SCIS 2021

Programme

Kaliningrad — Svetlogorsk, Russia, 2021

Russian Science Foundation

Research and Education Center
Smart Materials & Biomedical Applications
IKBFU

Smart Composites International School

The Smart Composites International School (SCIS) is a satellite event of the International Baltic Conference on Magnetism 2021.

The School is divided in two parts – for beginners and advanced participants.

Main topics:

- Magnetic particles;
- Piezo particles;
- Polymer-based composites;
- Smart composites applications.

Organizers:
Assos. Prof. Valeria Rodionova
Prof. Claudio Sangregorio
Prof. Davide Peddis

Programme committee:
Prof. Larissa Panina
Prof. Yuri Raikher

Local organizing committee:
Dr. Katerina Levada
Mr. Victor Belyaev
Ms. Valeria Kolesnikova

School Chair:
Assoc. Prof., Valeria Rodionova
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SCIS-2021 SUPPORT

Immanuel Kant Baltic Federal University

Russian Science Foundation

“Development and investigation of multimaterials with magnetic nanoinclusions for additive 3D-5D technologies” grant No. 21-72-30032

EARLY CAREER MEETINGS

During the Conference and School, the Early Career meetings special section will be organized to promote communication, collaboration and career opportunities for students and young scientists. Four successful representatives of science, business and academia will share their expertise and give talks on how to build a high-class career, develop soft skills, and create scientific startups.

Prof. Sergei Guriev
Professor of economics and director of graduate programs in economics, Sciences Po, France

"What are the similarities and differences between social and natural sciences, how does an economist's career work, what methods are used in modern economics" — Sergei Guriev will answer these and other questions for the audience.

Polina Khapaeva
Director for development of SCAMT institute, ITMO university, Russia

Polina Khapaeva will discuss the basics of science communication and why science communication is important for a successful scientist. In addition, she will speak on some how-tos of effective public speaking.

Early career meetings

Dr. Alexandr Vinogradov
Head of chembio cluster, vise-head of SCAMT institute, ITMO university, Russia

Dr. Alexandr Vinogradov will speak on what a scientific startup is and how to develop it.

Prof. Des Mapps
Professor Emeritus at the University of Plymouth, UK

At SCIS-21 Prof. Des Mapps will give a talk "Publishing (really) Good Research Papers".

"This is an entertaining talk giving advice on how to write good research papers. It lists all the essential ingredients and discusses them in detail with some examples. It then explains what not to do when submitting a paper for review and concludes with some general advice. All questions are welcome."

— Prof. Des Mapps.

August 29 / Sunday

09:00 – 14:00	Time for excursions (optional)	
14:00 – 17:00	Registration	
14:30 – 16:30		**Early Career Meetings** **Polina Khapaeva:** Team building for young scientists *On-site*
17:00 – 17:30	**Opening ceremony**	
17:30 – 18:15	Chair: Valeria Rodionova **Tutorial-Plenary I: Andrey Fedyanin** Resonant magnetophotonics: where light meets magnetism	
18:15 – 19:00	**Tutorial-Plenary II: Davide Peddis** Design advanced magnetic nanocomposites	
19:00 – 21:00	**Welcome cocktails**	

August 30 / Monday

08:00 – 09:00	Registration
11:00 – 11:30	Coffee break
11:30 – 13:15	Smart Composites International School Chair: Alexander Pyatakov
11:30 – 12:00	**Yuriy Raikher:** Ferromagnet particles in polymer harness: mesoscopic description of magnetoactive polymers
12:00 – 12:30	**Dmitry Balaev:** Physical mechanisms governing the magnetic behavior of nanoparticles of magnetically ordered materials
12:30 – 13:00	**Konstantin Neyman:** In-silico design of bimetallic nanocrystallites to speed-up their manufacturing
13:00 – 13:45	**Early Career Meetings** **Polina Khapaeva:** How to communicate your science
13:15 – 15:00	Lunch

15:00 – 16:30	Smart Composites International School Chair: Alexander Omelyanchik
15:00 – 15:30	**Paola Lova:** From photopolymers to 4D printing: a blueprint for a new manufacturing paradigm
15:30 – 16:00	**Alexander Pyatakov:** Magnetic straintronics: underlying physical effects and promise for ultra low-consumption electronics
16:00 – 16:30	**Fedor Senatov:** Biomimetic polymer materials and tissue engineering
16:30 – 17:15	**Early Career Meeting** **Alexandr Vinogradov:** Portfolio of the best SEO
17:00 – 17:30	**Technical break**

AUGUST 31 / TUESDAY

08:00 – 09:00	Registration
11:00 – 11:30	Coffee break
11:30 – 13:15	Smart Composites International School Chair: Valeria Rodionova
11:30 – 12:00	**Andrei Petukhov:** Self-assembly at the nanoscale in polymers and composites
12:00 – 12:30	**Larisa Panina:** Structural and magnetic properties of arrays of nanowires/nanotubes in polymer templates
12:30 – 13:00	**Ester M. Palmero:** Permanent Magnet-Polymer based Composites for Bonding and Additive Manufacturing
13:00 – 13:15	**Askold Trul:** Conjugated oligomers and polymers for gas sensing via organic field-effect transistors
13:15 – 15:00	Lunch
15:00 – 17:15	Conference/ School Section – II Chair: Larisa Panina
15:00 – 15:30	15:00 – 15:30 **Manuel Vázquez:** Hybrid magneto-polymers arrays
15:30 – 15:45	**Oleg Stolbov:** Field-induced pseudoplasticity of magnetoactive elastomers: a phase transition interpretation

