method is very challenging. Here we applied Small Angle X-ray Scattering method (SAXS) and molecular design for identification of Gli-233 three-dimensional structure in its native state in solution. The experiments were conducted on the DIKSI station at the National Research Center "Kurchatov Institute". The obtained scattering curves were used to calculate the basic structure parameters of the biomolecule in solution, such as gyration radius, maximal molecule dimension, volume and molecular weight, the distance distribution function was plotted.

Using the calculated data, we have built the bead model of the overall electronic shell of the molecule. According to the constructed earlier secondary structure, we performed the molecular design of the aptamer Gli-233. Two molecular structures were generated with the differences between conformations. The SAXS model played the crucial role to select the native form of the aptamer in the solution. Obtained molecule model consists of three parts: first is the loop containing the central part ofthe sequence, second is the duplex DNA of B-type containing complementary nucleotide pairs, third is the “tail” consisted of non-complementary nucleotides.

In addition, we simulated a binding model for the aptamer and its target – post-translationally modified tubulin-alpha. Therefore, the next our SAXS experiment will be the study of aptamer-protein complex with the target protein extracted from the glioblastoma tissues.

Sensitivity tuning of magnetoplasmonic crystal based magnetic field sensor

D.V. MURZIN[a,*], V.K. BELYAEV[a], A.A. GRUNIN[b], A.A. FEDYANIN[b], V.V. RODIONOVA[a].

[a]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[b]Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

dvmurzin@yandex.ru

One of the possible ways to make a highly localized and sensitive magnetic field sensor (MFS) is to use the enhancement of magneto-optical (MO) response frommagnetoplasmonic crystals (MPlCs). MPlCs are periodic metal nanostructures that can support the excitation of surface resonant evanescent coupled oscillations of metallic plasma and photons called surface plasmon polaritons (SPPs) [1]. The best-achieved sensitivity of previously shownMFS based on SPPs driven enhancement of transverse magneto-optical Kerreffect (TMOKE) was$4.4\cdot10^{-6}$ Oe in modulating field of 5.0 Oe at an area of 1 mm^2. It was also shown, that its sensitivity and measurable field region depend on MPlCs magnetic properties [2].

This research demonstrates spectral dependences of reflectivity and TMOKE, shown in figure 1,and field dependences of MO responseat the wavelength corresponding to the SPPs excitation. Local and integral magnetic properties of studied samples were carried out with vibrating-sample magnetometer and magneto-optical magnetometer, respectively. MPlCs were made by DC magnetron sputtering of functional layers onto one-dimensional polymer quasi-sinusoidal or trapezoidal diffraction gratings Sub_2 and Sub_3. Declared parameters of substrates were: periodsd_2=320 nm and d_3=740 nm and profile heights h_2=20 nm and h_3=100 nm, respectively. Reference samples based on smooth silica substrates Sub_1 were fabricated in the same fabrication cycles. Deposited materials were 50 nm of silver (Ag), 5, 10, 15 or 20 nm of permalloy ($Ni_{80}Fe_{20}$) and 20 nm of silicon nitride (Si_3N_4).

Measurements of magnetic properties and spectral dependences presented in this work showthe way to tune studied MFS sensitivity, measurable field region and the value of necessary modulating AC magnetic field through the MPlC morphology change.

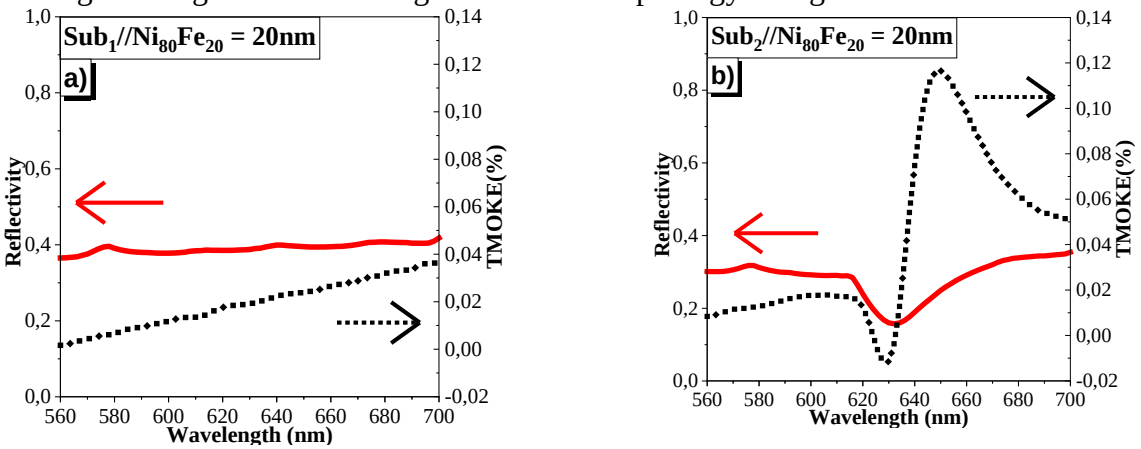


Figure 1. Spectral dependences of reflectivity (straight red lines) and TMOKE (dotted black lines) for samples with $Ni_{80}Fe_{20}$ of 20 nm based on the Sub_1 (a) and Sub_2 (b), respectively.

[1] A. Zayats, J. Opt. A-Pure Appl. Op. 5, 16 (2003)
[2] V. Belyaev, J. Magn. Magn. 482, 292 (2019)

Magnetotransport Properties of InSb Crystals Doped with Mn and Te

S.A. Obukhov[a*], E .Lahderanta[b] and T.Y. Panysheva[c]

[a]A. F. Ioffe Physical-Technical Institute, 194021, Saint Petersburg, Russia

[b]Lappeenranta University of Technology, 53851, Lappeenranta, Finland

[c]Peter the Great Saint-Petersburg Polytechnic University, 195251, Saint Petersburg, Russia

*sobukhov@inbox.ru

The realization of Dilute A^{III} (Mn) B^{V} ferromagnetic semiconductors operated above room temperature will potentially lead to a new generation of spintronic devices with revolutionary electrical and optical properties. Previous works have shown that $In_{1-x}Mn_xSb$ had high temperature ferromagnetism for Mn concentrations at 2-10% [1,2]. However the role of Mn in InSb crystals remains the matter of discussions in the literature [3]. It is not clear yet how manganese induces ferromagnetism in InSb and how manganese, being an acceptor, influences InSb transport properties.

Previously we studied magnetic and transport properties of InSb crystals doped with Mn at doping level slightly above critical concentration of metal-insulator transition $p_{cr}= p = n_{Mn} \sim 10^{17}$-$10^{18}cm^{-3}$ [4]. It was demonstrated there that low temperature transport properties of InSb(Mn) crystals was determined by interaction of charge carriers –holes and electrons i.e. excitons.

To assess the role of Mn in excitons formation and their properties it would be of interest to study the influence of compensation of InSb(Mn) crystals with donor impurity – telluride (Te), as in compensated crystals we have possibility to maintain the hole concentration $p=n_{Mn}-n_{Te}$ close to concentration of metal-insulator transition but simultaneously to rise the Manganese concentration.

In this work we studied transport properties (conductivity, magnetoresistance and the Hall effect) of two p-InSb crystals doped with Mn and Te at compensation ratio $K= n_{Te}/n_{Mn}= 0,5$ and 0,75 and compared their properties with uncompensated crystals p-InSb(Mn) we have studied previously [4].

We observed significant differences in transport properties compensated and uncompensated materials. So in this project we propose to study transport and magnetic properties of InSb crystals doped both by Mn and Te with the hole concentration within $p=n_{Mn}-n_{Te=}\ n_{cr}\sim10^{17}cm^{-3}$. We propose to measure magnetic susceptibility and transport properties (conductivity, magnetoresistance and the Hall effect) of two p-InSb crystals doped with Mn and Te at compensation ratio $K= n_{Te}/n_{Mn}= 0,5$ and 0,75 and compare their properties with uncompensated crystals p-InSb(Mn) we have studied previously [4]. We plan to study 5 samples at K=0,5 and 5 samples at K=0,75 and 5 samples at K=0 in the wide ranges of temperature and magnetic field: conductivity and the Hall effect at T=77K-1,6K and magnetic field at B=0-40T and Magnetic susceptibility at T=77-1,6K and magnetic field at B=0-6T.

[1]J. A. Peters, N. Rangaraju, C. Feeser, and B. W. WesselsAppl. Phys. Lett. **98**, 193506 (2011)
[2]L. Lari, S. Lea1, C. Feeser, B. W. Wessels, and V. K. Lazarov. Journal of Physics: Conference Series **371,**012032 (2012)
[3]D. Chiba, M. Sawicki, Y. Nishitani, Y. Nakatani, F. Matsukura, and H. Ohno, Nature**455**, 515 (2008)
[4]S. A. Obukhov, T. L. Makarova, E. Lahderanta, I. A. Zakharchuk, and T. Yu. PanyshevaAIP Advances **8**, 105214 (2018)

Controlling the magnetic properties of sub 10 nm ferrite nanoparticles by engineering the synthesis process

G. MUSCAS[A,B], M. COBIANCHI[C], A. LASCIALFARI[D,E], A. LASCIALFARI[D,F], A. MUSINU[E], A. OMELYANCHIK[G], V. RODIONOVA[G,H], A. ARDU[E,F] AND D. PEDDIS[A,I,*]

[a]Istituto di Struttura della Materia, CNR, 00015 Monterotondo Scalo, (RM) Italy

[b]Department of Physics and Astronomy, Uppsala University, Box 516, SE-751 20 Uppsala, Sweden

[c]Dipartimento di Fisica, Università degli Studi di Pavia and INSTM, I-27100, Pavia, Italy

[d]Dipartimento di Fisica, Università degli Studi di Milano and INSTM, I-20133, Milano, Italy

[e]Department of Chemical and Geological Sciences and INSTM, University of Cagliari, 09042 Monserrato, Italy

[f]Consorzio AUSI, CREATE, Palazzo Bellavista Monteponi, Iglesias, CI, Italy

[g]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[h]National University of Science and Technology "MISIS",119049, Moscow, Russia

[i]Department of Chemistry and Industrial Chemistry (DCIC), University of Genova, Via Dodecaneso 31, 16146, Genova, Italia

*davide.peddis@unige.it

The magnetic properties of particles are strongly affected by their dimensions. In particular, when the particle size decreases under 100 nm, the particles dramatically differ from the bulk and organize themselves in a single domain state, when, under a critical radius, a multi-domain state is not energetically convenient [1]. Nowadays, magnetic single-domain nanoparticles' ensembles have found a place in several important technological applications thanks to their peculiar magnetic properties [2], e.g., MRI [3], hyperthermia [4] and drug delivery [5].In this work, we investigate the flexibility of the high-temperature thermal decomposition (HTD) synthesis to design magnetic nanoparticles with engineered properties for specific applications. We demonstrate the possibility to prepare spinel iron oxide particles with the desired composition (Fe_3O_4 and $CoFe_2O_4$) and well-controlled average size (5-8 nm) by tuning the synthesis procedure. The design of nanoparticle-based magnetic materials with specific properties hinges on the control of their physical-chemical structure. We show that the substitution of Fe by Co produces a dramatic increment of the magnetocrystalline anisotropy, well behind the effect of the increment of particle volume. The magnetocrystalline anisotropy has shown to be the leading player in the magnetic behavior of high crystalline particles of such small size, except for the smallest iron oxide sample, where the surface anisotropy plays an extraordinary role. Finally, we observed that the presence of organic surfactant (oleic acid) on the nanoparticles prevents direct exchange coupling among them. Nevertheless, the particles are close enough to be influenced by dipolar interactions, which are proportionally stronger for particles with less intrinsic magnetocrystalline anisotropy.

[1]D. Fiorani, J. Magn. Magn.Mater. 196–197 (1999) 143–147.
[2] L. Suber, in: Nanomater. Life Sci., Wiley, (2009).
[3] C. Sun, Adv. Drug Deliv. Rev. 60 (2008) 1252–65.
[4] M. Andrés Vergés, J. Phys. D. Appl. Phys. 41 (2008) 134003.
[5] P. Guardia, Langmuir. 26 (2010) 5843–7.

Magnetic properties of Fe-Ge compounds

O. Pavlukhina[a,*], M. Zagrebin [A,B],V. Buchelnikov [A,B], V. Sokolovskiy [A,B],

M. Matyunina [a]

[a]Chelyabinsk State University, 454001, Bratiev Kashirinykh st. 129 Chelyabinsk, Russia

[b]National University of Science and Technology "MIS&S", 119991, Leninskiy prospect 4,

Moscow, Russia

pavluhinaoo@mail.ru

Intermetallic Fe-based phases have attracted a lot of attention owing to their unusual mechanical, magnetic and electrical properties [1]. In this work, we report on the theoretical calculations of the temperature dependence of magnetization in $Fe_{100-x}Ge_x$ ($0 \leq x \leq 25$) alloy by Monte Carlo simulation.

The Curie temperatures were found by the Monte Carlo simulation and from the mean field theory. We use the magnetic exchange parameters from first-principles calculations to obtain the magnetic phase diagram by means of Monte Carlo simulations using the classical Heisenberg model. The Monte Carlo simulations have been carried out employing the standard Metropolis algorithm [2].

We calculated the exchange coupling constants J_{ij} by using the SPR-KKR package (spin-polarized-relativistic Korringa-Kohn-Rostoker). To perform this study, the coherent potential approximation (CPA) has been used. For the optimized lattice parameter, the selfconsistent potential (SCF) is calculated. All calculations converged to 0.01 mRy of total energy. The maximum number of SCF iterations was taken to 200. The magnetic properties of $Fe_{100-x}Ga_x$ alloys are studied computationally in the composition range up to $x \leq 25$. The following phases are considered: the A2 with anα-Fe-type structure with Fe and Ga atoms randomly distributed, space group Im-3m; the $D0_3$ with a BiF_3-type structure with Fe and Ga atoms partially ordered, space group Fm-3m; the L12 with a Cu_3Au-type structure with Fe and Ga atoms partially ordered, space group Pm-3m. For example, the Curie temperature $Fe_{75}Ge_{25}$ calculated for the $D0_3$ structure by the Monte Carlo method was 755 K by the mean field theory 1000 K. We note that the calculated Curie temperatures for Fe-Ge alloy is in a good agreement with experimental values.

This work was supported by Russian Science Foundation No. 18-12-00283.

[1]K. Shanavas, M. McGuire, D. Parker, J. Appl. Phys. 118, 123902 (2015).
[2]D. Landau and K. Binder, Cambridge Univesity Press, Cambridge (2000).

Role of Ti in magnetic properties of $GdFe_{0.95-x}Mn_xTi_{0.05}Si$

S.P. PLATONOV[a,*], A.G. KUCHIN[a] , V.S. GAVIKO[a,b], M.YU. YAKOVLEVA[a]

[a]M.N. Miheev Institute of Metal Physics of Ural Branch of Russian Academy of Sciences, 620108, 18 S. Kovalevskaya Str., Ekaterinburg, Russia

[b]Ural Federal University named after First President of Russia B.N. Yeltsin, 620002, 19 Mira Str., Ekaterinburg, Russia

*platonov@imp.uran.ru

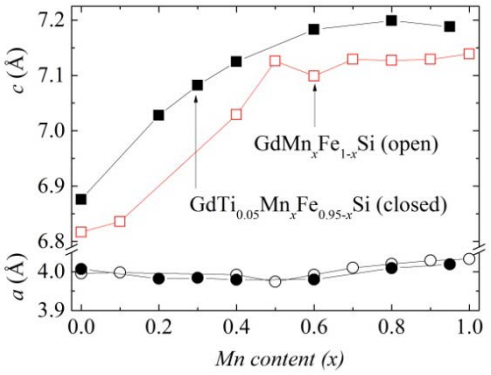


Figure 1.Concentration dependences of lattice parameters a (o,●) and c (□,■) of $GdMn_xFe_{1-x}Si$ (o, □) [1] and $GdFe_{0.95-x}Mn_xTi_{0.05}Si$ (●,■).

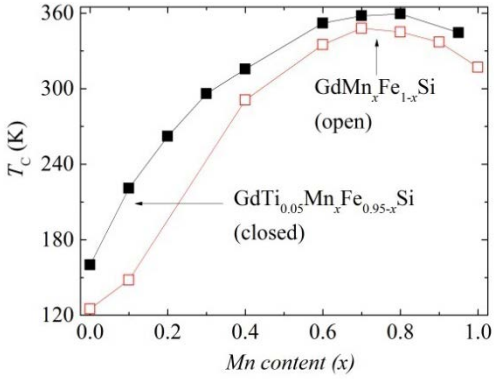


Figure 2. Concentration dependences of Curie temperature T_C of $GdMn_xFe_{1-x}Si$ (□) [1] and $GdFe_{0.95-x}Mn_xTi_{0.05}Si$ (■).

Mn is a unique example of a 3*d*-transition metal T with a magnetic moment in RTSi compounds. The hybridization between Si *p* states and Fe 3*d* states causes the absence of the magnetic moment of Fe in the GdFeSi compound. The increase of Fe content in the $GdMn_xFe_{1-x}Si$compounds results in a decrease in lattice parameters *a*, *c*, as is seen in Figure 1 from Ref. [1]. Therefore, an increase in the overlap of 3*d* electron wave functions results in strengthening of R-T and T-T exchange interactions and hence in an increase of the Curie temperature $T_C$for $x > 0.7$, as is presented in Figure 2 from Ref. [1]. Thus, it was interesting to study magnetic properties of $GdFe_{0.95-x}Mn_xTi_{0.05}Si$with Ti having atomic radius larger as compared with Fe or Mn. This is why the lattice parameter *c* is bigger for $GdFe_{0.95-x}Mn_xTi_{0.05}Si$ in comparison with $GdMn_xFe_{1-x}Si$ as is shown in Figure 1. Ti contributes to the slight increase in T_C of the compositions $x = 0.7$-0.9 (Figure 2). However, T_C of the $GdFe_{0.95-x}Mn_xTi_{0.05}Si$ compounds is much bigger for $x < 0.6$. Two competitive factors influence on T_C of $GdFe_{0.95-x}Mn_xTi_{0.05}Si$. The increase of the interatomic distances due to the large Ti atoms weakens the R-T and T-T exchange interactions. At the same time, the partial substitution of Fe by Ti decreases number of the 3*d* electrons in the system because Ti and Fe atoms have 2 and 6 of the 3*d* electrons, respectively. Therefore, the polarization of the delocalized 3*d* electrons by the exchange interactions between Gd atoms increases and contributes to the growth of T_C for all compositions. As a result, $T_C$are close for the compounds with $x > 0.7$ in both systems and are much bigger for $x < 0.6$ in $GdFe_{0.95-x}Mn_xTi_{0.05}Si$ as compared with $GdMn_xFe_{1-x}Si$.

The work has been supported by RSF (Project No. 18-72-10098).

[1] S.A. Nikitin, T.I. Ivanova et al., Journ. Alloys and Compounds 280, 16(1998)

Hollow silica nanoparticles for wastewater treatment

M. PONOMAREV[a,*], E. KOZENKOVA[a], I. KOZENKOV[a], Y. NALENCH[b], M. ABAKUMOV[b],
S. JOVANOVIC[c,d], D. VENGUST[c], V. RODIONOVA[a]

[a]Immanuel Kant Baltic Federal University, 236041, Kaliningrad, Russia

[b] National University of Science and Technology «MISiS», 119049, Moscow, Russia

[c] Advanced materials department, Jožef Stefan Institute, 10000, Ljubljana, Slovenia

[d] Laboratory of Physics, Vinca institute of nuclear sciences, University of Belgrade, Belgrade, Serbia

* muwkaaa2@mail.ru

Nanoparticles of magnetite were synthesized by co-precipitation method at 80°C [1]. On the second step, the obtained nanoparticles were covered by silica-based organic precursor shell [2]. The core was etched with hydrochloric acid to achieve hollow structures.