15:45 – 16:00	**Oleg Stolbov:** Field-induced pseudoplasticity of magnetoactive elastomers: a phase transition interpretation
16:00 – 16:15	**Dmitriy Saveliev:** Dependence of fiber diameter on magnetoelectric effect in flexible composite
16:15 – 16:30	**Vyacheslav Lobekin:** Torsion mode of the magnetoelectric effect in a Metglas/GaAs layered structure
16:30 – 16:45	**Rafael Shakirzyanov:** High frequency properties of P(VDF-TFE)/Mn-Zn ferrite/carbonyl iron/graphite composites
16:45 – 17:00	**Anastasia Dryagina:** Synthesis and magnetic properties of Co nanowires/PVDF composites
17:00 – 17:15	**Pierfrancesco Maltoni:** Optimizing the design of magnetically hard $SrFe_{12}O_{19}$ based nanocomposites
17:15 – 17:30	Technical break

SEPTEMBER 1 / WEDNESDAY

08:00 – 09:00	Registration
11:00 – 11:30	Coffee break
11:30 – 13:15	Smart Composites International School Chair: Alekhina Iuliia
11:30 – 12:00	**Nikolai Perov:** Magnetoelectric effects in composite materials
12:30 – 13:00	**Liudmila Makarova:** Polymer-based composites: fabrication, study and application
13:00 – 13:30	**Sergey Ponomarenko:** Smart polymer materials for organic bioelectronics and robotics
13:00 – 13:15	**Svetlana Voronina:** Target properties elements control made of polymer composite materials
13:15 – 15:00	Lunch

15:00 – 17:00	Conference/ School – II Chair: Dmitriy Balaev
15:00 – 15:30	**Jerome Depeyrot:** Magnetic colloids: from magnetofluorescent nanofluids to magnetic anisotropies of core/shell nanoparticles
15:30 – 15:45	**Elizaveta Gubanova:** Heating efficiency of magnetic nanoparticles with cubic anisotropy in a viscous liquid
15:45 – 16:00	**Ruslan Rytov:** Specific absorption rate of elongated polydisperse assemblies of magnetic nanoparticles
16:00 – 16:15	**Sawssen Slimani:** Magnetic mesoporous silica nanostructures: investigation of magnetic properties
16:15 – 16:30	**Bachir Ouari:** Specific absorption rate of magnetic ferromagnetic nanoparticles having a biaxial anisotropy
16:30 – 16:45	**Daniela P. Valdés:** Role of anisotropy, frequency, and interactions in magnetic hyperthermia applications: noninteracting nanoparticles and linear chain arrangements
16:45– 17:45	Coffee break
17:45 – 19:15	**Early Career Meetings** 17:45 – 18:30 **Sergei Guriev:** Why physicist can be interested in economics career? 18:30 – 19:15 **Des Mapps** Publishing (really) good research papers
19:50 – 20:00	**Joint photography**
20:00 – 22:00	**School/Conference Dinner**

SEPTEMBER 2 / THURSDAY

09:45 – 11:30	Poster session III Chairs: Akhmed Aliev, Sokolov Aleksey, Christina Gritsenko
11:30 – 13:15	Smart Composites International School Chair: Sergey Ponomarenko
11:30 – 12:00	**Andrei Kholkin:** Magnetoelectric composites for sensing and energy harvesting applications
12:00 – 12:30	12:00 – 12:30 **Gaspare Varvaro:** Synthetic antiferromagnets for biomedical and flexible spintronic applications
12:30 – 12:45	**Valeriy Vlasov:** Strength characteristics of 3D-printed samples determinate
13:15 – 13:45	**School closing and awards ceremony**
15:15	Time for excursions (optional)

Time limitation:

- **Tutorials** are limited by **40 minutes** with addition of 5 minutes for questions;
- **Lectures** are limited by **25 minutes** with addition of 5 minutes for questions;
- **Oral talks** are limited by **12 minutes** with addition of 3 minutes for questions.

LIST OF POSTERS

SCIS-1	Polina Zhukova	Polymer composite materials with shape memory effect based on polylactide for adaptable medical structures
SCIS-2	Dmitry Panov	Obtaining of calibrated nickel nanoparticles for local drug delivery
SCIS-3	Danil Borov	Force sensors for miniature actuators
SCIS-4	Iuliia Alekhina	Layered polymer-based structure for multiferroic applications
SCIS-5	Kirill Sobolev	Scanning probe microscopy as a multifunctional tool to study polymer-based composites
SCIS-6	Valentina Antipova	Effect of magnetoelectric polymer composites on the activity of bNCSCs
SCIS-7	Valeria Kolesnikova	FORC-approach for magnetoactive polymer-based composites
SCIS-8	Karim Amirov	On the prospects of magnetoelectric composites for biomedical applications
SCIS-9	Julia Filippova	Application of the energy criterion of point agglomeration to Ni and Fe nanowires synthesized in the pores of track membranes.
SCIS-10	Maqsudsho Nematov	Stress and temperature sensitivity of magnetization process of magnetic microwires for structural health monitoring
SCIS-11	Alexander Omelyanchik	Magnetic properties of $CoFe_2O_4/SiO_2$ nanocomposites
SCIS-12	Isaev Danil	Numerical modelling of FORCs of magnetoactive elastomers based on ferromagnetic and ferroelectric particles
SCIS-13	Anna Zakharova	Preparation and characterization of fabricated PVDF/BiFeO3 nanocomposite and its application as a device to monitor respiration signals
SCIS-14	Aleksey Bogdanov	Simulation of two magnetic particles in an elastic matrix with external magnetic field
SCIS-15	Dmitry Kuznetsov	Influence of magnetoelectrical biological interfaces on HepG2 cells adhesion
SCIS-16	Dinara Khairetdinova	Metal oxide/PVDF magnetoelectric nanocomposite for multifunctional autonomic sensor applications

CONTENTS

Tutorial talks

Design advanced magnetic nanocomposites

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

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Resonant magnetophotonics: where light meets magnetism

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Control of light by an external magnetic field is one of the important methods for modulation of its intensity and polarization. Magneto-optical effects at the nanoscale are usually observed in magnetophotonic crystals, nanostructured hybrid materials, or magnetoplasmonic crystals.