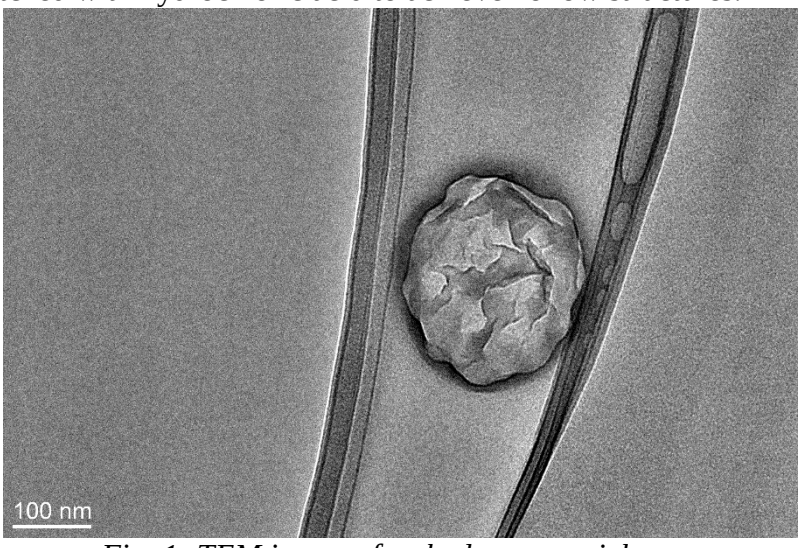


Fig. 1: TEM image of etched nanoparticle.

The morphology and size of the samples were investigated by Transmission Electron Microscopy (TEM) and according to results the size of nanoparticles is in the range from 80 to 140 nm. To analyze the structure on the surface of particles was observed Raman spectroscopy and formation of maghemite (γ-Fe_2O_3) was confirmed. The composition and temperature of shell around 300°C were determined by the methods of differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA).

The tests for sorption of Co^{2+} ions and commercial dyes from water were carried out by spectrophotometry. The efficiency of silica nanospheres against non-covered iron oxide nanoparticles for treating wastewater from pollutants was described.

[1] F. Yazdani, at al., Mater. Chem. Phys. 184, 318 (2016)
[2] J.-L. Hu, at al., RSC Adv. 3, 25620 (2013)

Influence ofmagnetic nanoparticlesin the presence ofstatic magnetic fieldson human peripheral blood mononuclear and T-lymphoblasts Jurkat cells viability

S. PSHENICHNIKOV*, E. SHUNKIN, V. MALASHCHENKO, N. GAZATOVA, V. KOLESNIKOVA, A. OMELYANCHIK, L. LITVINOVA, V. RODIONOVA, K. LEVADA

Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

*SPshnikov@gmail.com

Static magnetic fields (SMF) of varying strengths and magnetic nanoparticles (MNPs) can be used as therapeutic tools. It is known that a high magnetic field significantly inhibits the proliferation of Jurkat cells, but does not affect normal lymphocytes [1]. The large variability and diversity of biological structures are capable of largely redefining the nature of the interaction of the “cell-nanomaterial-magnetic field” system. Thus, the study of the effect of magnetic fields on individual cell lines is an important task in the development of cancer theranostics [2].

In this research,human peripheral blood mononuclear cells (PBMC) and human T-lymphoblastic leukemia cell line (Jurkat) were used to determine the effect of SMF and iron oxide MNPs on cells viability.Cell lines were cultured in 24-well plates at a concentration of 5×10^5 cells /ml.Water-based suspension of MNPs in the concentration of 100 µg/ml was added to a cell suspension. Then the plates were transferred for 24 hours to an incubator (5% CO2, 37°C). After 24 h of cultivation,Nd-Fe-Bbased cylinder magnetswith a magnetic field strength on surface 0.30, 0.35 and 0.41 T were placed directly under the wells.Analysis of cell viability was performed with two methods: flow cytometry analysis using the dye propidium iodide andWST-1 assay.

The experimental results show that the incubation in SMF of 0.30 and 0.35 T withMNPs induce a cytotoxic effect in the Jurkat cell line (Jurkat viability was not inhibited after 0.41 T SMF with MNPs treatment) but did not change the viability of the PBMC (Fig. 1). At the same time, theMNPs decreased Jurkat viability after 24 h cultivation without magnetic field sources. The difference of cytotoxic processes in the PBMC and Jurkat cell line which induced byMNPs in the presence of SMF can be used in biomedical techniques development.

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

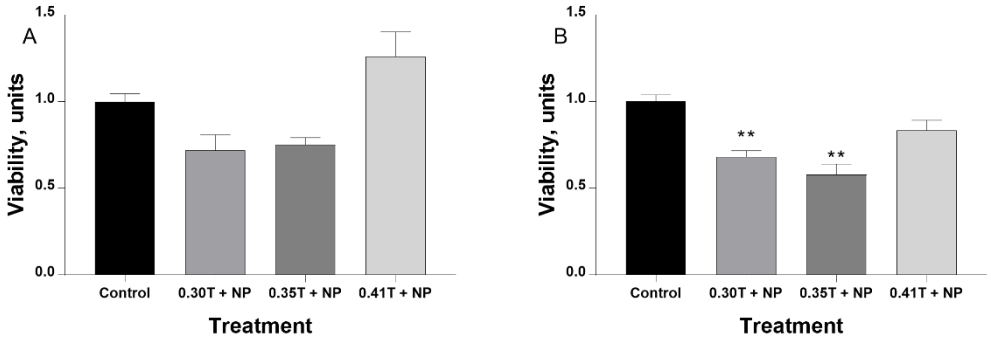


Figure 1. Viability of PBMC (A) and Jurkat cells (B) after 24 h SMF (0.30T, 0.35T, 0.41T) treatment with MNPs(100 µg/ml). Analysis of cell viability was performed by WST-1 assay.

[1] L. Zhang, ONCOTARGET13126, 8.8 (2017)
[2] J. Barreto, ADV MATERH18-H40, 23.12 (2011)

Fundamental and technical restrictions for possibilities of magnetic targeted drug delivery

M.A. PYATAEV*, M.N. ZHARKOV, N.A. PYATAEV

National Research Ogarev Mordovia State University, 430005, Bolshevistskaya, 68, Saransk, Russia

*pyataevma@gmail.com

Targeted drug delivery based on magnetic nanoparticles is one of the rapidly developing areas of modern medical science. A large number of works are devoted to various aspects of the microcapsules manufacturing and the incorporation of various drugs into them. However, the restricted possibility to deliver the magnetic carriers into a specified region of a living body is often overlooked. Meanwhile, there are both fundamental and technical limitations of the possibilities of magnetic-controlled transport. For many drugs, targeted delivery is practically useful only when the concentration of the substance in the inner region of the body is significantly higher than on the surface. In the present work, we investigate theoretically the possibility of concentrating particles by the magnetic field in various sites of a living organism.

One of the important features of the magnetic particles used in targeted delivery is the possibility of free rotation of particles in a liquid. As a result, the average magnetic moment of the particles is always directed along the external magnetic field, and the force acting on the particle is directed along the gradient of $\boldsymbol{B}^2$, regardless of the shape and internal structure of the particle. Based on the Maxwell's equations, we have shown that it is impossible to create a static magnetic field having a maximum of $\boldsymbol{B}^2$ inside a simply connected domain without sources of field. Therefore, it is impossible to create a force that would attract particles to some internal point of the body using static magnetic field. This result is similar to the well-known Irnshaw theorem for the electrostatics.

The use of an alternating field for the concentration of particles in the inner region of the body faces limitations of another kind, which can be considered as "technical" but are almost impossible to overcome. Although some modern devices with a feedback are able to provide a levitation of magnetic objects, there are at least two requirements for such devices: the sufficient value of force and the feedback. We will discuss here the force only, although the feedback is an extremely difficult problem too. It seems reasonable that to provide control over the particle motion the magnetic force in the device has to be able to at least to stop the particle in the bloodstream. The magnetic force is proportional to the mass of the particle or to the cube of its diameter while the Stokes force acting on a motionless particle in the bloodstream is proportional to its linear size. Therefore, the larger the particle size, the greater the ratio of magnetic force to the Stokes force. However, in the case of medical use of particles, their size is bounded from above by the diameter of capillaries and must be of the order of 1 micron. The field gradient is also limited by sufficiently long required distances from the source (about 10 cm). That is why the magnetic force is not enough even for stopping of a particle in the blood vessels in the inner point of body. Therefore, it seems quite incredible to create a system capable to concentrate particles at a certain point within randomly distributed fluid flows.

Thus, we can conclude that at the modern level of technology the use of magnetic targeted drug delivery is limited to the near surface areas of the body only.

The work is supported by the Russian Foundation for Basic Research (grant 18-415-130007).

Nanoparticles as Multifunctional Probes for Cancer Theranostics

YANGLONG HOU[a,*], JIUHONG QIAN[b]

[a]Beijing Key Laboratory for Magnetoelectric Materials and Devices (BKLMMD)，College of Engineering, Peking University, Beijing 100871, CHINA

[b]Editorial Office of Rare Metals, Beijing 100088, CHINA

*****hou@pku.edu.cn

Photothermal therapy(PTT), using light to cause thermal damage, is a revolutionaryapproach in tumor therapy because of its spatiotemporalcontrollability, high efficiency and minimal harm to normaltissues. However, without using imaging contrast agents,it is very difficult for PTT to achieve its precise therapeuticeffects since its accuracy is compromised[1-3].

Herein, we firstly introduced general protocol to produce multifunctional Fe_5C_2nanoparticles, which developed as multifunctional probes for imaging-guided cancer therapy owing to their magnetic features and additive photothermal characteristics. T_2-weighted MRI and PAT signals were observed, and tumors were effectively ablated by PTT under NIR irradiation without no obvious side effects [4]. In order to further develop iron carbides, we incorporated Au element, which has excellentoptical properties, into MNPs to form nanocomposites that can show both magnetic and optical properties in one unit. The material exhibited strongPTT effects with a 30.2% calculated photothermal transductionefficiency *in vitro*. Au-Fe_2C NPs were capable of MRI/multispectral photoacoustic tomography/computed tomography tri-modal imaging-guided PTT agents [5].

What's more, Au_3Cu tetrapod nanocrystals (TPNCs) were prepared by a facile seed-mediated growth method for imaging-guided PTT for tumors in the NIR-II window. The Au_3Cu TPNCs exhibited remarkable photostability, ability for deep tissue photothermal therapy and excellent photothermal performance with 75.27% photothermal conversion efficiency under 1064 nm laser irradiation, and could serve as efficient photoacoustic and photothermal agents. Furthermore, Au_3Cu TPNCs could achieve renal clearance through degradation in the tumor microenvironment after the process of PTT [6].

In summary, we developed multifucntional nanoparticles, including Fe_5C_2, Au-Fe_2C NPs and Au_3Cu TPNCsas a multifunctional probes for cancer treatment.

[1] R. Hao, R. Xing, Z. Xu, Y. Hou, S. Gao, S. Sun, *Adv. Mate*r. 22 (2010) 2729–2742.
[2] Z. Xu, C. Shen, Y. Hou, H. Gao, S. Sun. *Chem. Mater*.21(2009), 1778−1780.
[3] J. Yu, F. Chen, W. Gao, Y. Ju, X. Chu, S. Che, Y. Hou. *Nanoscale Horiz.* 2 (2017), 81-88.
[4] J. Yu, C. Yang, J. Li, Y. Ding, L. Zhang, M.Z. Yousaf, J. Lin, R. Pang, L. Wei, L. Xu, *Adv. Mater.* 26 (2014) 4114−4120.
[5] Y. Ju, H. Zhang, J. Yu, S. Tong, N. Tian, Z. Wang, X. Wang, X. Su, X. Chu, J. Lin, Y. Ding, G. Li, F. Sheng, Y. Hou, *ACS Nano* 11(2017), 9239−9248.
[6] Z. Wang, Y. Ju, S. Tong, H. Zhang, J. Lin, B. Wang , Y. Hou, *Nano Horiz.*2018, DOI: 10.1039/c8nh00135a

Gas bubbles in magnetic fluids in a non-uniform magnetic field

P.A. RYAPOLOV[a,*], V.M. POLUNIN[a], E.A. SOKOLOV[a]

[a]Southwest State University, 305048, 50 let Octyabrya 94, Kursk, Russia

*r-piter@yandex.ru

Studies of gas inclusions: bubbles and cavities in a magnetic fluid (MF) are of interest due to the possibility of control using an external magnetic field [1-3]. In the previous work [4], the dynamics of gas inclusions in the MF, filling a cylindrical tube with a diameter of 12 mm, was studied. In this paper, the installation used in [4] is upgraded by using a transparent channel and video recording system with special software developed in LabView. A concentration series of MFs based on kerosene was studied. Concentrations of samples MF-1-MF-4 are 10.56%, 6.32%, 3.93%, 2.08% respectively. Figure 1 shows the result of video recording of the air cavity in the MF-1 in a flat channel. It can be seen from the figure that the upper part of the gas-MF interface intersects the isolines of the magnetic field strength modulus of 35 kA/m.

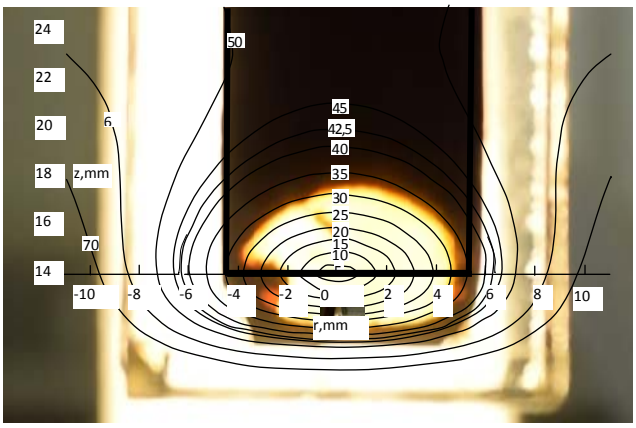


Fig 1. Air cavity in the magnetic fluid MF-1

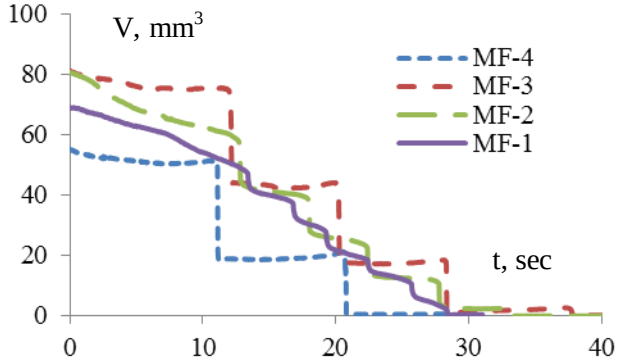


Fig. 2. Dependence of the air cavity volume on the time

Figure 2 shows a graph of the dependence of the volume of the air cavity on time; the time of touching the air cavity to the bottom of a flat channel is taken as a reference point. Vertical segments on the graph reflect the moment of a sharp change in the volume of the gas cavity, associated with the separation of the gas bubble. It can be seen from the graph that a small number of gas bubbles of large diameter is formed in the low concentrated MFs, the bubble is detached earlier. Concentrated MFs, on the contrary, are characterized by the formation of a large number of bubbles of small diameter. The data obtained for the sample MF-1, coincide with the data obtained in [4] using acoustic-magnetic method for experimental setup with a cylindrical tube filled with MF.

This work was supported by the grant of the President of the Russian Federation MK-1393.2019.8 and the basic part of the state assignment of the Ministry of Education and Science of the Russian Federation No. 3.8949.2017/BP.

[1]Ishimoto J, Okubo M, M 1995 JSME Int. J. Ser. B Fluids Therm. Eng. 38 382-387
[2]He Y Q, Bi Q C and Shi D X 2011 FDMP 7 357-370
[3]Bashtovoi V, Kovalev M and Reks A 2005 JMMM 289 350-352
[4]Polunin V M, Ryapolov P A, 2018 MHD 54 211-224

Determination of the physical parameters of magnetic fluids in oscillations in a magnetic field

P.A. RYAPOLOV[a,*], V.M. POLUNIN[a], E.V. SHEL'DESHOVA[a]

[a]Southwest State University, 305048, 50 let Octyabrya 94, Kursk, Russia

*r-piter@yandex.ru

To carry out complex measurements of the elastic-magnetic parameters of an MF column in a strong magnetic field — the frequency and attenuation coefficient of the oscillations, the displacement of the liquid when pressure is applied, and two different experimental setups are described for measuring the magnetization curve of the studied MF samples [1,2].

A concentration series of MFs based on kerosene was studied. Concentrations of samples MF-1-MF-3 are equal to 10.56%, 6.32%, 3.93%, respectively. Figure 1 presents experimental data on the magnetization curve of MF-1-MF-3 in the 3–750 kA/m strength range and calculated data obtained from the model theory for the 200–800 kA/m strength range. The values of the magnetostatic magnetization M_{xs}, shown in Figure 1 by squares, are calculated by formula (5) in [1]. To obtain M_{xs}, an array of experimental data is used to measure the gradient of the magnetic field strength at the base of the MF column and static measurements of the displacement of the MF column under pressure. The magnetodynamic magnetization M_{xd} is calculated by formula (18) in [1] using the results of measuring the oscillation frequency of the MF column. These data are shown in Figure 1 by triangles. Experimental results of direct measurement of magnetization (magnetization curve) of the objects under study are plotted with lines.

The values of magnetization shown in Figure 1, obtained by the method of "direct" determination and calculated according to the data of static and dynamic experiments for samples of MF-1-MF-3 in the field of magnetic fields close to the magnetic saturation, are in good agreement.

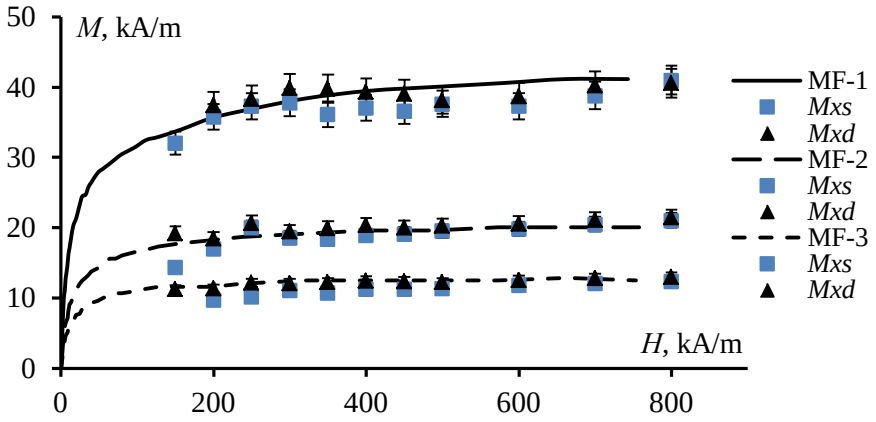


Figure 1

The work was performed as part of the project part of the state task of the Ministry of Education and Science of the Russian Federation. Project code 3.2751.2017/PP.

[1]Polunin V M, Ryapolov P A, Platonov V B, Sheldeshova E V, Karpova G V and Arefyev I M 2017 *ACOUST PHYS*+ 63 371–379

[2]Polunin V M, Emelianov S G, Ryapolov P A, Sheldeshova E V 2017 *MHD* 53 471–481.

Coil-Free Registration Of Converse Magnetoelectric Effect In Ferromagnetic-Piezoelectric Bilayers

D.A. Burdin, Y.K. Fetisov, N.A. Ekonomov, D.V. Chashin, D.V. Saveliev*

MIREA - Russian technological university, 119454, Vernadskogo 78, Moscow, Russia e-mail: dimsav94@gmail.com

The converse magnetoelectric (ME) effect in planar composite structures consisting of ferromagnetic (FM) and piezoelectric (PE) layers is manifested as a change of magnetization M under action of an electric field E [1]. The effect arises from a combination of the piezoelectric effect in the PE layer and the elastomagnetic effect in the FM layer due to the mechanical coupling between the layers. The change in M is usually detected with an electromagnetic coil. However, the use of coils significantly limits applications of the converse ME effect in integrated electronic devices. This paper demonstrates the possibility of registering the converse ME effect in planar structures without using coils - by measuring the voltage generated by the FM layer of the structure.

A structure containing a PE layer of dimensions 5x33 mm^2 and 0.3 mm thick made of PZT-5 ceramics and an FM layer of dimensions 2x20 mm^2 and 20 μm thick of amorphous Metglas 26053A alloy was used in measurements. A photo-curable polymer film, 5 μm thick, was deposited on one PZT electrode. Then the Metglas ribbon was bonded to the insulated surface of the PE layer using the cyanoacrylate glue. The structure was placed in a DC magnetic field H, directed parallel to its long side. A voltage of main longitudinal acoustic resonance frequency f =46 kHz was applied to the PZT layer electrodes, creating the electric field e=330 V/cm. The ac voltage $u(f)$ generated between the ends of the Metglas layer was measured using a SR770 FFT spectrum analyzer.

We observed two harmonics with amplitudes $u_1(f)$ and $u_2(2f)$ in the spectrum of generated voltage. Figure 1 shows dependences of these harmonics amplitudes on the bias field H. It is seen, that the first harmonic is observed in presence of pickup signal of about 100 μV and reaches a maximum of $u_1 \approx$ 150 μV at $H \approx$6-8 Oe. The second harmonic has maximum $u_2 \approx$100 μV at H=0, vanishes at H~7 Oe, reaches a local maximum at H~15 Oe, and thentends to zero when the FM layer is saturated. Field dependences of the harmonic amplitudes at converse ME effect, as for the direct ME effect, qualitatively repeat the field dependences of the 1st and 2nd derivatives of themagnetostriction over the field [2].

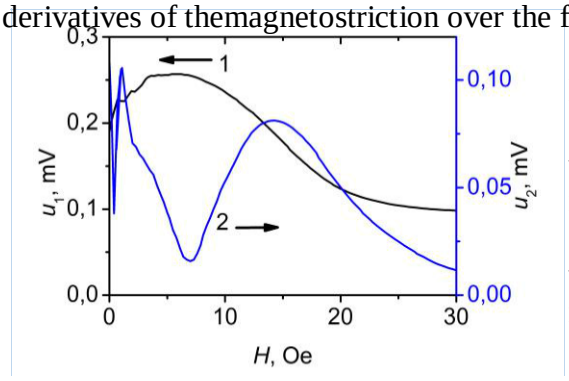


Fig.1. Dependences of harmonics amplitudes u1 (1) and u2 (2) on field H

The voltage u appears between ends of FM layer due to electromagnetic induction in the loop formed by the conducting FM layer and connecting wires. This induction results from variation of magnetization of the Metglas layer caused by the converse ME effect. In spiteof small output signal value, the coil-free method of converse ME effect registration in composite structures has several advantages over using of volumetric coils, such as reducing the sizes and simplifying design of the device, ability to manufacture the entire device in a single technological cycle.

The work was supported by the Ministry of Education and Science of Russian Federation, grant MK-2639.2018.2.

[1]D. Viehland, Journal of Physics D:Applied Physics, 51, 26 (2018)

[2]D.A. Burdin, D.V. Chashin, N.A. Ekonomov, L.Y. Fetisov, Y.K. Fetisov, G. Sreenivasulu, G. Srinivasan, JMMM 358-359, 98-104 (2014)

Magnetocrystalline anisotropy and magnetic domain structure of the $Y_2(Fe_xCo_{1-x})_{17}$ compounds

E. SEMENOVA[a,*], M. LYAKHOVA[a], A. SINKEVICH[a], A. KARPENKOV[a,b], E. AIRIYAN[a], YU. PASTUSHENKOV[a]

[a]Tver State University, 170002, Sadoviy per. 35, Tver, Russia

[b]Lomonosov Moscow State University, 119991, Leninskie gory GSP-1, Moscow, Russia

*semenova_e_m@mail.ru

Both binary intermetallic compounds Y_2Co_{17} and Y_2Fe_{17} have magnetocrystalline anisotropy (MCA) "easy magnetization plane" at room temperature [1,2]. However, according to [3,4] in the $Y_2(Fe_xCo_{1-x})_{17}$ quasi-binary rare earth intermetallic compounds the change in MCA from the "easy magnetization plane" to the "easy axis of magnetization" in the iron concentrations interval of $0.05 < x < 0,5$ was found.

In this paper, the effect of Co substitution on Fe on magnetocrystalline anisotropy and the magnetic domain structure of $Y_2(Fe_xCo_{1-x})_{17}$ single crystals was studied. Magnetic measurements were carried out by vibration sample magnetometer, structural studies by x-ray diffraction, optical (Axiovert 200MAT) and magnetic force microscopy (Solver Next). It was shown that the substitution of Co by Fe leads to changes in the saturation magnetization, field and MCA type, Curie temperature, as well as the configuration of the magnetic domain structure of $Y_2(Fe_xCo_{1-x})_{17}$ compounds. Fig.1 shows the images obtained by magnetic force microscopy on the basal plane of the single crystals with different concentrations of Fe. In this paper, a micromagnetic analysis of the domain structure was performed.

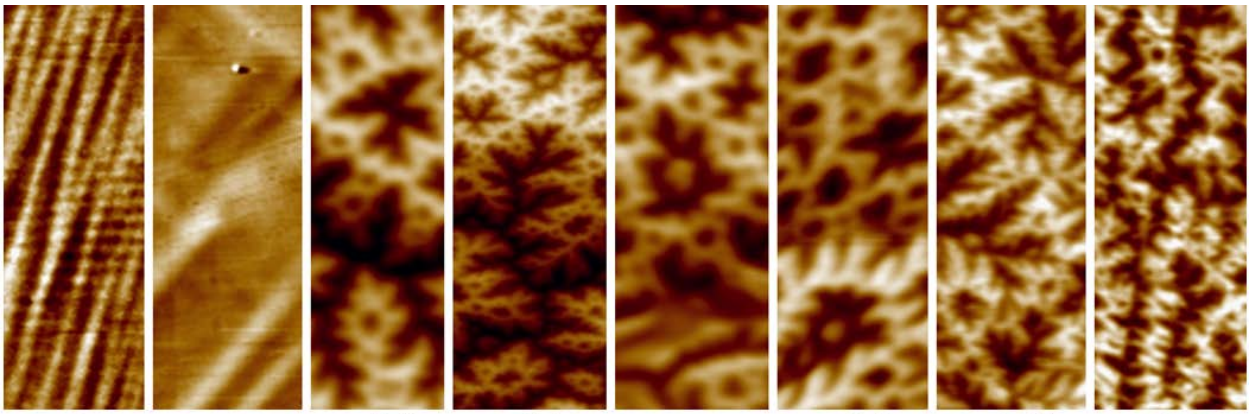


Fig.1. MFM images of the domain structure at the basal surface of a $Y_2(Fe_xCo_{1-x})_{17}$ single crystals recorded from a 10x25 μm area.

This work is performed with financial support of the grant of Russian Scientific Foundation (project № 18-13-00135)

[1] S. Brennan, R. Skomski, O. Cugat, J.M.D. Coey, JMMM 140-144, 971 (1995)
[2] J. Hoffer, K. Strnat, IEEE Trans. Mag. MAG-2, 487 (1966)
[3] R.S. Perkins, H. Nagel, Physica 80B, 143(1975)
[4] H. Chen, W.-W. Ho, S.G. Sankar, W.E. Wallace, JMMM 78, 203 (1989)

Anomalous magnetic contribution to thermal expansion in $Ce_2Ni_3Si_5$.

D. Serebrennikov[a,*], E. Clementyev[a,B], A. Shapilov[b]

[a]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[b]Institute for Nuclear Research RAS, 117312, Fizicheskaya 27, Moscow, Russia

*****dimafania@mail.ru

Intermediate valence systems based on cerium are of particular interest for both fundamental physics and potential applications. These systems are characterized by the unique ground state – many-particle Kondo singlet, which gives rise to many anomalous lattice, electronic and magnetic properties. Cerium binary compounds have been studied extensively while a lack of experimental data is observed for many ternary compounds. Among these systems we will draw attention to intermetallic compound $Ce_2Ni_3Si_5$, which demonstrate many properties typical for intermediate valence systems. It's well known that cerium intermediate valence compounds may show anomalous high thermal expansion caused by additional magnetic/electronic contribution, which is temperature dependent.

This work presents experimental investigation of $Ce_2Ni_3Si_5$ thermal expansion: temperature dependence of the lattice constant has been defined by the diffraction technique, coefficient of thermal expansion (CTE) has been computed for 3 main crystallographic directions. To define the lattice contribution to CTE of $Ce_2Ni_3Si_5$ a novel approach has been proposed. Anomalous magnetic/electronic contribution to CTE has been analyzed quantitatively, the Kondo temperature has been estimated.

This work was supported by the RFBR grant 18-32-00583 mol_a.

Effect of Fe doping on structural, magnetic and elerctrical characteristics of manganites $La_{0.7}Sr_{0.3}Mn_{0.9}Zn_{0.1-x}Fe_xO_3$

A. BADELIN[a], V. KARPASYUK[a], D. MERKULOV[a], R. EREMINA[b],
I. YATSYK[b], A. SHESTAKOV[*, b], S. ESTEMIROVA[c, d]

[a]Astrakhan State University, 414056, Astrakhan, Russia

[b]Zavoisky Physical-Technical Institute ofFRC "KazSC of RAS", 420029, Kazan, Russia

[c]Institute for Metallurgy UB RAS, 620016, Yekaterinburg, Russia

[d]Ural Federal University, 620002, Yekaterinburg, Russia

*aleksey665@gmail.com

Substituted lanthanum manganites continue to attract the attention of researchers and applied specialists all over the world [1, 2]. The effects of colossal magnetoresistance, giant magnetostriction, electrical switching, high magnetocaloric effects were used in modern technology and medicine.

The aim of this work was to study effect of Fe^{3+} substitution of Zn^{2+} in lanthanum-strontium manganite $La_{0.7}Sr_{0.3}Mn_{0.9}Zn_{0.1-x}Fe_xO_3$ (x = 0; 0.025; 0.075; 0.100) by the microwave absorption by using magnetic resonance method. The electron spin resonance (ESR) spectra were recorded in the X- (9.4 GHz) range on a Bruker ER 200 SRC (EMX/plus) spectrometer in the temperature range from 100 to 300 K and on a Varian E-12 spectrometer in the range of 300 - 600 K.

In samples with high Fe concentration (x = 0.075 и 0.1) over the entire temperature range there is only one exchange narrowed line, caused by the Mn^{3+} and Mn^{4+} ions, at x=0.075, x=0 there is an additional line from ferromagnetic nanoclusters (Fig. 1., Fig. 2.).

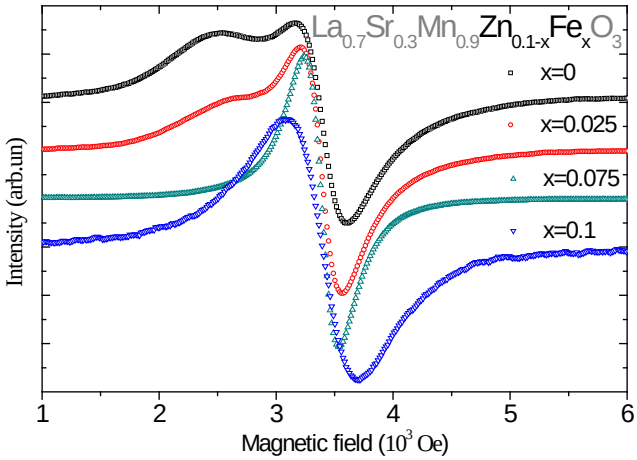


Fig. 1. The EPR spectra at room temperature of the manganites $La_{0.7}Sr_{0.3}Mn_{0.9}Zn_{0.1-x}Fe_xO_3$

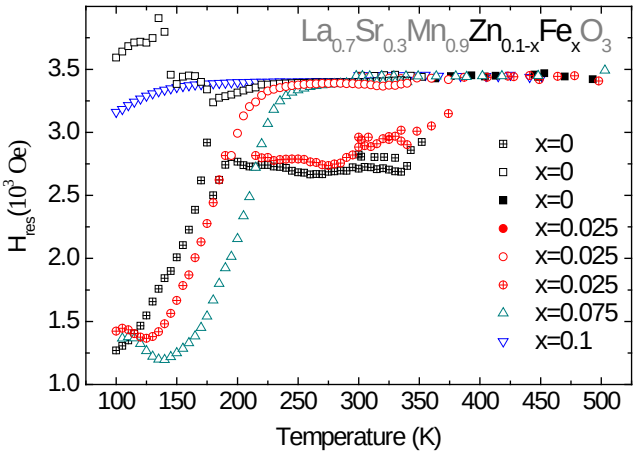


Fig. 2. Temperature dependence of the resonance magnetic field (Hres) of EPR lines in manganites

This work was supported by the RFBR grant № 18-52-06011.

[1] R. Jacobs, J. Booske, D. Morgan, Advanced Functional Materials, 26, 30 (2016)
[2] A. Golenishchev-Kutuzov, V. Golenishchev-Kutuzov, R. Kalimullin, A. Semennikov, Bulletin of the Russian Academy of Sciences: Physics, 79 (11), 1394–1396 (2015)

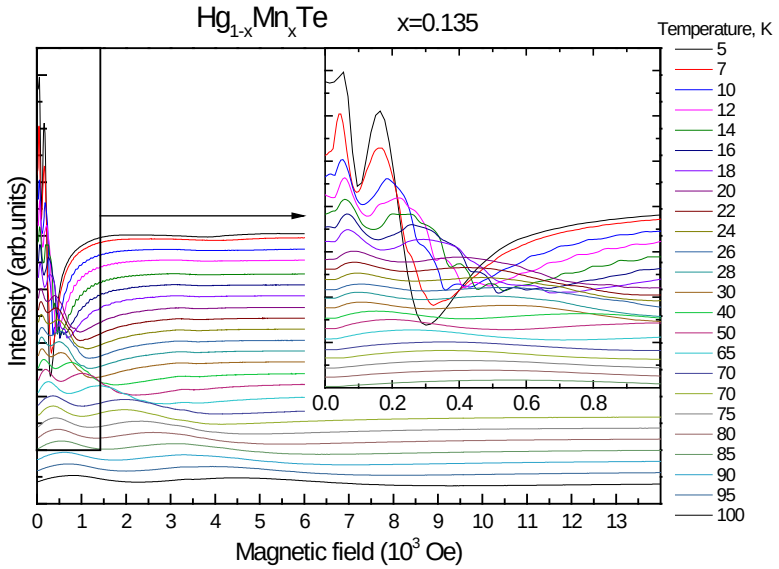
Magneticproperties temperature dependence of $Hg_{0.865}Mn_{0.135}Te$

A. SHESTAKOV*, I. YATSYK, M. IBRAGIMOVA, I. R. EREMINA,

Zavoisky Physical-Technical Institute ofFederal Research Center "Kazan Scientific Center of RAS", 420029, Sibirsky tract 10/7, Kazan, Russia

*aleksey665@gmail.com

In diluted magnetic semiconductors, the strong spin-spin interactions between band electrons and localized magnetic ions lead to a host of entirely new magnetooptical physical phenomena, such as giant Faraday, giant Kerr, photoinduced magnetization effects, which was first demonstrated in monocrystals $Mn_xHg_{1-x}Te$ (MHT) by Krenn [1]. Characteristics of charge carriers can be investigated by the microwave absorption by using magnetic resonance method. The aim of this work was to study the magnetic and transport properties of the $Mn_xHg_{1-x}Te$ (x=0.135) monocrystals by magnetic resonance method. The electron spin resonance (ESR) spectra were recorded using ER 200 SRC (EMX/plus) spectrometer (Bruker) in X-band 9.4 GHz. Measurements were performed at the temperatures 4.2–100 K and at the magnetic fields varying from 0 to $1.4 \cdot 10^4$ Oe. Temperature dependencies of ESR spectra are presented in Fig. 1 for single crystals $Hg_{0.865}Mn_{0.135}Te$. As shown in Fig.1, two lines with strong temperature dependence were observed in X- band spectra due to all Mn^{2+} ions and charge carriers. We obtained the temperature dependencies of resonance fields and linewidths of magnetic resonance lines in $Hg_{0.865}Mn_{0.135}Te$.



Specific heat in different magnetic were measured at a temperature of 5 and 300K on the multifunctional system for measuring physical properties with superconducting magnet PPMS-9. The nature of the exchange interactions between the spins of the charge carriers and the spins of the manganese ions is discussed.

[1]H. Krenn, W. Zawadzki, and G. Bauer, Phys. Rev. Lett. 55, 1510(1985)

The evolution of martensitic transformation in Ni-Mn-Ga/Al2O3 and freestanding polycrystalline films with Ni- and Ga-excess

S. SHEVYRTALOV[a,*], H. MIKI[b], I. LYATUN[a], V. RODIONOVA[a, c]

[a]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[b]Frontier Research Institute for Interdisciplinary Sciences (FRIS), Tohoku University, Sendai, 980-8578, Japan

[c] National University of Science and Technology MISiS, Moscow, 119049, Russia

*shevyrtalov@gmail.com

Polycrystalline $Ni_{54}Mn_{18}Ga_{28}$ films with thicknesses ranging from 100-nm to 2-um were fabricated by deposition on alumina ceramic substrates; bulk and surface properties were then characterized by structural and magnetic methods. The evolution of martensitic transformation of the films was studied. Both martensitic transformation and Curie temperature were found to be above room temperature, with the former overlapping the latter when films thicker than 100-nm were used. Static magnetic properties revealed the presence of strong internal stresses in the films, thus influencing coercive force value which changes with the increase in thickness. A distinct presence of martensitic twinning at room temperature was revealed, which started with the 400-nm film and increased with the 1- and 2-um films. A maze-like domain structure (without correlation to the surface features), was found in the 1- and 2-um films. A strong dependence between crystallites and magnetic domains was discovered in films ranging from 100- to 400-nm. A nonlinear dependence of the domain width on the film thickness was also observed, which converges with the coercive force dependence.

We compared martensitic transformation (MT) parameters and magnetic properties in a polycrystalline Ni-Mn-Ga freestanding and a sputter deposited on Al_2O_3 substrate 2-um films with excess Ni and Ga. Both films had MT above the room temperature. The MT region was wider in the freestanding film. The films demonstrated the isotropic in-plane behavior of magnetic properties. A step-like behavior was observed in the magnetization reversal process in the freestanding film because there were second phase impurities. In the substrate-constrained film, only broadening in magnetization loops because of internal stresses was observed. The easy magnetization axis oriented normally to the film plane of the freestanding film but had a preferred orientation in the film plane of the substrate-constrained film. Both films exhibited a maze-like surface magnetic domain structure with the domain width of approximately 0.9 um with different stripe structures, which confirms the presence of out-of-plane anisotropy. Based on these results, the effects of the substrate on the MT, structural and magnetic properties and the type of internal stresses were discussed.

A Full Sample-Type MI Gradiometer Based on Programable Circuit

A.Ke.Shi[a*], B.T. Uchiyama[a]

[a]Graduate School of Engineering, Nagoya University, Nagoya, AICHI, 464-8603, JAPAN

*shike910418@gmail.com

The magnetic sensor used for various applications, such as geomagnetic measurement, foreign matter detection and bio-magnetic signal sensing.MI sensor is based on magneto impedance (MI) effect in an amorphous wire [1]. We find that the conventional circuit is not suitable for all type of MI sensor.in our research, a field-programmable gate array (FPGA) is used to develop a programable circuit to suitable for any type of MI sensor.