The early studies on the enhancement of magneto-optical response in nanostructured materials were done more than 30 years ago. An indirect action of an external magnetic field (e.g., through the Faraday an magneto-optical Kerr effect) is explained by the fact that natural materials exhibit negligible magnetism at optical frequencies. However, the concept of metamaterials overcome this limitation imposed by nature by designing artificial subwavelength meta-atoms that support a strong magnetic response, usually termed as optical magnetism, even when they are made of nonmagnetic materials. The fundamental question is what would be the effect of the interaction between an external magnetic field and an optically induced magnetic response of metamaterial structures. In the presentation, recent advances in magnetophotonic nanostructures, including metasurfaces, photonic crystals and plasmonic crystals are discussed in detail.

Lectures

Physical mechanisms governing the magnetic behavior of nanoparticles of magnetically ordered materials

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Magnetic nanoparticles are promising for applications in various fields of engineering and technology, including permanent magnets, magnetic memory, catalysis, biotechnology, and medicine (drug delivery, magnetic hyperthermia, etc.). Practical application of magnetic nanoparticles in any area assumes understanding magnetic behavior of nanoparticles in appropriate conditions. In this talk the basis mechanisms governing the magnetic behavior of nanoparticles of magnetically ordered materials will be discussed.

In principle, there are only two simple changes occurring during the transition from “bulk to nano”: (1) the size of a particle becomes comparable with the crystallographic lattice parameter and the (2) fraction of atoms on the surface becomes predominating over that for “inner” atoms. These two obvious sources give rise to well known “finite size effect” and “surface effect”. In magnetic properties the “finite size effect” reveals as transition from multi-domain state to the single-domain state with the decrease in the particle size. Also, with further decrease in size the magnetic moment of single-domain particle undergoes from the, so called, blocked to the unblocked, or superparamagnetic – SPM, state. The behavior of main parameters characterizing the magnetic state of nanoparticles during mentioned transitions can be described by well known formulations, such as Néel–Brown relation, etc. Meanwhile, the “surface effect” makes allowance to the classical (Néel–Brown) consideration of magnetic properties of magnetic nanoparticles. The main mechanism, governing the impact “of surface” on the magnetic properties, is the occurrence of additional magnetic anisotropy due to broken chemical bonds on the surface. This contribution is usually called as surface magnetic anisotropy [1-4]. So, experimentally one can see how mentioned two effects cooperate in formation of magnetic properties of nanoparticles. In order to observe the “surface” and the “finite size” effects in experiments it is necessary to use techniques with various times of measurement [2.3,5.6]. These techniques are DC static magnetic measurements, AC-magnetic susceptibility, magnetic resonance (including Mössbauer spectroscopy), etc. Every of the mentioned techniques specify the critical blocked – unblocked (SPM) temperature (at a constant particle size) or blocked–unblocked critical size (at a constant temperature). Experimental determination of the blocking temperature vs “experimental technique” dependence allows to evolute both the “size” and the “surface” effects on the magnetic properties of an ensemble of magnetic nanoparticles. Solving of specified problems for a concrete material of magnetic nanoparticles gives the basis for use of this material in concrete area of application. In the talk the examples for iron oxide magnetic nanoparticle systems will be shown.

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Magnetoelectric composites for sensing and energy harvesting applications

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Magnetoelectric (ME) effect is defined as a linear coupling between polarization and magnetic field (direct effect) and vice a versa between magnetization and electric field (converse effect). This effect has been of immense interest in the scientific community over the past years. Unlike ME single-phase multiferroics, numerous ME composites, combining elastically coupled piezoelectric and magnetostrictive phases, have been shown to yield very strong ME effects even at room temperature. These structures also offer a great flexibility in the sense that a large number of parameters may be tuned independently including the materials properties of the constituent phases and the connectivity between them. Consequently, these composites are nowadays very close to a range of promising applications including: DC and AC magnetic vector field and electric current sensors, magneto-electro-elastic energy harvesters, multiple-state memory devices, micro-sensors in read heads, transformers, spinners, diodes, spin-wave generators, electrically tunable microwave filters, and various biomedical devices.

In this work, we report fabrication and investigation of a variety of different magnetoelectric composites made of magnetostrictive (metglas) and piezoelectric materials such as $LiNbO_3$ (LNO), $GaPO_4$ (GPO) and $PbMg_{1/3}Nb_{2/3}O_3$-$PbTiO_3$ (PMN-PT). ME measurements were performed as a function of the crystal cuts, magnitude and orientation of the magnetic bias field and frequency of the modulation field. Despite much weaker piezoelectric coefficients of LNO and GPO, direct ME effects were found to be competitive with PMN-PT as piezoelectric. Greatly enhanced ME coefficients in certain resonance modes were explored and their relations to the materials properties of piezoelectric materials and the geometry of the composites were investigated. We demonstrate that the orientational control of piezoelectric components can be used in order to obtain almost any desired quasi-static and resonant anisotropic ME properties for a given application. The anisotropic quasistatic ME coupling was generally found to be two times larger in bidomain LNO composites as compared to their monodomain counterparts. Large ME effects were obtained in low-frequency electromechanical resonance modes that are important for biomedical applications. Interestingly, the contour modes were strongly suppressed in bidomain systems, whereas bending modes were greatly enhanced in the studied composites. At a bending resonance frequency of 6862 Hz, we found a giant $|\alpha E31|$ value up to 1704 $V\cdot(cm\cdot Oe)^{-1}$ in laminate composites metglas/bidomain y+140°-cut LNO. Furthermore, the equivalent magnetic noise spectral density of these composites was as low as 92 $fT/(Hz^{1/2})$, a record value for such a low operation frequency. Therefore, we have shown that such composite systems may be used in simple and sensitive low-frequency magnetic and current sensing devices, including simultaneous magnetic/mechanical energy harvesting systems and magnetic field sensors. Biomedical applications of such composites will be considered as well.