We consider a novel circuit design for MI sensor system, which is based on analogue integration circuit.to sample the full waveform of sensor's output..We put our measuring system in a magnetic shielding box, the input magnetic field,which is generated by the Helmholtz coil, was set to be a sine wave of 10Hz with an amplitude of 450pT.

Figure.1 indicate that although the decibel value around 10 Hz was -20 dB in the previous system, the decibel value around 10 Hz was -25 dB in the proposed system.

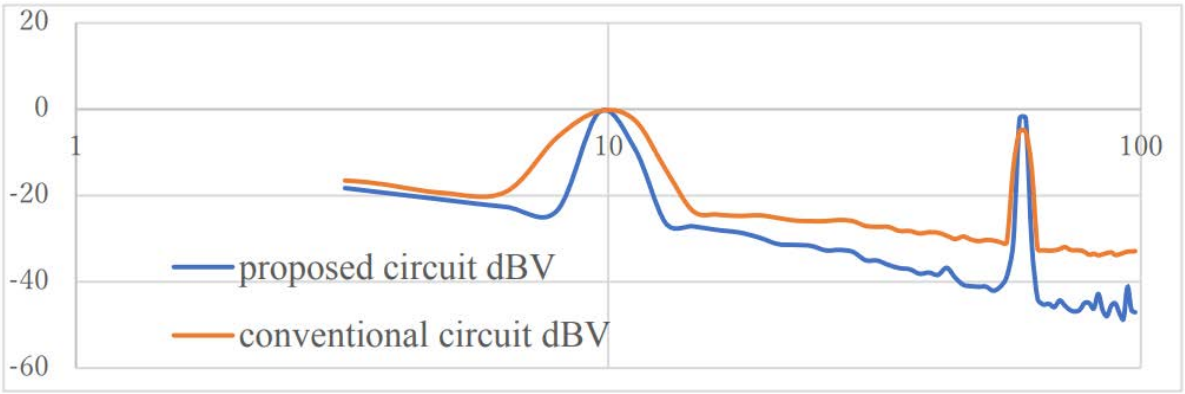


Figure.1 The S/N ratio of the system by frequency analysis.

We have demonstrated a new MI sensor system based on programable circuit, which can suitable for any type of MI sensor. The experimental results indicate that the proposed system has high resolution and high signal-to-noise ratio.

[1]K. Mohri and Y. Honkura, "Amorphous wire and CMOS IC based magneto-impedance sensors—origin, topics, and future—," SENSOR LETTERS, vol. 5, pp. 267-270, 2007.

Nanostructured gradient Cu–Cr–W composites by combined use of high energy ball milling and spark plasma sintering

N.F. SHKODICH[a,b*], K.V. KUSKOV[b], A.A. NEPAPUSHEV[b], G.V. TRUSOV[b], YU.S.VERGUNOVA[a].

[a]Merzhanov Institute of Structural Macrokinetics and Materials Science Russian Academy of Sciences, Academician Osipyan str. 8, Chernogolovka, Moscow Region, 142432 Russia

[b] Center of Functional Nano-Ceramics, NUST "MISIS", Moscow, 119049 Russia

*n.f.shkodich@mail.ru

Combination of refractory metals (such as Cr, W, Mo Ta and etc.) with a low-melting electro/thermo-conducting Cu opens up a way to designing novel materials for various applications (such as heat sinks elements, electrodes in thermoelectric devices and etc.) in modern engineering. Such copper-based metal matrix composites, also called pseudo alloys, possess excellent mechanical, electrical and thermo physical. Despite a wide range of existing materials suitable for use in various electrical contact materials, the problem of highly reliable one still remains far from its resolution. To produce high quality Cu-based pseudo alloys require that initial components should be mixed in a nanostructural level. However, the difficulty in production of such composites is low mutual solubility, high difference between their melting points and densities, and high wetting angle. And it cannot be overcome completely through the conventional melting and casting methods. High energy ball milling (HEBM) can yield stable microstructures with better homogeneity and nanostructures.

In this communication, we report on fabrication of nanoctructured gradient Cu–Cr–W pseudoalloys with different tungsten content by combined use of high energy ball milling and spark plasma sintering techniques (fig.1).

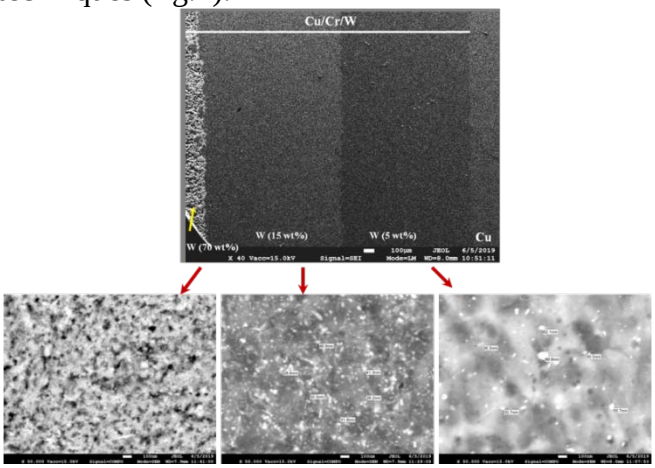


Figure 1.SEM of the cross action of nanostructured gradient Cu–Cr–W composite SPS-consolidated at 800°C.

The XRD and SEM results showed the composites Cu-Cr-W (5 wt/% - 70 wt.%) ball milled in "Activator 2S" for 150 min represent the Cu matrix uniformly doped with nanograins of W (20–100 nm) and Cr (20–50 nm). The structures formed during HEBM are retained after SPS-consolidation. HEBM leads to a fivefold increase in the microhardness of consolidated Cu–Cr–W pseudoalloys (max. value of H_v = 9.5 ±0,72 GPa) compared to the alloys derived from non-activated powders. Electrical resistance of our Cu–Cr–W composite is higher than 25% of International Annealed Copper Standard (1.72 μΩcm), which is tolerable for its use as an interrupter contact material.

This work was financially supported by the Russian Foundation for Basic Research (project no. 18-38-00843mol_a).

Peculiarities of morphology and magnetic properties of metallic nanotubes

A. SHUMSKAYA[a,*]

[a]Scientific and Practical Materials Research Centre of the National Academy of Sciences of Belarus, 220072, P.Brovki str., 19, Minsk, Belarus

*lunka7@mail.ru

Today, significant efforts of research groups are focused on synthesizing and studying the properties of nanoscale metallic materials such as nanotubes (NTs) and nanowires (NWs) [1,2]. They are perspective for to the wide range of potential applications: from electronics, computer technology and communications to the biotechnology. Investigation of nanosize structures is an attractive and important area of research not only due to possibility to miniaturize devices but to understand the unique properties of nanostructures, which could be different from macro objects.

One of the most attractive methods of obtaining NTs and NWs is a template synthesis, which allows designing metallic or semiconductor NTs and NWs with an aspect ratio from 1 to 1000. Ion-track membranes or matrixes of anodized aluminum oxide are usually used as templates. Both types of templates have parallel pores and allow synthesizing NTs and NWs from a diameter of several tens of nanometers to microns. We present a special case of the use of template synthesis method to obtain nanostructures from iron, nickel and their alloys in the pores of polyethylene terephthalate ion-track membrane by electrochemical deposition. The main idea of the work is to study the influence of dimensions of obtained nanotubes on structure, morphology and crystallinity as well as the main magnetic parameters.

NTs on the base of iron, nickel and their alloys with different length and diameters were synthesized by electrodeposition in pores of PET ion-track membranes. Moreover, series of NTs arrays were produced under different deposition conditions: at potential difference of 1.25–2.00 V and temperatures of 25–50°C and electrolyte concentrations. It was shown that the increase of temperature and potential as well as pores diameter provides a rise of deposition rate. Corresponding decrease of wall thickness and amount of defects is estimated.

Analysis of hysteresis loops allows to determine that the synthesized NTs belong to the class of magnetically soft materials with strong magnetic anisotropy. The presence of defects and oxide impurities in the structure of some samples leads to a deterioration of structural properties, the appearance of amorphous inclusions in the structure, which cause the deterioration in magnetic characteristics of synthesized NTs. Magnetic anisotropy in NTs has nonlinear character of its dependence on the morphology and structure. The change in structural characteristics greatly influence on NTs magnetic properties. The complex dependence nature is related to the total effect of magnetocrystalline anisotropy, amount of deffects in NTs structure, and shape anisotropy. The contribution of each factors for iron, nickel and their alloys NTs is determined.

[1]V. Vega, T. Böhnert, S. Martens, et al. Nanotechnology. 23 465709 (2012).
[2]I. V. Korolkov, D.B. Borgekov, A.A. Mashentseva, et al. Chem Pap. June 2017 (2017).

Synthesis and characterization of PVP-coated Fe_2O_3 nanoparticles for DNA extraction

I. SMIRNOV[a,*], E. KOZENKOVA[a], O. MOZHEY[a], I. KOZENKOV[a], J. NALENCH[b], M. ABAKUMOV[b], S. JOVANOVIC[c,d],A. OMELYANCHIK[a], S. TOSHCHAKOV[e], A. ZYUBIN[a], I. SAMUSEV[a], V. RODIONOVA[a]

[a]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

[b]National University of Science and Technology "MISiS", 119049, Moscow, Russia

[c]Advanced materials department, Jožef Stefan Institute, Ljubljana, Slovenia

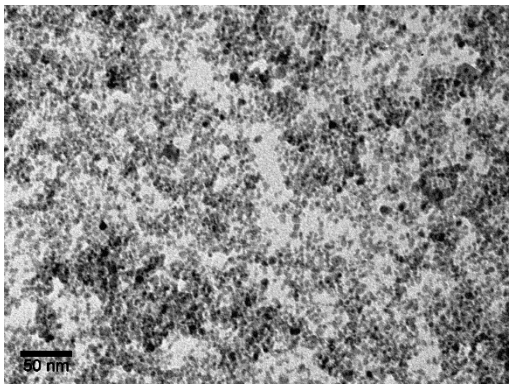
[d]Laboratory of Physics, Vinca institute of nuclear sciences, University of Belgrade, Belgrade, Serbia

[e] Winogradsky Institute of Microbiology, Federal Research Center for Biotechnology, Russian Academy of Sciences, Prospect 60-Letiya Oktyabrya7/2, Moscow 117312, Russia

***** igorgrigorevych@mail.ru

Magnetic iron oxide nanoparticles (IONs) were synthesized by co-precipitation method in an alkaline medium according to the protocol of Jovanovic et al. with some modifications [1]. IONs size distribution, morphology and phase composition was studied using transmission electron microscopy (TEM), X-ray diffraction (XRD) and Raman spectroscopy. According to TEM, individual nanocrystallites has a hexagonal shape with the average size of 8.2±0.4nm and the hematite phase formation was confirmed by XRD pattern and RAMAN spectra.The iron oxide core was covered with a high molecular weight polyvinylpyrrolidone (PVP) shell in the separate synthesis step. Such coating used for preventing agglomeration of IONs, fig.1 [2].
The composition and temperature of destruction of the polymers around 380° C were determined by the methods of differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA).

These nanostructures show low tendency to agglomerate, therefore, are suitable for further modification [3].



The PVP-coated IONs structures were successfully loaded with a test drug for demonstration of the capability of carrying a payload. Also, the total DNA extraction from different type of samples was done and compared for the commercially available kits with magnetic beads for DNA extraction.

Figure 1. TEM image of IONs covered by PVP

[1] S. Jovanović, J. Alloys Compd. 589, 271–277 (2014).
[2] Y. Zhang, J. Mater. Sci.: Mater. Med. 21, 1205 (2010)
[3] B. Nagorniewicz MSc, Nanomed.: Nanotech., B. and Med. 17, 106-118 (2019)

Silicon Nanowires for Biosensing Applications

T. Smolyarova[a,C,*], A. Lukyanenko [B,C], A. Tarasov [B,C], L. Shanidze [A,C], M. Rautskii [B], N. Volkov[A]

[a] Krasnoyarsk Science Center SB RAS, 660036, Academgorodok 50, Krasnoyarsk, Russia

[b]Kirensky Institute of Physics, 660036, Academgorodok 50/38, Krasnoyarsk, Russia

[c]Siberian Federal University, 660041, Svobodny pr. 79, Krasnoyarsk, Russia

*smol.nano@yandex.ru

Integrated nanoscale electronics pay the considerable attention to devices based on silicon nanowires [1] and to investigation of fundamental properties in nanoscale [2]. Silicon nanowires were fabricated from commercially available SOI (100) wafers with 200 nm of the buried oxide (BOX) and 100-nm monocrystalline top boron doped silicon layer using standard technology of electron beam lithography and reactive ion etching. The metal contact pads for the source (S) and drain (D) were connected to each end of the fabricated nanowire.

The result of the technological process is an array of silicon nanowire structures on a dielectric layer with metal pads, which allow to carry out the measurements of the electrical properties. Besides of the metal pads for the measurement of electrical properties in the fabricated structure a back gate was fabricated on the backside of the SOI substrate using doping with indium (In).

To make the silicon nanowires functionalized the organic polymer 1-octadecanethiol (ODT) dissolved in acetonitrile was deposited on the nanowire surface using the probe of atomic-force microscope [3]. When a detectable molecule is deposited on the surface of a nanowire, it acts as a virtual gate. AFM images show the width of the silicon nanowires are approximately 0.4, 0.8, 2 μm Fig 1(b, c, d). The I_{SD}-V_{SD} characteristics for nanowire with 0.4, 0.8, 2 μm width are presented in Fig. 1 (e).

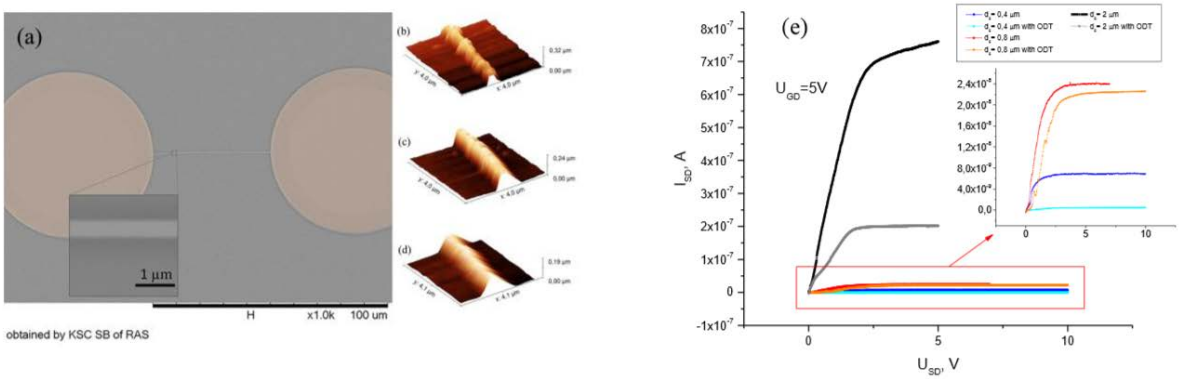


Figure 1. (a) SEM, (b, c, d) AFM images and (e) I_{SD}-V_{SD} characteristics of fabricated devices with nanowire 0.4, 0.8, 2 μm in width correspondingly

[1]Y. Ning, Analytica Chimica Acta 749, 24 (2012)
[2]T. Mikolajick, Anisotropic Nanomaterials, 1-25 (2015)
[3]R. D. Piner, J. Science 283 (5402), 661 (1999)

The ternary phase diagrams of the Ni-Mn-Ga alloys

Y. SOKOLOVSKAYA, O.N. MIROSHKINA, V. SOKOLOVSKIY*, M.A. ZAGREBIN, V.D. BUCHELNIKOV

[a]Chelyabinsk State University, 454001, Br. Kashirinykh Str. 129, Chelyabinsk, Russia

*vsokolovsky84@mail.ru

Nowadays. Heusler alloys represent a large family of ternary and quaternary metallic compounds that became known at first as magnetic shape-memory effect materials, like the canonic Ni2MnGa [1-3]. The large number of members of Heusler family and the richness of properties exhibited by them make this class of materials highly suitable for emerging materials-dependent technologies. It is generally accepted that properties of known alloys can be largely extended with numerous chemical substitutions. Computational approaches have been traditionally limited to stoichiometric compositions, like Ni_2MnGa, Co_2MnGa, Fe_2MnAl, and many others. Experiments, on the other hand, deal with wide ranges of chemical compositions. A number of computational approaches exists for studying such off-stoichiometric systems, however, this task remains very challenging, because none of the existing computational methods provide a comprehensive descriptions of an off-stoichiometric system.

In this work, we present a systematic study of disordered Heusler Ni-Mn-Ga alloys in martensitic phase with the goal of obtaining realistic and predictive compositional (ternary) phase diagrams, which will be used to reveal chemical trends that maximize realization of desired physical observables. Our calculations are performed by means of the density functional methodology as implemented in VASP code [4, 5] within the generalized-gradient approximation [6]. In order to generate a complete set of disorder compositions, the direct 16-atom supercell approach taking into account different atomic and magnetic configurations is used. Magnetic, structural and dynamic properties of selected Heusler alloys in martensitic phase are mapped on compositional diagrams, providing experimentalists with the roadmap for compositional tuning, and helping us to develop an efficient Monte-Carlo model for simulating mesoscopic properties of disordered Heusler alloys.

This work is supported by the Russian Foundation for Basic Research Grant 18-32-00507.

[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] G. Kresse, J. Furthmuller, Phys. Rev. B 54, 11169 (1996).
[5] G. Kresse, D. Joubert, Phys. Rev. B 59, 1758 (1999).
[6] J.P. Perdew, K. Burke, M. Ernzerhof, Phys. Rev. Lett. 77, 3865 (1996).

Magnetic properties of high entropy CoCrFeMnNialloy prepared by high-energy ball milling

M. Spasova[1*], N. F. Shkodich[2,3], K. V. Kuskov[3], Yu. S. Vergunova[2], G. V. Trusov[3], M. Farle
[1]Faculty of Physics and Center of Nanointegration, University of Duisburg-Essen, Duisburg, Germany
[2]Merzhanov institute of Structural Macrokinetics and Materials Science, Russian Academy of Sciences, Moscow, Russia
[3]Center of Functional Nano-Ceramics, National University of Science and Technology, Moscow, Russia
*e-mail: marina.spasova@uni-due.de

A novel approach to the fabrication of a new class of alloys—also known as high-entropy alloys (HEAs) was developed by Yeh et al. [1]. The HEAs containing at least 5 components in equiatomic or nearly equiatomic amounts (ranging between 5 and 35 at. %) are attractive in terms of mechanical, thermal, electrical and magnetic properties [2]. These HEAs are stabilized by the increase of the mixing entropy which is thought to suppress the formation of binary and ternary metallic phases and thus favors the formation of solid solutions of many elements.

HEAs have been fabricated by several methods, including arc melting and casting, mechanical alloying, and laser cladding. Among these, especially promising seems to be high-energy ball milling (HEBM) in planetary ball mills that can yield stable microstructures and nanocrystalline alloys of better homogeneity compared to other non-equilibrium processes [3].

We report the fabrication of CoCrFeMnNi HEA 10-20 μm particles by high-energy ball milling (HEBM) and spark plasma sintering (SPS) and provide their structural and magnetic characterization. Our XRD, SEM, and EDX results showed that a fcc CoCrFeMnNi solid solution with uniform distribution of the elements and refined microstructure of nanosized grains (~10 nm) could be obtained after 60 min HEBM. Magnetic studies reveal the presence of ferromagnetic (FM) and antiferromagnetic (AFM) phases below 50 K. Occurrence of exchange coupled FM and AFM phases is manifested in field-cooling (FC) induced effects [4], such as an unidirectional anisotropy (exchange bias), an increase in uniaxial anisotropy (enlarged coercivity) as well as a vertical shift of the hysteresis loop (Fig.1).

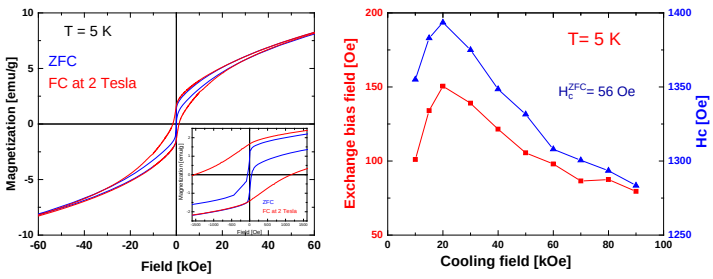


Fig. 1. Left: Magnetic hysteresis of CoCrFeMnNi HEA micrometer-sized powder recorded at 5 K after zero-field and field-cooling from 300 K. Right: Cooling-field dependence of exchange bias field (red) and coercivity (blue).

The as-milled HEA powder was subsequently consolidated by spark plasma sintering (SPS) at 800°C. In the consolidated HEA samples the fcc phase was preserved. A high Vickers hardness of 4.5 GPa is measured in the SPS consolidated HEA CoCrFeNiMn.

We thank M. Acet and U. Wiedwald for helpful discussions and I. D. Kovalev for his kind help in experiments. This work was financially supported by Russian Foundation for Basic Research through grant 18-53-15006.

[1]J.-W. Yeh, et al., Nanostructured high-entropy alloys with multiple principal elements: Novel alloy design concepts and outcomes, Adv. Eng. Mater. 6 (2004) 299-303.
[2]D.B. Miracle, O.N. Senkov, A critical review of high-entropy alloys and related concepts, *Acta Mater*. 122 (2017) 448–511.
[3]A.S. Rogachevet al, Experimental investigation of milling regimes in planetary ball mill and their influence on structure and reactivity of gasless powder exothermic mixtures, Powder Technology 274 (2015) 44–52.
[4]J. Nogués et al., Exchange bias in nanostructures, Phys. Reports 422 (2005) 65-117.

Effect of Al doping on the martensitic transformation andmagnetic properties of Ni-Co-Mn-Sb Alloy

Feng Luo [a, b], Xiong He [a], Zhen Yang [a], Bin He [a], Wenyu Zhao, and Zhigang Sun [a,*]

[a]State Key Laboratory of Advanced Technology for Materials Synthesis and Processing, Wuhan University of Technology, Wuhan 430070, China

[b]School of Physics and Electronic Science, Hubei University, Wuhan 430062, China

*sun_zg@whut.edu.cn

Due to its large magnetocaloric effect and excellent magnetoresistance, Heusler alloys have a wide application prospect in the field of magnetic refrigeration and magnetic sensors, and have received extensive attention. In this work, we studied the effects of Al doping on martensitic transformation, magnetocaloric effect and magnetoresistance of Ni-Co-Mn-Sb alloy. Ni46Co4Mn38Sb12 and Ni46Co4Mn38Sb11.5Al0.5 ingots in nominal composition were prepared by vacuum arc melting together with annealing treatment.

In Fig. 1, the martensitic transformation temperature interval *Tint*, magnetic entropy change Δ*Sm*, and refrigeration capacity RC are 8.5 K, 9.3 J/kgK@210 K and 42.2 J/kg@30 kOe for Ni46Co4Mn38Sb12 alloy, respectively. The addition of a small amount of Al decreases *Tint* to 5.0 K, meanwhile increase the Δ*Sm* and RC to 17.8 J/kgK@250 K and 72.4 J/kg @30 kOe for Ni46Co4Mn38Sb11.5Al0.5 alloy, respectively. Therefore, a small amount of Al doping can greatly increase the Curie temperature and promote the cooling capacity of NiMnSb.

This work was supported by the National Natural Science Foundation of China (Grant Nos. 11574243 and 11174231)

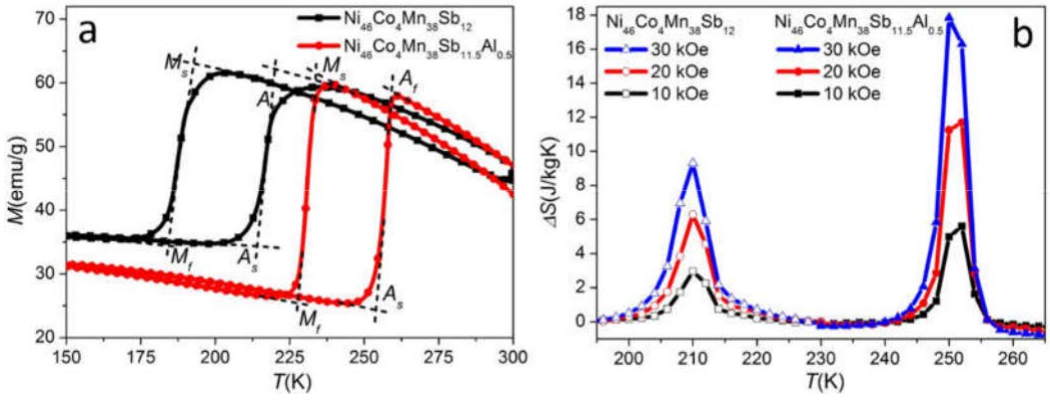


Fig.1 *(a)M-Tcurves of $Ni_{46}Co_4Mn_{38}Sb_{12}$and $Ni_{46}Co_4Mn_{38}Sb_{11.5}Al_{0.5}$, (b) ΔSm-Tcurves of$Ni_{46}Co_4Mn_{38}Sb_{12}$ and $Ni_{46}Co_4Mn_{38}Sb_{11.5}Al_{0.5}$*

[1]Zhang X, Qian M, Miao S, et al. J Alloy Compd, 656, 154(2015).
[2]Cong D Y, Huang L, Hardy V, et al. Acta Mater, 146(2018).

Formation and structure phase transition of Co nanowires on vicinal Cu(111) surfaces

A. Syromyatnikov* , A. Klavsyuk, A. Saletsky
Faculty of Physics, Moscow State University, Leninskie Gory, 1-2, 119991 Moscow, Russia
ag.syromjatnikov@physics.msu.ru

The energies of magnetic interactions between Co adatoms at the vicinal Cu(111) surface were calculated in the framework of the density functional theory [1]. It was demonstrated that the interactions between Co adatoms appreciably depend on the distance from a surface step. Our calculations show that the magnitude of the repulsive barrier related to the surface step is larger for Co adatoms located at the upper surface terrace than for those located at the lower surface terrace. This di erence is related to the charge redistribution at the step edge. The obtained results give an explanation to the fact that the formation of nanostructures at temperatures of the order of 100 K occurs at the lower part of the step, whereas at room temperature, they are formed at the upper part of the step.

A systematic theoretical study of the growth of metal atomic wires on a vicinal surface using rst-principles DFT calculations and kMC simulations was performed. We showed that the bond energy depends on the length of the atomic wire. This energy is considerably higher than the bond energy obtained experimentally [2]. This is due to the fact that the wires are metastable structures. It is not bond energy but di usion barriers that determine the length of metal atomic wires. Therefore, bond energy cannot be determined from the distribution of atomic wire lengths. Perhaps bond energy can be estimated from the melting point or the temperature at which the wires are destroyed.

We found that so-called wires with magical lengths [3] will be formed on the surface with di erent sizes of terraces [4]. The quantum size e ect does not a ect the distribution of atomic wire lengths. It depends mainly on the size of the terraces of the surface, the di usion barriers of dimers and adatoms along the step and such experimental parameters as temperature, coverage and ux [5].

In work [6] low-temperature scanning tunneling microscopy observations of a dimerization instability of a Co atomic-wire system self-assembled on a vicinal Cu(111) substrate were presented. The ab initio calculations are performed to study the structure of atom-wide Co wire on a vicinal Cu(111) surface [7]. We have found two ferromagnetic states of Co wires. In the rst state the Co wire consists of dimers, while in the second state the distance between atoms in Co wire is equal. Using Monte Carlo simulations we demonstrated the structure phase transition in a Co wire. Moreover, the phase transition temperature was determined and the size-e ect was studied [8].

We believe that our study will be very useful to understand the mechanisms that govern the growth of metal atom-wide wires and will initiate the creation of a new, more realistic theoretical model describing the length distribution of atomic wires.

[1]Syromyatnikov, A. G., Klavsyuk, A. L. and Saletsky, A. M. Analysis of interactions between Co adatoms on the vicinal Cu(111) surface. JETP Lett. 100, 2427 (2014).
[2]Zaki, N. et al. Atom-wide Co wires on Cu(775) at room temperature. Phys. Rev. B 80, 155419 (2009).
[3]Mocking, T. F. et al. Electronically stabilized nanowire growth. Nature Communications 4, 2387 (2013).
[4]Syromyatnikov, A. G., Saletsky, A. M. and Klavsyuk, A. L. Distributions of atomic wire lengths. Phys. Rev. B 97, 235444 (2018).
[5]Syromyatnikov, A. G., Saletsky, A. M. and Klavsyuk, A. L. Dependence of the Distribution of Atomic Chain Lengths on a Vicinal Surface on External Parameters. JETP Letters 107, 766769 (2018).
[6]Zaki, N. et al. Experimental observation of spin-exchange-induced dimerization of an atomic one-dimensional system.Phys. Rev. B 87, 161406 (2013).
[7]Syromyatnikov, A. G. et al. The structure phase transition in atom-wide Co wires on a vicinal Cu111 surface. Mater. Lett. 179, 6972 (2016).
[8]Syromyatnikov, A. G. et al. Formation and structural phase transition in Co atomic chains on a Cu(775) surface. J. Exp. Theor. Phys. 124, 139142 (2017).

Hard/soft magnetic heterostructures. Monte Carlo study

T.A. TAAEV*, K.SH. KHIZRIEV, M.A. MURTAZAEV, SH.K. KHIZRIEV, M.M. ISAEVA

Institute of Physics of Daghestan Scientific Centre of Russian Academy of Science, 367015, M. Yaragsky st. 94, Makhachkala, Russia

*taaev89@mail.ru

The synthesis of hard/soft magnetic heterostructures was first proposed in the 1991 year [1] and attracted the interest of researchers. They are composite materials involving alternating hard/soft magnetic layers, where unusual phenomena, such as one-dimensional heterophase spin spring, appear [2]. As well they are expected to use for the production of constant magnets, the creation of fast attenuators, perfect micro- and nano-devices for store, transmission, and processing of information, what makes them highly attractive for thorough examination.

In the most of hard/soft magnetic heterostructures there is strong in-plane anisotropy and magnetic moments lie in plane of bilayers [2]. Therefore, thermodynamic and field properties of magnetic hard/soft heterostructures can be estimated using a simple model integrating the standard XY-model [3-5]. The Hamiltonian of the model is written as:

$$H = -\frac{1}{2}\sum_{i,j} J\left(S_i^x S_j^x + S_i^y S_j^y\right) - \sum_i K\left(S_i^x\right)^2 - g\mu\sum_i \left(H_0^x S_i^x + H_0^y S_i^y\right), \qquad (1)$$

where the first sum allows for the exchange interaction of each magnetic atom with nearest neighbors inside layers; the second sum is a contribution of the anisotropy into a system energy; the third sum is a contribution of an external magnetic field into a system energy, $g \approx 2$ is the Lande factor, μ is the Bohr magneton, $H_0^{x,y}$ are projections the external magnetic field $\mathbf{H}_0$, $S_i^{x,y}$ are spin projections $\mathbf{S}_i$ localized on site i.

The temperature dependences of magnetization M, M_{hard}, and M_{soft}, their longitudinal and transverse components, heat capacity C, and magnetic susceptibilities χ, χ_{hard}, and χ_{soft} of the hard/soft magnetic bilayer model on the constant of the magnetic intralayer and interlayer exchange interaction were investigated.

We also investigated the processes of magnetization reversal of the hard/soft bilayer model under the action of an external magnetic field: the influence thickness of the hard and soft magnetic layers on the magnetization reversal of the magnetic bilayer. The magnetic reversal curves for all values of the magnetic intralayer and interlayer exchange interaction were plotted. Behavior of the magnetic bilayer under the external magnetic field was shown to agree with theoretical predictions well enough.

The study was funded by RFBR according to the research project № 18-32-00526.

[1] E.F. Kneller, R.Hawig, IEEE Trans. Magn.27**,** 3588 (1991).
[2] E.E. Fullerton, J.S. Jiang, et. al., Phys. Rev. B58**,** 12193 (1998).
[3] T.A. Taaev, K.Sh. Khizriev, et. al., J. Alloys and Comp.678, 167 (2016).
[4] T.A. Taaev, K.Sh. Khizriev, et. al., JETP 124, 924 (2017).
[5] T.A. Taaev, K.Sh. Khizriev, et. al., J. Alloys and Comp.785, 1253 (2019).

Thermal treatment of a magnetic metal-organic framework with improved electrochemical sodium storage performances

YAN ZHANG[1], HUINAN GUO[1], Huatang Yuan[1], Yongmei Wang[1], ChunXIA TIAN[2],YIJING WANG[1],*

[1]Key Laboratory of Advanced Energy Materials Chemistry (Ministry of Education), Renewable Energy Conversion and Storage Center (ReCast), College of Chemistry, Nankai University, 300071, Tianjin, P. R. China

[2]Journal of Analysis and Testing GRINM Group Co., Ltd. , 100088, Beijing, P.R.China

*wangyj@nankai.edu.cn

Metal-organic frameworks (MOFs) have emerged as novel porous crystalline materials and been applied to many fields due to their various crystal structures, controllable and permanent pore size.[1] Among the enormous family, transition metal (especially Fe, Co and Ni) based MOFs show not only excellent magnetic property but also interesting electrochemical performances and obtain much attention.[2] However, pristine MOFs generally show poor electrochemical performance and post-synthesize modification is a promising strategy to improve it.[3]

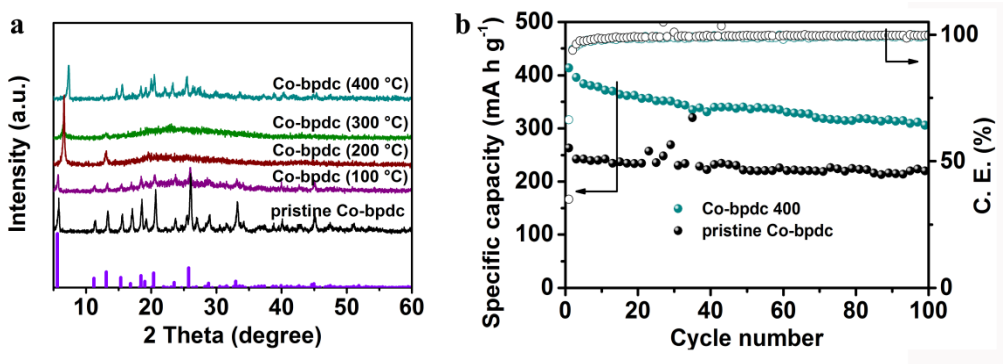


Figure 1 *(a) XRD patterns of Co-bpdc MOF at different temperature, (b) cycle performances of pristine Co-bpdc and Co-bpdc 400 at 100 mA* g^{-1}.

Herein, we offer a thermal treatment modification to enhance the sodium storage performances of a Co based magnetic MOF. The pristine MOF, Co-bpdc (bpdc, biphenyldicarboxylate) was obtained by a facile method in aqueous and further experienced a thermal treatment modification. As shown in Figure 1a, XRD patterns obtained at different thermal treatment temperature indicate an obvious phase transformation process occurring from 100 °C to 400 °C. More interesting, after thermal modification, the Co-bpdc 400 sample exhibits distinct electrochemical sodium storage behavior comparing with pristine Co-bpdc MOF. As illustrated in Figure 1b, Co-bpdc 400 delivers a high capacity more than 300 mA h g^{-1} after 100 cycles while that of pristine Co-bpdc is only 220 mA h g^{-1}. Such different electrochemical behavior perhaps results from the thermal induced phase transformation which is more feasible to accommodate sodium ion in molecular level and further mechanism is still in progress.

[1] Y. Xu, Q. Li, H. Xue, H. Pang, Coordin. Chem. Rev., 376, 292(2018)
[2]M. Kurmoo, Chem. Soc. Rev., 38(5), 1353(2009)
[3] Y.B. Niu, Y.X. Yin, Y.G. Guo, Small, e1900233(2019)

Thermodynamic properties of the nickel/anodic alumina magnetic material

A.I. Vorobjova[a], D.L. Shimanovich[a], D.I. Tishkevich[b,C,*], D.A. VINNIK[C], A.V. Trukhanov[b,C]

[a]Belarusian State University of Informatics and Radioelectronics, 220013, P.Brovki str. 6, Minsk, Belarus

[b]SSPA "Scientific and Practical Materials Research Centre of NAS of Belarus", 220072, P.Brovki str. 19, Minsk, Belarus

[c]South Ural State University, 454080, Lenin ave. 76, Chelyabinsk, Russia

*dashachushkova@gmail.com

Arrays of vertically arranged metallic nanowires (NWs) have attracted a lot of attention due to their applications as ultra high-density magnetic recording media, electronic, biomedical and optical nano-scale devices [1]. Additionally, the magnetic composite on base of ferromagnetic NWs ordered arrays are interesting as scientific object for pure research of magnetism in nanosystems. Arrays of NWs can be produced by a template-assisted method using electrochemically anodization of aluminum foil [2]. Magnetic properties of metal NWs werepresented in many works, however data on thermodynamic parameters of this material are practically absent. In particular the question of influence of high-temperature on such fundamental magnetic parameter as Curie temperature (T_C) remains open. In some works observed decrease of T_C with reduction of NWs diameter which was connected with the fact thatthe spin-spin correlation length is cut-off by the wire boundaries.

Through-pores alumina membranes (PAM) of 35±0.2 μm thickness and 70 × 70 mm size were prepared by two-step dc anodization of Al foil, as described in details elsewhere [3]. Metal thin films for contact conductive layer (Ti, Cu, or Ta, Cu) with thickness 450 ± 50 nm were deposited by electron beam sputtering in the 01NE-7-004 (Oratoriya-9) equipment. The filling ofthe pores is carried out by galvanostatic dc deposition of Ni in PAM by applying a low currentdensity of 3.0 $mA \cdot cm^{-2}$ at room temperature (22 ± 2 °C). To fabricate Ni NWs, we used a solution containing $NiSO_4 \cdot 6H_2O$ and $NiCl_2 \cdot 6H_2O$ as a Ni source, and boric acid as a stabilizer. NaOH was used to adjust the pH value of the solution (5.2) with pH meter HI83141, HANNA instruments. Preventer Na_2SO_4 was added to decrease corrosion activity of the electrolyte. As result uniform, highly ordered, densely packed NWs of 18 micrometers length (a.r. = 250) are formed.

The membrane nanowires composite morphology, structure and thermodynamic characteristics have been studied by scanning electron microscopy, atomic-force microscopy, X-ray diffraction and differential thermal analysis. The magnetic properties of nickel nanowiresembedded in porous alumina, such as Curie temperature (T_C) and specific magnetization as afunction of temperature σ(T) have been performed and analyzed. The temperature dependence of σ(T) was studied in the range from 77 to 800 K in the "heating–cooling" mode in a magnetic field of 860 mT. It was determined the thermal stability of Ni nanowires into porous alumina template. The magnetic characteristics of the obtained Ni are then compared with those of bulk nickel.

[1]M.P. Proenca, C.T. Sousa, J. Ventura, M. Vazquez, J.P. Araujo, Nanoscale Res. Lett. 7, 1 (2012).

[2]D.L. Shimanovich, A.I. Vorobjova, D.I. Tishkevich, A.V. Trukhanov, M.V. Zdorovets, A.L. Kozlovskiy, Beilstein J. Nanotechnol. 9,1423 (2018).

[3]D.I. Tishkevich, A.I. Vorobjova, D.A. Vinnik, Mat. Sci. Forum 946,235 (2019).