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From photopolymers to 4D printing: a blueprint for a new manufacturing paradigm

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Since the first reports on stereolithography in the ‘80s[1] polymers for 3D printing have evolved rapidly giving rise to a variety of new technologies and in turn to new applications. 3D printing is indeed increasingly exploited in fields including prototyping, engineering and medical owing to fast and low cost transformation of 3D files into physical objects.[2] After the mass diffusion of fused deposition modelling, we witnesses an even faster evolution from the material point of view that lead to the combination of smart responsive polymers with additive manufacturing, thus allowing engineering objects along a fourth dimension, the time, and giving rise to 4D printing.

In 4D printing, opportunely printed responsive materials can modify their shape as desired when subjected to external stimuli such as light, heat, electricity, pressure, and magnetic field. These variations are dynamic and can occur on demand without any mechanical moving part and without any human intervention. This ability arises from a fine chemical and chemico-physical tuning of the materials properties combined to an opportune manufact engineering.[3]

This lecture will revise the evolution of 3D printing materials from original photopolymers to responsive ones, focusing on the chemico-physical properties allowing objects reshaping and on the chemistry of these systems. We will also analyze the new manufacturing frontiers opened by 4D technology that are creating a new prototyping and manufacturing paradigm.

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Polymer-based composites: fabrication, study and application

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Magnetic elastomers are smart composite materials that consist of a polymer filled with ferromagnetic nano- or microparticles. Combining the ferromagnetic properties of the filler particles with the viscoelastic properties of the polymer matrix opens up new prospects for their use in robotics, sensors and energy converters. Deformation, elastic modulus, dielectric and magnetic permeability of elastomers and other properties depend on the type of filling particles, their size and concentration, as well as on the elastic modulus of the polymer and external conditions during sample fabrication. For example, an external homogeneous magnetic field applied to the elastomer during polymerisation results in an anisotropic alignment of the particles in the final sample. One important factor that affects the properties of magnetic elastomers is how the particles are magnetized when the magnetic field changes. Depending on the elasticity of the polymer matrix, the particles can shift and rotate and thereby create internal stresses in the polymer. This has been used to create a new type of multifunctional material that has several types of ferro-ordering. Adding ferroelectric particles together with ferromagnetic particles to the polymer medium resulted in a magnetoelectric effect in the new sample. In the absence of direct contacts between the ferromagnetic and ferroelectric phases, it is the internal stresses created by the motion of one type of particle that leads to changes in the states of the other type of particle. This indirect interaction has been labeled the elastic coupling model, which takes into account dipole-dipole interactions between particles of the same type and elastic interactions between particles of different types. In addition, the magnetoelectric conversion was obtained in layered composites based on a magnetic elastomer and a piezoelectric polymer substrate. The bending of the magnetic elastomer is observed in a gradient magnetic field, resulting in an electrical signal in the piezoelectric layer. At low frequencies, resonance signal amplification and a corresponding increase in the magnetoelectric effect were detected.

Permanent Magnet-Polymer based Composites for Bonding and Additive Manufacturing

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Additive manufacturing (AM) of composite materials is attracting much attention in high-tech sectors (e.g., transport, energy, aerospace, medicine), as it allows fabricating objects with complex shapes, tailored properties and high performance [1]. Manufacturing permanent magnets (PMs) with no geometrical limitations and non-deteriorated magnetic properties is a key point and a challenge at present [2], in addition to finding alternatives (such as improved ferrites and the promising MnAlC-based alloys) to rare earth (RE)-based magnets [3].

Different alternative PM materials (gas-atomized τ-MnAlC, Sr ferrite and, by comparison, hybrids – Sr ferrite/NdFeB) were studied in collaboration with the companies Höganäs AB (Sweden) and IMA (Spain). The process for developing RE-free magnets by AM will be presented: from the composite synthesis (PM/polymer) to 3D-printing of magnets. The effect of particle size and its distribution on the resulting properties was analysed, being key factors to obtain high-load (>80 wt% of PM particles content) flexible filaments (length over 10 m) and non-deteriorated PMs properties (Fig. 1(a)) [4]. Optimized high-load MnAlC-based filament was used for 3D-printing objects under controlled temperature (Fig. 1(b) and (c)), showing that alternative PM materials can be efficiently synthesized and processed to develop novel PMs by additive manufacturing [4].

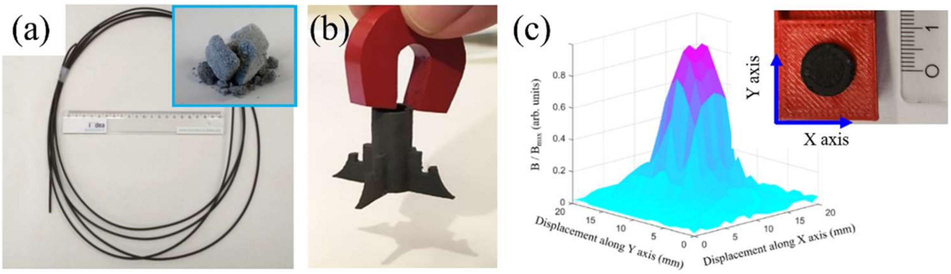

Fig. 1. (a) Extruded MnAlC/ABS filament (inset shows a MnAlC-polymer composite); (b) 3D-printed MnAlC-based object; and (c) magnetic flux density of a 3D-printed MnAlC-based disc.

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Structural and magnetic properties of arrays of nanowires/nanotubes in polymer templates

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Ferromagnetic 1D-nanostructures such as nanowires (NWs) and nanotubes (NTs) exhibiting a complex magnetic behavior are of a continuous interest. The easiest way to produce them is by means of a template synthesis by filling the pores of a specially prepared matrix with desired material. This method allows the control of physical properties by changing the geometrical parameters and chemical composition to suit a broad range of applications from spintronics and magnetic recording to hyperthermia treatments and biolabeling systems [1-3].