Emergence of new magnetic phases in alloy nanowires under elongation

K. Tsysar[a,*], E. Smelova[a], A. Saletsky[a], P. Karrion[a], V. Zelensky[a]

Lomonosov Moscow State University, 119991, Leninskie gory 1, Moscow, Russia

*smelova_k_m@mail.ru

Over the last decades one-dimensional (1D) magnetic nanowires (NWs) has attracted much attention for theoretical and experimental studies due to their unique magnetic properties [1]. Giant magnetic anisotropy (GMA), spin-filter states which be observed in atomic nanowires make them the promising object for creating of novel racetrack (RT) memory devices [2]. However its work is based on the motion of domain wall and requires the much current density. Recently a new type of topologically stable vortex-like spin textures, called skyrmions, have been discovered [3]. One of its prominent features is that the treshold current density required for skyrmions motion is much smaller than the current density for the domain wall motion. Skyrmions have been already observed in magnetic films, magnetic nanowires, multilayered systems and bulk magnetic systems. In present work we studied the spin phases of alloy atomic nanowires under alongation to predict the stable spin states formation into atomic chain. Besides contracted wire in zig-zag geometry is a good model of the multilayer film due to the same structure of interatomic bonds in a wire and multilayered structure [3].

All calculations in present work were performed in two stages. At first, the total energy calculations were performed using the program Vienna Ab-initio Simulation Package (VASP) which is based on the density functional theory (DFT) [4] and then the time-dependent magnetization dynamics are governed by the Langevin equation of motion realized in code SPILADY [5].

In our study we found the emergence of GMA in Au-Co nanowires and change of the energy of magnetic anisotropy under elongation of the wire. Moreover, it was found, that easy magnetisation axis lies in orthogonal to nanowire direction. However, in linear stretched nanowires we found a new metastable state formation with easy magnetization axis oriented along nanowire with an order of magnitude lower energy value in compare to ground state. Our study also predicted that in nanowire, supported on nonmagnetic substrate, the metastable state relized as ground state and the axis oriented along nanowire becomes the easy magnetization axis.

We have studied the all possible magnetic phases in alloy nanowire. We observed the changes of magnetic phases formed in freestanding nanowire with different geometry. We found the emergence of helicoidal magnetic spin phase in deformed alloy nanowires. All these phase transitions detected in contracted zig-zag wires can well describe the magnetic properties in layered structures due to same electronic structure of cross section of multilayered film and alloy zig-zag nanowire.

Work was supported by RFBR grants.

[1]Tsysar K.M., Bazhanov D.I., Smelova E.M., Saletsky A.M., Applied Physics Letters, 101, p. 043108-043112 (2012)
[2]Smelova E.M., Tsysar K.M., Saletsky A.M., Physical Chemistry Chemical Physics, 16, p. 8360-8366 (2014)
[3]Dupe B., Hoffmann M., Paillard C., Heinze S., Nature Communications. 5: 4030, (2014)
[4]Hafner J., Kresse G., Eichler A., Lorentz R., Hirschl R., Marsman M., Vasp workshop, http://cms.mpi.univie.ac.at/vasp-workshop/slides/documentation.htm
[5]Ma P.-W., Dudarev S.L., Computer Physics Communications, 207, p. 350-361, (2016)

Vacancy-doped $La_{1-x}MnO_{3+\delta}$ manganites: hybridization of electronic states and Raman modes

A.N. ULYANOV[a,*], A.V. SIDOROV[b], E.A. GOODILIN[a,b], N.E. PISMENOVA[c], S.V. SAVILOV[a]

[a] Department of Chemistry, Lomonosov Moscow State University, 119991, Moscow, Russia

[b] Faculty of Materials Science, Lomonosov Moscow State University, Moscow 119991, Russia

[c] Donetsk Physico-Technical Institute, Donetsk, 83114, Ukraine

***** a-ulyanov52@yandex.ru

Self- (or vacancy-) doped $Ln_{1-x}MnO_{3+\delta}$ (LMO) manganites attract considerable interest due to their interesting basic properties and potential applicability. LMO as well as the hole doped perovskites show colossal magnetoresistivity, large magnetocaloric effect and nonlinear conductivity. Recently, Griffiths-like phase was revealed in $La_{1-x}MnO_{3+\delta}$ [1] and $Pr_{1-x}MnO_{3+\delta}$ [2] oxides. Level of vacancies and oxygen content are the parameters controlling the LMO features. Explanation of properties of the LMO oxides is complicated because of their cation deficient structure [3] and anti-site defects formed at high value of vacancies [1, 4].

To shed light on the features of $La_{1-x}MnO_{3+\delta}$ (x=0.0, 0.15) perovskites we present here the study of their electronic and local crystal structure by x-ray photoelectron spectroscopy (XPS) and Raman spectroscopy measurements. The manganites were fabricated using a nitrate combustion technique with La_2O_3 and Mn_3O_4 oxides. The XPS measurements were done using the Kratos Axis Ultra DLD (UK)spectrometer equipped with a monochromatic Al Kα x-ray source (hv = 1486.6 eV, 150 W). Pressure inside the chamber was less than 5.0×10^{-9} Torr. Raman measurements were performed using the InVia spectrometer (Renishaw, UK) with a 514 nm laser and laser beam diameter ≈5.0 μm.

According to x-ray diffraction analysis the x=0.0 and 0.15 ceramics belong to orthorhombic *Pnma* and rhombohedral $R\bar{3}c$ singony, respectively. The XPS showed the constant Mn 3s splitting magnitude ΔS_{3s} (≈ 5.1 eV) for the both oxides indicating for their identical average manganese valences (≈3.2). The observed increase of Curie temperature with increase in x along with the constant manganese oxidation state is caused by different hybridization levels of the O 2*p* and Mn 3*d* states of the studied manganites. Unusual Raman modes revealed at 607 and 630 cm^{-1} for x=0.15 can be attributed to the vacancy origin of the oxide. The appearance of the 607 cm^{-1} peak in the perovskites belonging to the $R\bar{3}c$ structure but usually observed in the *Pnma* phase shows the difference between the local and average crystal structures of the oxide.

The reported study was funded by Russian Foundation for Basic Research according to the research project No. 18-08-01071 A. The authors thank Dr. K.I. Maslakov for the help with the XPS measurements. The work was performed using MSU Chemistry Department "Nanochemistry and Nanomaterials" Equipment Center, supported by Moscow State University Program of Development.

[1] A.N. Ulyanov, N.E. Pismenova, D.S. Yang, V.N. Krivoruchko, G.G. Levchenko, J. AlloyCompd. 550, 124 (2013).
[2] A.N. Ulyanov, S.V. Savilov, A.V. Sidorov, A.V. Vasiliev, N.E. Pismenova, E.A. Goodilin, J. Alloy Compd. 722, 77 (2017).
[3] B.C. Tofield, W.R. Scott, J. Solid State Chem. 10, 183 (1974).
[4] E. Pollert, Z. Jirák, J. Solid State Chem. 35, 262 (1980).

The Influence of Severe Plastic Deformation on Magnetic Properties of Free Rare-Earth Permanent MagnetFe-Ni-Al

S. TASKAEV[a,b], M. ULYANOV[a,b*], K. SKOKOV[c], D. BATAEV[a,b], V. KHOVAYLO[d]

[a]Chelyabinsk State University, Chelyabinsk, 454001, Russia

[b]National Research South Ural State University, Chelyabinsk, 454080, Russia

[c] Material Science, Technische Universität Darmstadt, 64289 Darmstadt, Germany

[d] National University of Science and Technology "MISIS", Moscow, 119049, Russia

*****max-39@yandex.ru

The current commercial high-energy permanent magnets use considerably large amounts of critical raw materials, such as Sm and Nd, to develop high values of coercivity and increase in thermal stability. The China is a practically complete monopolist in the market of rare-earth elements. There are no alternatives to China in the supply of rare earth elements. Growing in recent years, domestic demand for rare-earth elements in China and the recent rare-earth crisis led to worldwide efforts to develop rare-earth lean/free permanent magnets [1-6].

The proposed project is aimed at integrating the achievements of theoretical and experimental research which aimed at creating innovative directions for obtaining new functional materials, in particular, new types of free critical elements permanent magnets (including rare earth elements). High performance permanent magnets have become indispensable materials in many industries, ranging from data storage to small motors and clean energy devices. Thus, the reduction of the content of critical elements in the production of permanent magnets is an adequate response to the crisis of the supply of rare earth metals and their oxides and will make it possible to avoid the monopolistic dominance of China in the market of rare earth elements.

Along with rare-earth systems, some Fe-based alloys are some of the most promising candidates for rare-earth compounds for the production of permanent magnets.

In this work we report on the effect of severe plastic deformation (SPD) on the magnetic properties of perspective materials to create free rare earth permanent Fe-Ni-Al system with the L10 phase. Information about of the effect of severe plastic deformation on the magnetic anisotropy and properties of magnetic materials almost have not in the international scientific paper.

The authors gratefully acknowledge the Russian Science Foundation-Helmholtz project # 18-42-06201.

[1] K. Kramer, Phys. Today. 63, 22-24 (2010).
[2] J. M. D. Coey, Scripta Materialia, 67, 524-529 (2012).
[3] S Sugimoto, J. Phys. D: Appl. Phys. 44, 064001 (2011).
[4] R. Skomski, J.E. Shield, and D.J. Sellmyer, Magnetics Technology International, UKIP Media & Events, Ltd., p. 26-29 (2011).
[5] M.J. Kramer et al., JOM. 64, 752-763 (2012).
[6] B. Balamurugan et al., Scripta Materialia. 67, 542-547 (2012).

Magnetic Properties of Severe Plastic Deformed Free Rare-Earth Permanent MagnetFe-Ni-X (X = Cr, Co)

S. TASKAEV[a,b], M. ULYANOV[a,b*], K. SKOKOV[c], D. BATAEV[a,b], V. KHOVAYLO[d]

[a]Chelyabinsk State University, Chelyabinsk, 454001, Russia

[b]National Research South Ural State University, Chelyabinsk, 454080, Russia

[c] Material Science, Technische Universität Darmstadt, 64289 Darmstadt, Germany

[d] National University of Science and Technology "MISIS", Moscow, 119049, Russia

*max-39@yandex.ru

Permanent magnets are used in a huge number of areas of activity, which increases exponentially in both industrial and household applications. The market is huge, but mostly permanent magnets based on rare-earth elements are used, which demonstrate the best characteristics nowadays. The main supplier of rare earths is China. At any time, due to the unstable situation in the world and all different of sanctions, deliveries may stop. The fear of restricting the supply of rare-earth materials led to the search for rare-earth permanent magnets, the purpose of which is the synthesis of new hard magnetic materials that are not inferior in characteristics to permanent magnets based on hexagonal ferrites and neodymium [1-6]. Thus, the development of new and innovative technologies for the production of high-efficient free rare-earth magnets is the most actual question worldwide.

In this work we report on the effect of severe plastic deformation (SPD) on the magnetic properties of perspective materials to create free rare earth permanent Fe-Ni-X (X = Cr, Co). The fundamental significance of the work is the search for new highly anisotropic phases and the modification of the magnetic properties by the action of the SPD and creating a nanostructured state in them necessary for the realization of high values of the coercive force and residual magnetization. Applied importance is caused by the widest application of permanent magnets because they are important components in devices such as electric motors, speakers, computers, CD players, microwave ovens, toys, and refrigerators, etc. However, in the international scientific paper almost have not information about of the effect of severe plastic deformation on the magnetic anisotropy and properties of magnetic materials.

The authors gratefully acknowledge the Russian Science Foundation-Helmholtz project # 18-42-06201.

[1] K. Kramer, Phys. Today. 63, 22-24 (2010).
[2] J. M. D. Coey, Scripta Materialia, 67, 524-529 (2012).
[3] S Sugimoto, J. Phys. D: Appl. Phys. 44, 064001 (2011).
[4] R. Skomski, J.E. Shield, and D.J. Sellmyer, Magnetics Technology International, UKIP Media & Events, Ltd., p. 26-29 (2011).
[5] M.J. Kramer et al., JOM. 64, 752-763 (2012).
[6] B. Balamurugan et al., Scripta Materialia. 67, 542-547 (2012).

Low Temperature Magnetocaloric Materials

$REAl_2$ (RE = Dy, Gd, Ho) for of Cryogenic Gas Liquefaction by Magnetic Cooling Technique

S. TASKAEV[a,b], M. ULYANOV[a,b*], K. SKOKOV[c], D. BATAEV[a,b], V. KHOVAYLO[d]

[a]Chelyabinsk State University, Chelyabinsk, 454001, Russia

[b]National Research South Ural State University, Chelyabinsk, 454080, Russia

[c]Material Science, Technische Universität Darmstadt, 64289 Darmstadt, Germany

[d] National University of Science and Technology "MISIS", Moscow, 119049, Russia

*****max-39@yandex.ru

With the recent progress in superconducting magnets with static magnetic fields of up to 15 – 22 T, cooling at cryogenic temperatures can enable a revolution in the technology of gas liquefaction. A review on recent scientific publications reveals the large variety of different magnetic materials showing a significant magnetocaloric effect in the relevant temperature region of 15 to 150 K [1]. Some R-based compounds, such as Tb_3Co, $TbCo_2C$, R_3Ni_2 and $ReTm_2$ compounds (Re –rare earth's, Tm – transition metals), have been suggested to be promising candidates for magnetic refrigeration in the low temperature region, due to their large and highly reversible MCE [2-3]. Thus, the efficient liquefaction of almost any natural gas in the same type of magnetic cooling machine would be possible [4-7].

The $REAl_2$ (RE – rare earth metal) compounds have the cubic Laves phases (Cu_2-Mg)-type structure. The $REAl_2$ intermetallic compounds have interesting magnetic properties at low temperatures and received great attention. The magnetic properties of this series were studied intensively in the 1970s, but a new wave of interest in this compound family has appeared due to research into materials with a large magnetocaloric effect for future magnetic refrigerators.

The aims of this work are to report on experimental measurements of the low temperature magnetocaloric materials based on $REAl_2$ (RE = Dy, Gd, Ho) compounds for magnetic refrigeration in cryogenic application. Special accent made for investigation an influence of severe plastic deformation on magnetocaloric properties of such alloys.

The authors gratefully acknowledge the Russian Science Foundation-Helmholtz project #18-42-06201.

[1] Jian Liu, Tino Gottschall, Konstantin P. Skokov, James D. Moore&Oliver Gutfleisch, Nature Materials, 11, 620-626 (2012).
[2] B. Li, J. Du, W.J. Ren, W.J. Hu, Q. Zhang, D. Li, Z.D. Zhang, Appl. Phys. Lett. 92 (2008) 242504.
[3] B. Li, W.J. Hu, X.G. Liu, F. Yang, W.J. Ren, X.G. Zhao, Z.D. Zhang, Appl. Phys. Lett. 92 (2008) 242508.
[4] Shirron P.J., DiPirro M.J., Adv Cryo Eng, 49, 1746-53 (2004).
[5] Shirron P.J., Canavan E., Di Pirro M.J., Francis J., Jackson M., Tuttle J., et al., Cryogenics, 44, 581-8 (2004).
[6] Bartlett J., Hardy G., Hepburn I.D, Brockley-Blatt C., Coker P., Crofts E., et al. Cryogenics, 50, 582-90 (2010).
[7] Duband L., Duval J.M, Luchier N., D'Escrivan S.D. Cryocoolers, 16, 699-707 (2011).

Low Temperature Magnetocaloric Materials $REAl_2$ (RE = Dy, Gd, Ho) as a Perspective Materials for Magnetic Cooling Technique

S. TASKAEV[a,b], M. ULYANOV[a,b*], K. SKOKOV[c], D. BATAEV[a,b], V. KHOVAYLO[d]

[a]Chelyabinsk State University, Chelyabinsk, 454001, Russia

[b]National Research South Ural State University, Chelyabinsk, 454080, Russia

[c]Material Science, Technische Universität Darmstadt, 64289 Darmstadt, Germany

[d] National University of Science and Technology "MISIS", Moscow, 119049, Russia

*max-39@yandex.ru

With the recent progress in superconducting magnets with static magnetic fields of up to 15 – 22 T, cooling at cryogenic temperatures can enable a revolution in the technology of gas liquefaction. A review on recent scientific publications reveals the large variety of different magnetic materials showing a significant magnetocaloric effect in the relevant temperature region of 15 to 150 K [1]. Some R-based compounds, such as Tb_3Co, $TbCo_2C$, R_3Ni_2 and $ReTm_2$ compounds (Re –rare earth's, Tm – transition metals), have been suggested to be promising candidates for magnetic refrigeration in the low temperature region, due to their large and highly reversible MCE [2-3]. Thus, the efficient liquefaction of almost any natural gas in the same type of magnetic cooling machine would be possible [4-5].

The $REAl_2$ (RE – rare earth metal) compounds have the cubic Laves phases (Cu_2-Mg)-type structure. The $REAl_2$ intermetallic compounds have interesting magnetic properties at low temperatures and received great attention. The magnetic properties of this series were studied intensively in the 1970s, but a new wave of interest in this compound family has appeared due to research into materials with a large magnetocaloric effect for future magnetic refrigerators.

The aims of this work are to report on experimental measurements of the low temperature magnetocaloric materials based on $REAl_2$ (RE = Dy, Gd, Ho) compounds for magnetic refrigeration in cryogenic application. Special accent made for investigation an influence of severe plastic deformation on magnetocaloric properties of such alloys.

The authors gratefully acknowledge the Russian Science Foundation-Helmholtz project # 18-42-06201.

[1] Jian Liu, Tino Gottschall, Konstantin P. Skokov, James D. Moore&Oliver Gutfleisch, Nature Materials, 11, 620–626 (2012).
[2] B. Li, J. Du, W.J. Ren, W.J. Hu, Q. Zhang, D. Li, Z.D. Zhang, Appl. Phys. Lett., 92, 242504 (2008).
[3] B. Li, W.J. Hu, X.G. Liu, F. Yang, W.J. Ren, X.G. Zhao, Z.D. Zhang, Appl. Phys. Lett., 92, 242508 (2008).
[2] Shirron P.J., Di Pirro M.J., Adv Cryo Eng, 49, 1746–53 (2004).
[4] Shirron P.J., Canavan E., Di Pirro M.J., Francis J., Jackson M., Tuttle J., et al., Cryogenics, 44, 581–8 (2004).
[5] Bartlett J., Hardy G., Hepburn I.D., Brockley-Blatt C., Coker P., Crofts E., et al., Cryogenics, 50, 582–90 (2010).

Development of ThMn12-type Compounds for Permanent Magnets

S. TASKAEV[a,b], M. ULYANOV[a,b*], K. SKOKOV[c], V. KHOVAYLO[d], M. ANIKIN[e],
A. URZHUMTSEV[e], M. GAVRILOVA[a]

[a]Chelyabinsk State University, Chelyabinsk, 454001, Russia

[b]National Research South Ural State University, Chelyabinsk, 454080, Russia

[c]Material Science, Technische Universität Darmstadt, 64289 Darmstadt, Germany

[d] National University of Science and Technology "MISIS", Moscow, 119049, Russia

[e] Ural Federal University, 620002, Yekaterinburg, Russia

*****max-39@yandex.ru

Since the development of Nd-Fe-B magnets, rare-earth magnets have been the essential components in many fields of technology because of their ability to provide a strong magnetic flux. The China is a practically complete monopolist in the market of rare-earth elements. There are no alternatives to China in the supply of rare earth elements. Growing in recent years, domestic demand for rare-earth elements in China has led to the restriction of their supplies to the international market, so there is an urgent need to develop alternative free rare-earth permanent magnets [1].

The important propertiesof the permanent magnets include their coercivity, remanence and energy product (see, e.g., the review [2]). There areessentially two ways how to achieve the large values of these properties necessary for today's applications. First, themicrostructure of the material can be optimized (in our case with the help of severe plastic deformation) to prevent rotation of ferromagneticdomains. The second factor is the intrinsic spin–orbit coupling of electrons that forces the spins to align along a particular crystallographic direction, giving rise to the magnetocrystalline anisotropy energy of the material. As it shown in [3-5], severe plastic deformation has a great effect on magnetic properties of 4-*f* elements.

In this work we report on the results of investigation of magnetic properties Sm-Zr-Fe-V alloys, which will be investigated by severe plastic deformation with high torsion pressure technique.

The authors gratefully acknowledge the Russian Science Foundation-Helmholtz project #18-42-06201.

[1] M.D. Kuz'min, K.P. Skokov, H. Jian, I. Radulov, and O. Gutfleisch. J. Phys.: Condens. Matter., 26, 064205 (2014).
[2] Oliver Gutfleisch, Matthew A. Willard, Ekkes Bruck, Christina H. Chen, S.G. Sankarand, J. Ping Liu., Advanced Materials, 23, 7, 821 (2011).
[3] S.V. Taskaev, M.D. Kuz'min, K.P. Skokov, D.Yu. Karpenkov, A.P. Pellenen, V.D. Buchelnikov and O. Gutfleisch, J. Magn. Magn.Mater., 331, 33 (2013).
[4] S. Taskaev, K. Skokov, V. Khovaylo, D. Karpenkov, M. Ulyanov, D. Bataev, A. Dyakonov, and O. Gutfleisch, AIP ADVANCES, 8, 048103 (2018).
[5] Sergey Taskaev, Konstantin Skokov, Dmitry Karpenkov, Vladimir Khovaylo, Maxim Ulyanov, Dmitriy Bataev, Alexander Dyakonov, Oliver Gutfleisch, Journal of Magnetism and Magnetic Materials, 479, 307-311 (2019).

Ni_2FeGa-based magnetic shape memory and magnetocaloric microwires.

M. HENNEL[1], L. FROLOVA[1], L. GALDUN[1,2], T. RYBA[2], P. IBARRA[1], O. MILKOVIC[3,4], P. DIKO[5], V. KAVECANSKY[5], Z. VARGOVA[1,*], R. VARGA[1,2]

[1]CPM-TIP, UPJS, Kosice 041 54, Slovakia

[2]RVmagnetics, Hodkovce 21, Slovakia

[3]Institute of Materials Research, Slovak Academy of Sciences, 040 01 Kosice, Slovakia

[4]Institute of Materials, Faculty of Metallurgy, Technical university of Kosice, 042 00 Kosice, Slovakia

[5]Institute of Experimental Physics, Slovak Academy of Sciences, 040 01 Kosice, Slovakia

*zuzana.vargova@upjs.sk

Nowadays, SMART shape memory materials attract a lot of interest due to their multifunctional nature, playing the role of actuators and sensors simultaneously. However, their practical application requires possibility of reproducible production on a large scale.

Here, it is shown how kilometers of monocrystalline wires exhibiting reasonable amplitude of two - way shape memory effect can easily be produced in a short time (minutes). Being magnetic in nature, such a wire exhibits 1600% variation of magnetic permeability due to a 2% strain in axial direction, as a result of well-developed anisotropy in the wire.

On the other hand, it is possible to employ the phase transition to enhance magnetocaloric effect. Here we show, that structural transition can increase the entropy variation twice in Ni_2FeGa microwires.

The transformation temperature can be played with using small variation of chemical composition within the range from 100-350K. These properties give to the wire function of very sensitive SMART mechanical and efficient magnetocaloric actuators that can be easily produced in a large amount.

This work was supported by Slovak Grant Agency VEGA 1/0053/19, Slovak Grant Agency grant number APVV-16-0079 and APVV-0027-11.

Circularly polarized electroluminescence of spin light-emitting diodes based on (In,Fe)Sb ferromagnetic injector

M. VED*, M. DOROKHIN, V. LESNIKOV, A. ZDOROVEYSHCHEV, YU. DANILOV, P. DEMINA, A. KUDRIN

Lobachevsky State University of Nizhny Novgorod, 603950, Gagarina 23, Nizhny Novgorod, Russia

*mikhail28ved@gmail.com

Diluted magnetic semiconductors (DMS) are semiconductor materials doped with atoms of transition elements. Such materials are considered promising as elements of spintronics devices [1]. To date, DMS (A3,Fe)B5 and, in particular, (In,Fe)Sb are considered the most promising, since its Curie temperature exceeds 300K [2]. For this reason the integration of (In,Fe)Sb into GaAs based devices is one important task. The main purpose of this work is the introduction of (In,Fe)Sb as a ferromagnetic injector into GaAs-based spin light-emitting diodes.

The sample for investigation was fabricated by a combined epitaxial method. First, the semiconductor structure with InGaAs/GaAs quantum well was grown on the p-GaAs substrate by the metal-organic vapor phase epitaxy and a thin MgO layer was formed on it. Then the DMS (In,Fe)Sb layer was deposited by the pulsed laser sputtering. At the last stage, a diode structure was formed using thermal evaporation, photolithography and chemical etching. The introduction of MgO provides high sharpness of the boundary between DMS and GaAs, while it has not a significant effect on the crystalline quality, since MgO grows epitaxially on GaAs [3].

For electroluminescence (EL) studies, a forward bias was applied to the diode sample (a negative voltage was applied to (In,Fe)Sb with respect to the substrate). When structure is introduced into perpendicular magnetic field, the EL emission becomes partially circularly polarized. The degree of circular polarization P_{EL} is calculated by the formula [1].

$$P_{EL}=(I(\sigma^+)-I(\sigma^-))/(I(\sigma^+)+I(\sigma^-)) \quad [1],$$

where $I(\sigma^+)$, $I(\sigma^-)$ are intensities of EL components polarized along the left and right circles, respectively.

$P_{EL}(B)$ is a non-linear function. Such type of dependence is associated with the injection of spin-polarized electrons from ferromagnetic layer. The maximum P_{EL} value was obtained at 10K and was ~ 0.7%. As the temperature increases, both the EL intensity and the P_{EL} monotonically decrease. At temperatures above 200K EL intensity signal becomes comparable with noise level which did not allow us to reliably measure P_{EL}. It should be noted, that in similar sample but without MgO the EL is not observed. So one can make a conclusion, that MgO is a protective layer, which prevents the negative impact of (In,Fe)Sb on the luminescence characteristic of the structure.

Also the change of $P_{EL}(B)$ dependences shapes with the change of temperature was observed and it can be attributed to different magnetization mechanisms in (In,Fe)Sb. In particular, Zeeman splitting in InSb can give rise either to additional P_{EL} increase at high magnetic fields or to some decrease of polarization degree depending on the sign [4].

Thus, in this work, the spin injection of electrons from the DMS (In,Fe)Sb into the semiconductor structure based on GaAs with further recombination and emission of EL radiation in the QW region was obtained

[1]M.Holub, P.Bhattacharya // J. Phys. D: Appl. Phys., 40, P.R179 (2007).
[2]A.Kudrin, et al. // Journal of Appl. Phys., 122, 183901 (2017).
[3]W.Hsu, R.Raj // Appl. Phys. Lett., 60, 3105 (1992).
[4]Ya.Terent'ev, et al. // Phys. Rew. B, 87, 045315 (2013).

Synthesis of manganese substituted strontium hexaferrite $SrFe_{12-x}Mn_xO_{19}$

D.A. VINNIK[a,*], A.YU. STARIKOV[a], V.E. ZHIVULIN[a], S.A. GUDKOVA[a]

[a]South ural state university, 454080, Lenin st. 76, Chelyabinsk, Russia

*vinnikda@susu.ru

Because of the good dielectric constant and magnetic susceptibility values, M-type hexagonal ferrites are encouraging for designing and creating ultra-high frequency electronics devices.

The magnetic properties of hexaferrites can be significantly improved by substitution of Fe^{3+} with ions of various metals, for example, Mn [1].

In this work, a single phase powders of Mn-substituted strontium hexaferrite were obtained by the method of solid state synthesis. The stoichiometric ratio of manganese and iron oxides and barium carbonate were used for synthesis. The mixture was carefully grinded and calcinated using the optimized regime (temperature 1150 °C and time duration 3 hours). The crystal structure and properties of obtained samples were studied.

The samples morphology and composition were carried out using a JEOL JSM-7001F electron microscope with an energy dispersive X-ray fluorescence spectrometer for elemental analysis.

The phase analysis of the obtained ferrite sample was carried out on a X-ray powder diffractometer Rigaku Ultima IV.

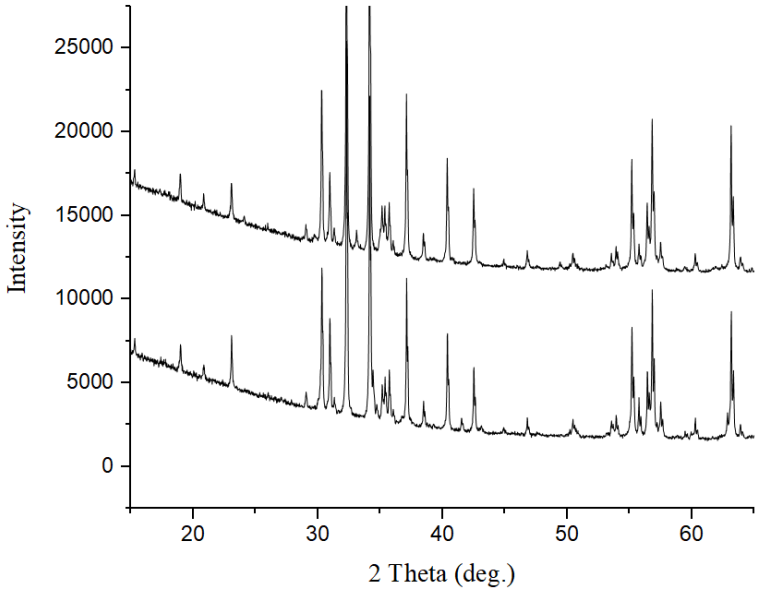


Figure 1. Radiograph obtained in the experiment $SrFe_{11,5}Mn_{0,5}O_{19}$ (lower) and $SrFe_{11}MnO_{19}$ (upper)

In this study the solid state synthesis regime for manganese substituted barium hexaferrites was developed. The chemical composition and single phase state were proved. The investigation of the Mn influence on the material properties for tuning the functional characteristics will be carried out.

The work was supported by the Russian Foundation for Basic Research, project No. 18-32-00663.

[1]F.N. Tenorio-González, Journal of Alloys and Compounds, 695 (2017)

Magnetic hysteresis in $BaFe_{12-x}Al_xO_{19}$ferrites

D.A. VINNIK[a,*], V.E. ZHIVULIN[a], A.YU. STARIKOV[a], S.A. GUDKOVA[a] , D.A. ZHEREBTSOV[a] , S. TASKAEV[a]

[a]South-Ural State University, 454080, Lenina ave. 76, Chelyabinsk, Russia

*vinnikda@susu.ru

In the recent decade barium hexaferrites and solid solutions on its base were widely investigated due to their prospective use for microwave and millimeter-wave devices, due to their favorable electrodynamic characteristics. It is known that the magnetic structure of hexagonal ferrites can be tuned by the substitution of iron Fe^{3+} ions. That can modify the magnetic, microwave and other properties. Here the influence of al substitution on the magnetic properties of initial barium hexaferrite matrix are presented.

The pure and Al-substituted barium hexaferrites were obtained using solid state method. The stoichiometric ratio of Fe_2O_3, Al_2O_3, and $BaCO_3$ were used. The mixtures were carefully grinded. The process temperature was up to 1673 K. The chemical and phase compositions were proved using electron microscope Jeol JSM7001F equipped with an energy dispersive X-ray fluorescence spectrometer Oxford INCA X-max 80 and a diffractometer Rigaku Ultima IV respectively.

Temperature and magnetic field dependencies of magnetization were measured in temperature interval from 50 to 350 K and in magnetic fields up to 3 T by Versa Lab Quantum Design Physical Properties Measurement System (PPMS). As it is shown the dilution of ferromagnetic iron subsystem by paramagnetic atoms of aluminium reduces total magnetic moment of $BaFe_{12-x}Al_xO_{19}$ alloys. In the range of concentration x=2 saturation magnetization at 50K reduces 29% from 87.6 Am^2kg^{-1} to 62.3 Am^2kg^{-1}. At the same time one can observe increasing coercivity with aluminium atoms addition. At 350K coercive force for $BaFe_{10}Al_2O_{19}$ is equal to 2545 Oe (more than18 times larger in compare to initial $BaFe_{12}O_{19}$ compound). In the region of low temperatures we see the same tendency, but value of coercivity is equal to 1066 Oe and 88 Oe for $BaFe_{10}Al_2O_{19}$ and $BaFe_{12}O_{19}$ compounds correspondingly.

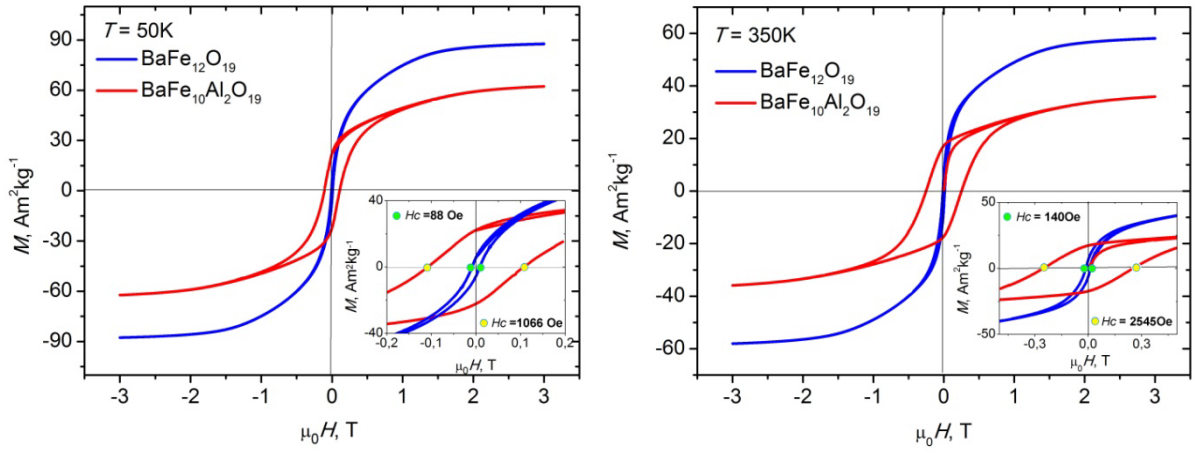


Figure 1. Magnetization hysteresis for $BaFe_{12-x}Al_xO_{19}$ (x=0, 2).

Based on these results we can conclude that the proposed method of ferrite synthesis is quite promising for novel hard magnetic materials production. By addition paramagnetic aluminium atoms into iron subsystem of $BaFe_{12}O_{19}$ ferrite we can significantly modify coercivity of the ferrite.

The work was supported by the Russian Foundation for Basic Research, project No. 18-32-00663.

The investigation of electrodynamics properties of $Zn_{1-X}Ni_XFe_2O_4$ ferrite in the frequency range 0.04-10 GHz

D.P. LELYUK[a], K.N. ROZANOV[a], D.A. PETROV[a], P.A. ZEZYULINA[a], S.N. STAROSTENKO[a], A.YU. STARIKOV[b], V.E. ZHIVULIN[b], D.A. VINNIK[b*]

[a]Institute for theoretical and applied electromagnetics, Russian Academy of Science, 125412, Izhorskaya 13, Moscow, Russia

[b]South Ural State University, 454080, Lenin st. 76, Chelyabinsk, Russia

*denisvinnik@gmail.com

Ni-Zn ferrites with a spinel structure have high potential for many electromagnetic applications in the microwave range [1]. The complex permeability spectra of ferrite ceramics depend on the chemical composition and microstructure of the ferrite. In this study, the microwave permeability dispersion of the sintered Ni-Zn ferrite with various ratios of nickel and zinc content were investigated.

Ferrite samples had a composition of $Zn_{1-x}Ni_xFe_2O_4$, with x varied from 0 to 1 with a step of 0.1. The samples were obtained by the solid state calcination method. The chemical composition was checked with SEM/EDX. The single-phase structure was proved using powder XRD. The complex microwave permeability, $\mu'+i\,\mu''$, was measured at frequencies of 0.04 to 10 GHz by a coaxial technique. The samples with $x \leq 0.3$ were observed to have no magnetic properties at frequencies under study. The samples with $x > 0.3$ had broad maximum of magnetic loss at certain frequencies. With x rising, the peak of μ" shifts toward higher frequencies, from 70 MHz to 1.2 GHz with x from 0.3 to 1, see Fig. 1.

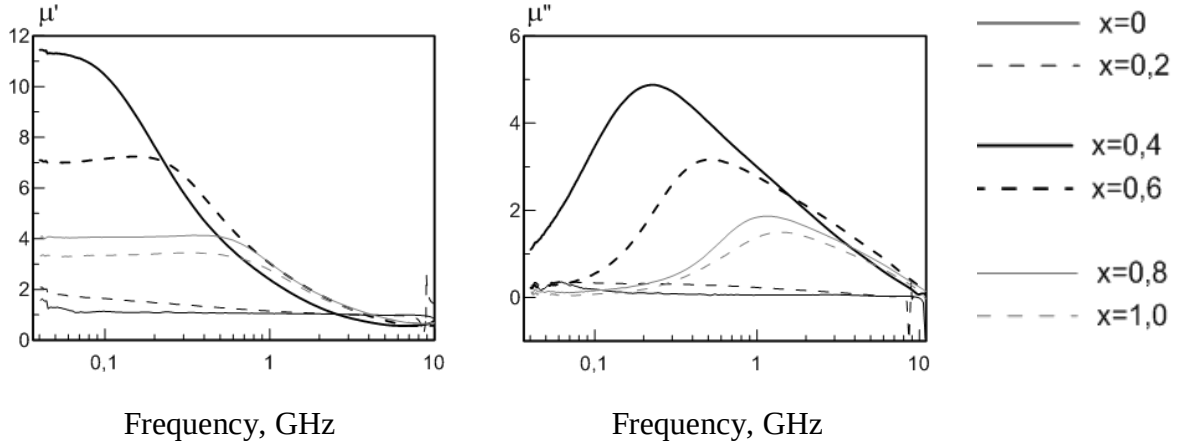


Fig. 1. *The measured frequency dependences of permeability for samples of composition $Zn_{1-x}N_{ix}Fe_2O_4$ with a nickel content x varying from 0 to 1.0*

Based on the measured data, the values of Snoek's constant have been estimated. These are in the range from 2 to 3 GHz, which is a typical value for spinel ferrites [2]. Due to sufficiently high magnetic loss in the decimeter wavelength range, ferrites under study may be useful as electromagnetic waves absorbers efficient in this frequency range.

The work was supported by the Russian Foundation for Basic Research, project No. 18-32-00663.