There are different porous materials that can be used as templates. Among them, polymer tract-etched membranes are frequently used [4]. These matrixes could be produced by irradiation of thin polymer film (such as polycarbonate, polyethylene terephthalate (PET), polyimide) with swift heavy ions. The pores are distributed irregularly in the matrix and the possibility of their overlapping increases with increasing their density. But the main parameters, such as the pore surface density and pore diameter can be independently varied over a wide range. This makes it possible to tune systematically the geometrical parameters, morphology and composition. The polymer membranes have a particular interest since they are suitable for flexible electronics.

In this paper, attention is given to the correlation of structure and composition with magnetic and magneto-transport properties. A number of elemental materials are described, including FeNi, FeCo, FeCoP as well as their combination with noble metals such as Cu and Au. Homogeneous over the length, layered and core-shell structures are considered. We analyze such key properties as magnetic anisotropy and shape anisotropy, coercivity, micromagnetic structure, modes of the magnetization reversal, spin dependent scattering and spin-valve magnetoresistance, optical properties due to Au- coatings and enhanced Raman scattering. Some aspects related to applications of 1D -magnets are briefly overviewed.

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Magnetoelectric effects in composite materials

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The magnetoelectric effect, which consists in the occurrence of magnetic or electric polarization under the action of an electric or magnetic field, respectively, is one of the most difficult effect to predict phenomena in solid state physics. Simultaneous consideration of the magnetic and electrical properties in a multiparticle system leads to the appearance of a number of approximations that complicate the theoretical consideration of the effect. Therefore, the study of magnetoelectric bonds in single-phase and composite materials is one of the urgent problems of solid state physics.

Magnetoelectric effect in magnetic composites is reviewed. The historical overview since P. Curie till first experimental results of D. Astrov is presented. The report provides an explanation of the mechanisms of the magnetoelectric effect origin from the first principles. Correlations of magnetic and electrical properties are considered in detail, both through their direct connection and through elastic interaction. On the basis of the Lanadu-Lifshitz theory and group theory, the minimum requirements that materials must have in order to observe the magnetoelectric effect are explained. The main parameter that largely determines the magnitude of the effect is the Dzayiloshinsky-Moriya interaction constant. To explain the main mechanisms and principles of the magnetoelectric effect, an atomic model with two competing interactions is considered: the Heisenberg interaction and the Dzayiloshinsky-Moriya interaction. After an intuitive explanation of the effect in antiferromagnetic Cr_2O_3, the following topics are discussed based on the experiments with composite materials. Multilayer and disordered heterogeneous samples are considered as composite materials. Using the example of various multilayer samples, the importance of the layer thickness, crystallographic parameters of neighboring layers, the magnitude of the spin-orbit interaction and the Dzayiloshinsky-Moriya interaction on the magnitude of the magnetoelectric effect is discussed. The static and dynamic approaches are considered.

After considering the main theoretical and experimental aspects of the study of magnetoelectric properties in composites, modern problems in predicting the properties of such systems and their possible applications are demonstrated.

Block co-polymer self-assembly at the nanoscale and small-angle scattering

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Structurally complex hierarchical block copolymer assemblies can be formed in solution via the interplay of multiple assembly pathways. Crystallizable block copolymers can undergo self-assembly, crystallization or phase separation in solution. By selecting appropriate solvency conditions (solvent and temperature) it is possible to induce an interplay between these processes resulting in a complex association behavior. This leads to the formation of assemblies with up to four levels of hierarchical organization. Furthermore, varying the copolymer composition enables to tune the formation mechanism and the morphology of the aggregates.

Smart polymer materials for organic bioelectronics and robotics

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Smart polymer materials play a key role in the development of novel devices of organic bioelectronics and soft robotics. They are based on a unique combination of properties of functional polymers such as electrical conductivity, light absorption, flexibility, viscoelasticity, shape-memory effect and others. In this presentation, various types of functional polymeric and oligomeric materials and their application in soft robotics, organic electronics and bioelectronics will be considered. In particular, materials for soft actuators and sensors, artificial skin, electronic nose, electronic tongue and artificial retina will be presented.

Novel metallosiloxanes [1] and their organosilicon composites are promising materials for efficient dielectric elastomer actuators with actuation stress/strain ration close to a natural muscle. New polyacrylonitrile-grafted copolymers based on poly(vinylidene fluoride) showed twice enhanced dielectric permittivity and better processability as compared to pristine copolymers [2] that can be utilized in ferroelectric devices for electronic skin applications.

Organic semiconductors are promising materials for modern (bio)chemical sensors and neuromorphic devices [3]. Organic electrolytic transistors (OET) are used as liquid biosensors. A simple approach to creating highly effective OET by phase microsegregation in mixtures of 2,7-dioctyl-[1]benzothiene[3,2-b]benzothiophene (BTBT) and polystyrene was demonstrated [4]. Self-assembled organosilicon derivatives of BTBT were successfully applied in monolayer organic field-effect transistors (OFETs) and ultrasensitive gas sensors based on them [5]. Recently the first fully integrated ultra-sensitive electronic nose based on OFETs was demonstrated [6]. Machine learning algorithms allowed distinguishing toxic gases at concentrations below 100 ppb and high relative humidity. It opens perspectives for application of the electronic nose in environmental monitoring, selective food spoilage detection and exhaled breath analysis.

Opto-stimulation of organic semiconductor-biointerfaces provides efficient pathways towards eliciting neural activity through selective spectral excitation. In visual retina prosthesis, tri-colour stimulation capability is the key to restoring full-colour vision. Organic photoactive π-conjugated donor–acceptor molecules based on triphenylamine with the absorption spectra similar to those of the photoreceptors of the human eye was developed [6]. Both photo-voltage and photo-current responses of the devices demonstrated spectral selectivity comparable to that of human eye' cones and rods.

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Magnetic straintronics: underlying physical effects and promise for ultra low-consumption electronics

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With the advent of Big Data and blockchain the demand for computing power have grown tremendously and stimulated the search for new energy-conscious technologies of information processing. This *straintronic* technology is an emergent trend in electronics with ultra-low power consumption that is characterized by switching energy at the level of 1aJ and below [1,2], down to the ultimate value allowed by thermodynamical laws, the Landauer limit *kTln(2)* [2].

Initially the straintronic principle, i.e. the usage of mechanical deformation for information systems, was proposed as a solution to the so-called "trilemma of magnetic memory" (reading/writing/storing information) [3]: the thermal stability of the recorded information implies high density of writing currents in conventional magnetic electronic devices. The idea of S*train-assisted Recording* [4–6] (by analogy with the Heat-Assisted Magnetic Recording) was to facilitate the writing information in magnetic media by reducing the magnetic anisotropy by strain that in its turn can be induced by electrically biased piezoelectric substrate.

Eventually this simple idea evolved into the straintronics as an umbrella term for a wide range of techniques including ultra-low energy electronics, energy harvesting and sensor systems [7] as well as biologically inspired electronic engineering and neuromorphic circuits [8].

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Ferromagnet particles in a polymer harness: mesoscopic description of magnetoactive polymers

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The microparticle fillers of magnetorheological suspensions (MRSs) and magnetoactive elastomers (MAEs) are multi-domain. This entails their linear magnetization in weak fields and saturation under strong ones. Being heavy enough, the particles are virtually nonaffected by Brownian motion and colloidal interactions. Therefore, when an external field is imposed, the particle behavior is entirely defined by their magnetostatic interaction.

In dense systems, which are most valid practically, the majority of the particles are separated by the distances counting just a fraction of their diameter. Under such conditions, when the field is imposed, their interaction differs drastically from usual dipole-dipole potential due to reciprocally induced non-uniformity of the intra-particle magnetization. This, in turn, affects the inter-particle forces, and, thus, the morphology and the magneto-mechanical response of a system.

As a model approach, we take a pair of particles subject to a uniform external field. Instead of a hundred+ term series – that is the exact solution for the case of highly-polarizable particles – we construct a handy interpolation formula for the interparticle magnetic energy at short ranges. With its aid we show that at short distances, the forces coupling the pair differ significantly from the predictions of the point-dipole model. This concerns both the magnitude of the center-to-center force and its angular dependence. In fact, when such particles are in close vicinity, mutual attraction dominates almost independently of the direction of the center-to-center vector.

When the magnetic field-induced forces strive to organize (re-group) the particles, the matrix reacts by generating elastic counter-forces impeding the particle displacements. Evidently, the macroscopic deformations of a MAE sample stem from mesoscopic balancing of the magnetic and elastic effects. To account for this elastic counteraction, we assume that the matrix is a Mooney-Rivlin elastomer. This model medium is non-linear, and we treat it with finite-element method. On the basis of the obtained numeric data, we construct an interpolation formula that is robust for arbitrary interparticle separations except for the direct particle contact.

Minimization of the joint magnetoelastic energy shows that in a certain field range the system becomes bistable. One of the possible equilibrium states corresponds to a weak compression of the pair, whereas the other energy minimum means a close approach of the particles and, thus, strong deformation of the matrix. On further increase of the field, the `distant' minimum disappears, and the tightly collapsed (cluster) state remains the only possible one.

Under bistability conditions, the transitions between the equilibrium configurations of the pair occur in a hysteretic manner. Under the field, the pair, first, would reside in weakly-deformed state even after appearance of the second minimum because thermal fluctuations are negligible. This configuration would exist until the `distant' energy minimum disappears. As a result, the particles would necessarily move into the only remained `collapse' minimum thus forming a cluster. Under diminution of the field, the cluster would break under the field that is lower than the field of its appearance. The area of the hysteresis loops grows with the increase of the initial interparticle distance.

The bistability effect in a pair of magnetizable particles embedded in an elastic matrix is of apparent importance for MAEs. It explains abundant clusterizing accompanied by shrinking of the sample in the direction of the field and a substantial change of rheology of the material.

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Biomimetic polymer materials and tissue engineering

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Biomimetic polymer materials are widely used in different medical applications, especially as scaffolds in tissue engineering. Bone is one of the most frequently transplanted tissues. An important task is the development of so-called biomimetic scaffolds with a certain geometry and porosity, which could contribute to the differentiation of cells aimed at bone formation.

Reverse engineering approaches, which include the study of native tissue and polymer using high-resolution microscopy and CT, combined with 3D printing methods, allows the formation of biomimetic anisotropic structures that repeat the architecture of cancellous bone.

Biosorbabe (PLA, PHB, PCL) and bioinert (UHMWPE and PEEK) were used as polymer base for biomimetic scaffold design. Bioceramics was used a filler to increase bioactivity of polymer matrix.

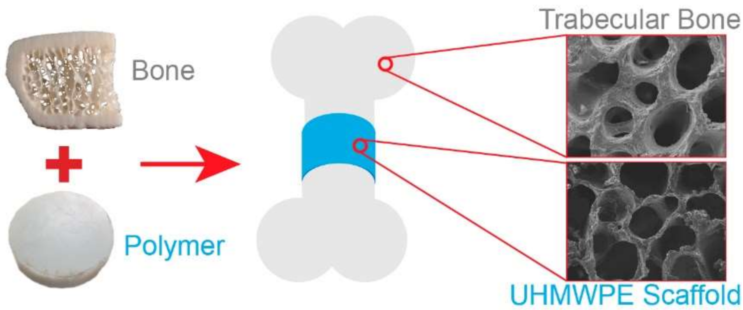

Figure 1 – Example of UHMWPE biomimetic scaffold made by bone templating

The developed biomimetic highly porous scaffolds can be used separately or in combination with MMSC for reconstruction of nonload-bearing parts of bones to solve the problems associated with difference between implant architecture and trabecular bone, low osteointegration and bioinertness.