[1] T. Tsutaoka, J. Appl. Phys. 93, 2789 (2003)
[2] Y. Naito, IEEE Trans. Microwave Theory Tech. MTT-19, 65 (1971)

Tailored magnetic Ni_2P nanoparticles as anode material for Li-ion batteries

Yan Zhang, Huinan Guo, Huatang Yuan, Yongmei Wang, Yijing Wang,*

Key Laboratory of Advanced Energy Materials Chemistry (Ministry of Education), Renewable Energy

Conversion and Storage Center (ReCast), College of Chemistry, Nankai University, 300071, Tianjin, P. R.. China

* wangyj@nankai.edu.cn

The nickel phosphide anode materials have received widespread attention of researchers, owing to their high capacities (500~1000 mA h g^{-1}) and low operating potentials (~0.4 V). [1,2] Nevertheless, nickel phosphide anode materials are confronted with large volume expansion (~400 %) and low electronic conductivity (1.0×10^{-12} S m^{-1}), which inevitably bring about the rapid capacity fading during cycling. [3,4]

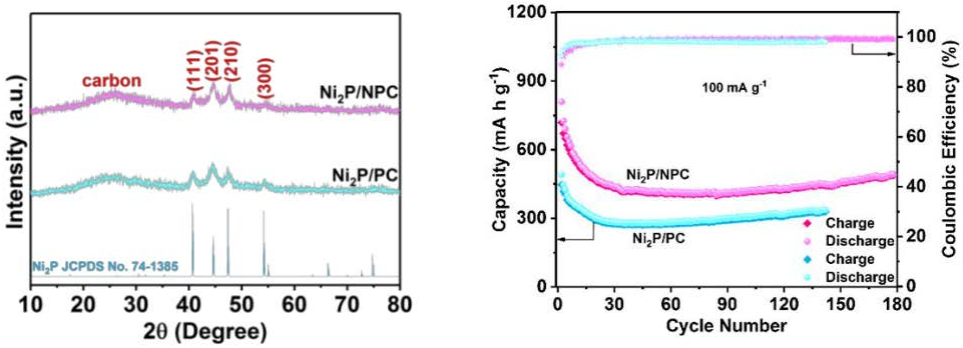


Figure 1 *(a) XRD patterns and (b) cycle performances Ni_2P@PC and Ni_2P@NPC at 100 mA g^{-1}.*

Herein, we designed a novel rod-like composite with magnetic Ni_2P nanoparticles encapsulated in nitrogen doped carbon (Ni_2P/NPC) as a superior anode material for Li-ion batteries. With the aid of N-doped carbon, the Ni_2P/NPC composite effectively buffers the volume expansion, and wondrously improves the electrochemical performances by creating more defects on the surface. With the unique structure, the tailored Ni_2P/NPC anode material shows remarkable lithium storage performances. The composite delivers a considerable initial discharge capacity of 1570.4 mA h g-1 at 100 mA g^{-1} (the theoretical specific capacity is 542 mA h g^{-1}), and a significant cycling stability (492.9 mA h g^{-1} after 178 cycles at 100 mA g^{-1}). Especially, a high rate capability of 230.0 mA h g^{-1} at 1000 mA g^{-1} is dispalyed.

[1]D. Zhou, L.-P. Xue and N. Wang, J. Alloys Compd., 2019, 776, 912-918.
[2]C. Dong, L. Guo, Y. He, C. Chen, Y. Qian, Y. Chen and L. Xu, Energy Storage Mater., 2018, 15, 234-241.
[3]P. Lou, Z. Cui, Z. Jia, J. Sun, Y. Tan and X. Guo, ACS Nano, 2017, 11, 3705-3715.
[4]M. Ihsan-Ul-Haq, H. Huang, J. Cui, S. Yao, J. Wu, W. G. Chong, B. Huang and J.-K. Kim, J.Mater.Chem.A, 2018, 6, 20184-20194.

Influence of insulation coating and heat treatment on magnetic properties of FeSiCr magnetic powder cores

XIAOJIE WU[a], JUNJIE HAO [a, *],TONGCHUN ZHAO[a]

[a]Institute for Advanced Material and Technology. University of Science and Technology Beijing, 100083, Beijing, China

* 847040779@qq,com

FeSiCr magnetic powder cores,with high electrical resistivity, magnetic permeability, saturation magnetic induction and good corrosion resistance,are widely applied to inductors, filters, choke coils and so on. However, with the development of electronic technology to high frequency and high power density, the relative decline of the magnetic properties limits the high frequency application of magnetic powder cores.In this paper, we studied adopting posphating/polyimide resin double layer insulation coating, forming insulating layer on the surface of magnetic powder core in order to reduce eddy current loss including hysteresis loss and eddy current loss.

FeSiCr phosphating powders were prepared with phosphating treatment with different phosphoric acid concentrations (0wt%,0.2wt%,0.5wt%,1.0wt%,1.5wt%). FeSiCr phosphatingpowders and polyimide were mixed, stirred and then dried at 80 ℃. Mixtures were pressed at 600Mpa into rings with 8 mm inner diameter, 14 mmouter diameter and 3 mm thickness. The rings were heated at different annealingtemperatures for 1 h in argon atmosphere. The effects of phosphating treatment on the surface morphology of FeSiCrpowders were analyzed by scanning electron microscopy (SEM). The inductance of the magnetic powder cores was measured by the LCR bridge tester and the magnetic loss was measured by the soft magnetic dynamic measuring device in the frequency range of 10-150 kHz.

Results showed that uniform insulating layers were formed on the surface of the particles,which cut off the flow of electricity among particles and reduced the eddy current loss. Annealing eliminated the stress in the core and reduce the hindrance of the internal stress on the pinning of domain wall and the movement of domain wall. Furthermore, the coercivity and hysteresis loss were reduced and the performances of magnetic powder cores were optimized further. The FeSiCr magnetic powder core, with 1.0wt% phosphoric acid concentration, the heat treatment temperature at 500℃ showed the ideal magnetic properties: L=8.72μH, μe=41H/cm, $P \leq 1000 mW/cm^2$.

Synthesis, structure and properties of nanoparticle/polysaccharide magnetic composites

S.V. STOLYAR[a,b,c], L.A. CHEKANOVA[b], R.N. YAROSLAVTSEV[a,b*], V.V. KRASITSKAYA[c], O.A. BAYUKOV[b], M.N. VOLOCHAEV[b], R.S. ISKHAKOV[b]

[a]Siberian Federal University, Krasnoyarsk, Russia

[b]Kirensky Institute of Physics, Federal Research Center KSC SB RAS, Krasnoyarsk, Russia

[c]Krasnoyarsk Scientific Center, Federal Research Center KSC SB RAS Krasnoyarsk, Russia

*yar-man@bk.ru

The development of methods for the synthesis of various types of multifunctional nanomaterials for biomedicine with a wide range of bactericidal, conductive and magnetic properties is a complex task and an important line of research. One of the promising directions in this area is the use of natural polysaccharides as stabilizing and reducing agents [1,2]. Magnetic nanobiocomposites created on the basis of polysaccharides have the properties of a stabilizing polysaccharide matrix and a magnetic core.

This paper is devoted to the synthesis and study of the properties of magnetite nanoparticles coated with a polysaccharide shell (arabinogalactan, chitosan, starch) as well as the study of the biospecific surface activity of the prepared composites. Magnetite nanoparticles were synthesized by co-precipitation from a solution of ferrous sulfate ($FeSO_4 \cdot 7H_2O$) in the presence of polysaccharide, which is suggested to be a stabilizing agent.

The nanoparticle samples were examined with a Hitachi HT7700 transmission electron microscope (accelerating voltage 100 kV) of the Center for Collective Use, Krasnoyarsk Scientific Center, Krasnoyarsk, Russia. Mössbauer spectra were measured on an MC-1104E5m spectrometer with the 57Co(Cr) source at room temperature. Static magnetic measurements were carried out on a vibrating magnetometer in the field range up to 6 kOe and temperatures from 77 to 300 K. Studies on the immobilization of biospecific proteins (immunoglobulins, Staphylococcus protein A, avidin) on the surface of nanoparticles were performed.

The reported study was carried out with the financial support of the Russian Foundation for Fundamental Research, the Government of the Krasnoyarsk Territory, the Krasnoyarsk Territory Fund for Support of Scientific and Technical Activity in the framework of scientific Project No. 18-43-243003. The work is supported by the Special Program of the Ministry of Education and Science of the Russian Federation for the Siberian Federal University.

[1]P. R. Chang, J. Yu, X. Ma, and D. P. Anderson, Carbohydr. Polym. **83**, 640 (2011).
[2]I. Khmara, O. Strbak, V. Zavisova, M. Koneracka, M. Kubovcikova, I. Antal, V. Kavecansky,
[3]D. Lucanska, D. Dobrota, and P. Kopcansky, J. Magn. Magn. Mater. **474**, 319 (2019).

Magnetic properties of Fe-Ga-Tb ternary system: a first-principles study

M. ZAGREBIN*, M. MATYUNINA, V. SOKOLOVSKIY, V. BUCHELNIKOV

Chelyabinsk State University, 454001, Brat'ev Kashirinykh Str. 129, Chelyabinsk, Russia

*miczag@mail.ru

Fe-Ga alloys are very interesting due to their unique variation of magnetostriction from the highest positive values to negative ones depending on proper compositions and heat treatment [1]. This fact together with high tensile strength, corrosion resistant, high Curie temperature makes those alloys attractive for actuating and sensing applications. Recent experiments show that the addition of rare earth element (for example Tb) lead to an improvement in magnetostriction of binary Fe-Ga alloys [2-4]. As well as experiments show that microalloying of Tb leads to the formation of ternary Fe-Ga-Tb regions in binary Fe-Ga matrix. The composition of the ternary Fe-Ga-Tb regions is close to $TbFe_6Ga_6$ [4]. Li et al. show that $TbFe_6Ga_6$ system in distinction to Fe-Ga is in the orthorhombic phase (*Immm*, #71 symmetry group) [5, 6]. In this study, we investigate the magnetic properties of Fe-Ga-Tb compounds by means of the density functional theory.

The calculations were carried out by using the Spin-Polarized Relativistic Korringa-Kohn-Rostoker (SPR-KKR) [7]. For calculations, we used lattice parameters, symmetry groups and Wyckoff positions of atoms obtained from experimental results [5]. Crystal lattices of the *Immm* (#71) and *I4/mmm* (#139) space groups were taken into account in our calculations. The generalized gradient approximation according to the Perdew-Burke-Ernzerhof parametrization [8] was used to take into account the exchange-correlation effects.

As a result, total magnetic moments and Heisenberg magnetic exchange parameters of Fe-Ga-Tb compounds have been obtained. In the second step of study Curie temperature for considering compositions were obtained by the help of mean-field approximation [9].

This work was supported by grant #18-12-00283 of the Russian Science Foundation.

[1] I.S. Golovin, Mater. Design. 88, 577 (2015)
[2] A. Emdadi, V.V. Palacheva, A.M. Balagurov et al., Intermetallics 93, 55 (2018)
[3] I.S. Golovin, A.M. Balagurov, A. Emdadi et al., Intermetallics 100, 20 (2018)
[4] V.V. Palacheva, V.V. Cheverikin, E.N. Zanaeva et al., Letters on Materials 9, 51 (2019)
[5] J.Q. Li, M. Ouyang, F.S. Liu et al., J. Magn. Magn. Mater. 321, 2541 (2009)
[6] J.Q. Li, M. Ouyang, F.S. Liu et al., Intermetallics 17, 733 (2009)
[7] H. Ebert, D. Ködderitzsch and J. Minár, Rep. Prog. Phys.74, 096501 (2011)
[8] J.P. Perdew,K. Burke and M. Enzerhof, Phys. Rev. Lett. 77, 3865 (1996)
[9] P.W. Anderson, Solid State Phys. 14, 99 (1963)

Distribution of magnetic particles in a model of capillary bloodstream

M.N. ZHARKOV*, M.A. PYATAEV, M.V. GERASIMOV, N.A. PYATAEV

National Research Ogarev Mordovia State University, 430005, Bolshevistskaya, 68, Saransk, Russia

*mikhail.zharkov.92@mail.ru

The work is devoted to the modelling of the magnetic particles distribution in living organisms in the presence of a non-uniform magnetic field. A theory and experimental model are proposed to understand the mechanism of particle accumulation in tissues. The theoretical model is based on determining of the force acting on a particle and its trajectory taking into account the inhomogeneous velocity distribution in the capillary. We have assumed that the particles does not interact with each other and does not disturb the distribution of liquid velocities. In this case, the particle that has reached the capillary wall is stopped because the velocity of liquid near the wall is zero. To obtain the particle spatial distribution we have calculated the magnetic field and its gradient in every point of space and then found the length travelled by each particle along the liquid stream. The theory allows one to estimate the parameters of the magnetic field and particle characteristics necessary for obtaining required concentrations of particles in a given site of the body. In the framework of our model, the relative part of particles accumulated in the area of magnetic field depends on two dimensionless parameters v_p/v_l and l/r, where v_p is the equilibrium velocity of the particle relative to liquid in a given field with given gradient, v_l is the speed of the liquid at the axis of capillary, r is the capillary radius and l is the length passed by the particle under the action of the field. In our experiment, l was determined by the diameter of magnet, but in a living body, it is restricted by the geometry of capillary.

An experimental model of the vascular bed is based on a system of microscopic tubes. For this purpose, we have used a dialyzer for the hemodialysis device containing 1.7×10^4 tubes with a diameter of 160 μm and a length of 30 cm in a cylindrical case with a diameter of 43 mm. A suspension of particles of iron oxide Fe_3O_4 stabilized by citric acid was used in the experiment. The average diameter of particles was about 100 nm. The suspension was pumped through the microtube system at a rate that provides a liquid velocity of approximately 2 mm/s at the axis of each tube. The magnetic field was created by a cylindrical permanent magnet with a magnetization of 0.47 T. At the end of the perfusion, the dialyzer was frozen in liquid nitrogen. Then it was sliced into pieces and the iron content in each piece was determined.

It was found that the concentration of accumulated particles monotonously decreased with distance from the magnet. The effective accumulation of particles is observed at distances up to 2 cm from the surface of the magnet. The measured concentrations of iron oxide are in agreement with results obtained by theoretical model.

It should be noted that the distribution of magnetic particles in a real circulatory system depends on many different factors (inconstancy of the capillary cross-section, the presence of branches, the influence of blood cells, the diffusion through the vascular wall, etc.). All this factors significantly complicates the detailed theoretical description of the particle distribution in the living body. However, to evaluate the possibility of particles accumulation in a given region in vivo it is sufficient in most cases to estimate roughly a few above-mentioned parameters.

The work is supported by the Russian Foundation for Basic Research (grant 18-415-130007).

Surface Enhanced Raman spectroscopy of organoluminophores adsorbed on quartz surfaces modified by hydrosols of silver and gold nanoparticles

A. ZYUBIN[a,*], K. MATVEEVA[a], I. SAMUSEV[a]

[a]Immanuel Kant Baltic Federal University, 236004, Nevskogo 14, Kaliningrad, Russia

*azubin@kantiana.ru

Surface Enhanced Raman spectroscopy (SERS) is used for non-invasive molecular analysis and can be used to determine a wide range of biological molecules. Thus, SERS can be used for DNA analysis [1], drugs [2], food additives [3], cells and spores [4], bacterial cells [5].

The main feature of the SERS spectroscopy is the presence of a nanoparticle (NP) of a metal (for example, gold or silver) that are in contact with the analyte. The use of HRS spectroscopy provides fast and reliable identification of biomolecules in the“fingerprint”area. In perspective, SERS spectroscopy can be a powerful analytical tool for accurate, specific and repeatable analysis of the structure of molecules.

This paper performs the results of research on the development of a methodology for creating silver and gold nanoparticles with a size of 20-70 nm and quartz surfaces modified with hydrosols. It is shown that the order of amplification of the Raman signal of light scattering by surface plasmons of silver nanoparticles for rhodamine 6G dye molecules can reach 10^2-10^4 times. To create silver and gold nanoparticles, we used controlled synthesis of silver and gold hydrosols using the method of reducing the salt $AgNO_3$ and $HAuCl_4$ with sodium citrate respectively. The size of the particles and the properties of the plasmon absorption of hydrosols were studied using photocorrelation spectroscopy and absorption spectroscopy, respectively. To study the SERS, a Centaur U Raman scattering spectrometer (LTD Nanoscantechnology, Russia) was used. Unit was equipped which helium-neon laser (632.8 nm) with a power of 37 mW. For each sample, the order of amplification of the Raman scattering signal was calculated.

The paper shows the promising use of the proposed approach as an effective method for further research of a wide range of analytes using spectroscopy of giant Raman scattering

Work was supported by the Grant of the President of the Russian Federation for young Ph. D. holders (project No. MK-1056.2019.2)

[1] Kneipp K. et al., Physical Review E 57 (2013)
[2] Stokes R. et al., Applied spectroscopy 62,4 (2012)
[3] Lin M. et al., Journal of food science 73, 8 (2008)
[4] Alexander T. A., Applied optics 46 (18), (2007)
[5] Sharma B. et al., Materials today 15,1 (2012)

Optical and magneto-optical properties of Al(Cr)/FeNi bilayer thin films with different thicknesses of the upper non-magnetic layer

H. Hashim[a,*], P. Kapralov[b], M. Kozhaev[b], L. Panina[a], V. Belotelov[b], V. Komanick[c], D. Chvostová[d], A. Dejneka[d]

[a] National University of Science and Technology (MISIS), Moscow, 119049, Russia.

[b] Russian Quantum Center, Skolkovo, Moscow Region 143025, Russia.

[c] Institute of Physics, Faculty of Science, P. J. Šafárik University, Košice, 04154, Slovakia

[d] Institute of Physics, Czech Academy of Sciences, Prague, 18221, Czech Republic

*corresponding author email: hh@science.tanta.edu.eg

The magneto-optical effects (MO) in nanostructural materials have acquired much attention due to their applications in nanoelectronics technologies and spintronics [1,2]. Multilayered nanostructures exhibit magnetic properties which significantly differ from those of their bulk materials due to the impact of interfaces with intermediate layers [3]. In particular, the coupling between the ferromagnetic and non-magnetic layers [4] makes it possible to control the magnetic response of the film by changing the non-magnetic layer thickness. The transverse magneto-optical Kerr effect (TMOKE) spectroscopy is a sensitive and powerful technique to investigate the behavior of magnetization in magnetic nanostructures [5]. In this work, the optical constants and thickness of the two thin films structures Al(Cr)/FeNi/glass were determined by variable-angle spectroscopic ellipsometry (VASE). The magnetization properties of films were investigated with different thickness of Cr and Al layers using TMOKE method. Figure 1 shows the impact of increasing the thickness of the upper Cr layer on the angular dependencies of TMOKE response which was measured in the range from 10^{O} to 70^{O} degrees. Transmission and reflectivity spectra were measured over a range of incident angles and with different wavelengths to explain the TMOKE behaviour.

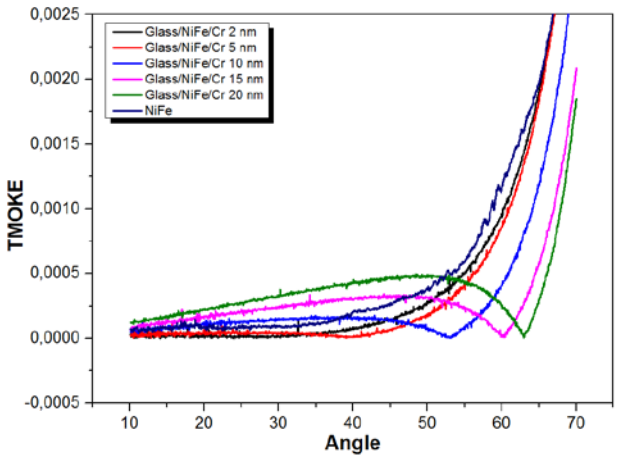


Fig.1. TMOKE response as a function of the upper Cr layer thickness in Cr/FeNi bilayer thin film measured at incident angle from 10^{O} to 70^{O} with a wavelength of 780 nm.

Key words: magnetic nanostructure multilayers, transverse magneto-optical Kerr effect (TMOKE), ferromagnetic coupling, magnetic hysteresis, Reflectivity and Transmission.

[1] H. Hashim and et al. Physics of the Solid State. V 59. (2017) p 2211–2215.
[2] K. Mok and et al. Physical Review B, V 84. (2011).
[3] B. Issa and et al. International Journal of Molecular Sciences. V 14, (2013) p 21266-21305.
[4] M.E. Aköz and et al. ACTA Physica Polonica A, V 127. (2015) p 992 – 994.
[5] O. V. Borovkova and et al. Applied Physics Letters, V 112, (2018).

AUTHOR INDEX

D

E

F

G

H

I

J

K

L

M

N

O

P

Q

R

S

T

U

V

W

Y

Z