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Synthetic antiferromagnets for biomedical and flexible spintronic applications

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Synthetic antiferromagnets (SAFs) consisting of two or more ferromagnetic layers separated by a thin non-magnetic metallic or insulating spacer have received a renewed attention in the last few years owing to their potential applications in many fields ranging from biotechnology [1,2] to spintronics [3-5]. Varying the thickness of the non-magnetic spacer, the interlayer exchange coupling between the two magnetic layers can be tuned from ferromagnetic to antiferromagnetic, thus giving rise to an artificial antiferromagnet for proper thicknesses. The interlayer exchange coupling in SAFs is much weaker than the direct exchange or super-exchange coupling in crystal antiferromagnets, thus enabling for an easy manipulation and control of the magnetic configuration (parallel/antiparallel alignment) by using relatively small and easily accessible magnetic fields. Moreover, the overall magnetic properties of the SAFs can be finely tuned by changing the single layers features (e.g., type of material, thickness), thus enabling for extra degrees of freedom for the optimization of the material performance with respect to crystal antiferromagnets.

After introducing the fundamentals of SAFs, their potential application in the fields of biomedicine and flexible spintronics will be discussed. The first part will focus on SAF microdisks prepared by top-down lithographic approaches for diagnostic and therapeutic applications. Such structures fulfill all the key criteria required for biomedical applications while allowing a significant degree of control and tunability of the magnetic properties, thus representing a promising alternative to superparamagnetic particles that are commonly used as the magnetic core in composite architectures. The second part will be dedicated to SAF-based spintronic heterostructures on flexible polymer tapes combining the peculiar features of SAFs with the unique characteristics of polymer tapes (e.g., lightweight, flexibility, shapeability, wearability, and low cost) for the development of novel multifunctional devices.

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Posters

Layered polymer-based structure for multiferroic applications

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Technological evolution forces the development of sensing systems and harvesting devices with improved efficiency and response time. For the detection and transformation of electromagnetic and mechanical oscillations, devices based on multiferroic materials are widely used. Layered composite multiferroics are widely investigated due to large values of magnetoelectric effect in comparison with single-phase multiferroics [1]. The area of application of multiferroic materials includes different electronic devices such as microwave absorbers, sensors, autonomous energy sources and other energy converting devices [2].

To enhance the magnetoelectric effect in layered structure, the material based on magnetorheological elastomer and piezoelectric polymer was developed. Deformational properties of magnetic elastomer and high values of magnetoelectric transformation in layered structures account for the attempts to create composite multiferroics with elastomer as a ferromagnetic layer. Piezopolymer allow to keep the mechanical properties of the composite.

The layered structure based on magnetorheological elastomer with iron microparticles and PVDF piezoelectric film was investigated. The PVDF layer is the commercially available polymer with conducting plates and protective covering. Magnetic elastomers with carbonyl iron microparticles at different concentrations (40-80 wt.%) were placed onto the PVDF layer and attached due to adhesion of surfaces. Carbonyl iron particles of nearly spherical shapes and 0.5-2 µm size distribution were used as a filler. Particles concentration varied from 40 to 80 wt.%. Silicon compounds (PDMS, Elastosil, Wacker Silicone™) with various Young's modulus were used as matrices of the samples. Magnetoelectric transformation can be obtained in layered structures due to huge bending deformations of magnetorheological elastomer in gradient magnetic field. This deformation leads to corresponding bending of PVDF layer, which results in induced voltage from the sample.

The experimental investigations were carried out with the measuring cell based on the microcontroller Arduino. The Arduino microcontroller reads the signal from the PVDF film and sends it to the computer. The external gradient magnetic field is produced by the electromagnet, which is also connected to the Arduino microcontroller. The microcontroller switches on the electromagnet and starts to read the signal of PVDF film. As a result of the experiment the dependence of PVDF film's signal (induced voltage) on time for each impulse of magnetic field is obtained.

The values of experimental magnetoelectric effect in the proposed structure can reach several hundred mV in terms of induced voltage. The effect is dependent on magnetic field amplitude, what makes it prospective for detecting purposes. The effect can be tuned by ferromagnetic particles content in magnetic elastomer, by the thickness of the layer and its rigidity.

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On the prospects of magnetoelectric composites for biomedical applications

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Recently, the great scientific interest has focused on the design of new smart materials with prospective for biomedical technologies. One of the promised class of smart materials are multiferroics with magnetoelectric (ME) coupling, due the interrelations their magnetic and electric properties. From this point of view ME composites are more promising type of multiferroics with strong magnetoelectric effect, that make them more interest for potential practical applications.

The main smart effect of ME composite is concluded in ability to mutual control magnetic and electric properties. The ME composites are the artificial materials and in opposite to single-phase multiferroics their ME nature is associated with an interaction between composite components. Thus, in an applied magnetic field, a magnetostrictive component transfers strain to a piezoelectric component that generates an output electric voltage.

In depend on output effects and resolved practical tasks, the various connectivity schemes are used in the design of ME composites. In general, connectivity schemes divides into : 0-3–type for particulate composites of piezoelectric and magnetic grains; 2-2–type for layered composites consisting of piezoelectric and magnetic layers; and 1-3–type for fiber composites with fibers of one phase embedded in the matrix of another phase.

ME composites have the prospective to enable mutual conversion of magnetic energy to electrical and thus can be utilized to power devices, electrically stimulate of tissues or cells using remotely magnetic field stimulus. It open new opportunities for applications as advanced biocompatible sensors, contactless electrical stimulation, health-monitoring, theranostic and bioenergy harvesting systems. In connection to the applications for biomedicine, the polymer-based ME composites are more prospective. Despite the magnetoelectric effects in polymeric ME composites are smaller than in ceramic structures, they have advantages in simple fabrication and flexibility [1]. Additionally, polymeric interfaces can show good biocompatibility, which together with multiferroic properties make them a unique tool for a set of bioapplications (e.g. cultivation surfaces with remotely controlled electric surface charge and mechanical stresses by applying an external magnetic field) [2]. Application of double stimuli—charge and mechanical stress can promote cell responses such as a controlled differentiation of stem cells.

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Effect of magnetoelectric polymer composites on the activity of bNCSCs

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Stem cells are actively used in the field of regenerative medicine and tissue engineering due to their ability to differentiate into various types of cells. Growth factors are usually used to control the fate of stem cells, but this method is expensive. In recent scientific works, it was shown that the microenvironment of cells is able to influence the mechanisms of mechanotransduction in cells, thereby stimulating differentiation in a certain direction [1].

The microenvironment of cells should mimic the natural extracellular matrix and be able to provide the influence of various signals: mechanical, biochemical, electrical, etc. The ability to ensure the action of these factors largely depends on the choice of material for making the frame of the biological interface. The use of a biocompatible piezoelectric polymer matrix modified with magnetic filler as a basis for a biological interface will make it possible to create an instrument capable of controlling the parameters of the biophysical and biochemical microenvironment of cells. This is necessary because each cell type has its own optimal range of differentiation conditions [2]. Interesting, from this point of view, is the use of magnetoelectric polymer composites.

Magnetoelectric polymer composites are a group of materials consisting of magnetic filler and a piezopolymer matrix. In this class of materials, magnetoelectric coupling is associated with deformation interactions between the magnetic filler and the piezoelectric matrix (or particles) [3]. The biocompatibility of the polymer base, along with the multiferroid properties of the composites, makes them interesting for a number of biological applications; in particular, it will make it possible to use them as a substrate for the cultivation of stem cells with remotely controlled physical parameters by applying an external magnetic field.

In this work, we developed composites based on polyvinylidene fluoride (PVDF) polymer and its copolymer Polyvinylidene fluoride-trifluoroethylene (PVDF-TrFE) modified with magnetic nanoparticles ($CoFe_2O_4$ and $Zn_{0.25}Co_{0.75}Fe_2O_4$) and piezoparticles ($BaTiO_3$). All samples were subjected to X-ray diffraction analysis, analysis of magnetoelectric properties, magnetic microscopy, and piezoresponse force microscopy. Various methods of making composites have made it possible to increase the magnetoelectric effect (α_{ME}) from ~ 5 mV/cm • Oe (PVDF composite with a random distribution of magnetic nanoparticles) to ~ 18.5 mV/cm • Oe (PVDF-TrFE composite with the addition of piezoelectric particles). PVDF-based substrates were additionally tested on a culture of neural stem cells isolated at an early stage of mouse embryonic development (bNCSCs) to analyze their effect on stem cell activity [4].

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Force sensors for miniature actuators

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Nowadays, there are a huge number of people with visual impairments that significantly affect their social life. In turn, so far there are no budget and effective devices that can allow a person to navigate in space. Therefore, within the framework of the project "Development of a device for the blind based on sensory substitution", it is planned to develop a wearable device capable of transmitting to a person the sensations of distance to objects through a tactile matrix. This matrix will consist of 144 miniature magnetic actuators that affect the skin with different forces depending on the distance of the surrounding objects. A matrix of such actuators is attached to a person's head, a special stereo camera and a processor unit build a depth map of objects and transmit it to the skin of the person's forehead.

However, the question arises about determining the optimal impact force: minimally sensitive and as comfortable as possible.

In this work, we propose to use of force sensors to determine the efficiency of miniature actuators. Depending on the force of the action of the actuator rod, a person can determine the distance of the corresponding area. In order to calibrate such actuators, it was proposed to use special force sensors.

Force sensors made from polyvinylidene fluoride (PVDF) – a typical piezoelectric polymer, which applied to capture the dynamic pressure field over the rod. The sensor consists of a 30-μm-thick PVDF film with copper electrodes, two shielding layers of aluminum and two layers of skin imitating material.

The top layer of skin imitation material is made of a silicone rubber with a thickness of 0.5 mm. This layer must be tighter than bottom layer. The bottom layer is gelatin-based material with a thickness of 1 mm. The shielding layer is next to skin imitation layer. It mainly used to shield the sensor against the background noise and electromagnetic interference, which is generated by the magnetic coil in actuator. The extraction electrodes are made of copper and fall into two parts, negative electrode and positive electrode, which are insulated from the other layers by PET plastic.

The experiment consists of two parts. To begin with, it is necessary to find the pressure force at the minimum threshold of sensitivity of the human skin and the maximum permissible force that will not bring discomfort to a person.

Then, based on these values, select the optimal current in the magnetic coil, at which the actuator rod will act on the force sensor with values that do not exceed the measured range.

Having obtained the values of the current strength, we can make corrections to the control circuit and determine the optimal levels of the signal supplied to the magnetic coils for each degree of distance of the object.

Application of the energy criterion of point agglomeration to Ni and Fe nanowires synthesized in the pores of track membranes.

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Arrays of metal micro- and nanowires (NW) are widely used in electronics and biotechnology. The problem of agglomeration of NW and their agglomeration to the surface is also of interest when creating micro-and nanomechanisms, micromachines. In a number of sensor devices, the use of separately located vertical NW is promising. For example, an array of metal wires is used as SERS substrates (Giant Raman Scattering).

It was previously shown [1] that with point contact of the vertices of several Ag NW, it is possible to obtain a significant gain of the SERS- signal, where a region of local increase in the electric field is realized (hot point). The vertices of NW stick together pointwise at a certain length L*, which can be estimated by the theoretical method [2]. With a smaller length, the NW doesn't stick together, with a larger one there is a disorderly sticking along a noticeable length of the NW.

The theoretical method for estimation the agglomeration of NW is based on an energy criterion similar to the well-known Griffith crack growth criterion. The degree of agglomeration is determined by the competition of the elastic bending energy of the wires and their surface energy.

Based on this method, theoretical calculations of this length L_0 were carried out for different metal, for example Ni and Fe for NW with a diameter of 100 nm. After that we experimentally obtained an array of Ni and Fe NW using the template synthesis method. Track membranes obtained in the Laboratory of Nuclear Reactions of JINR (Dubna) were used as matrices. During the removal of PET (polymer template) in a liquid medium with subsequent drying, NW may be grouped, or stick together at the ends, or remain isolated. The result depends on the parameters of the NW and the distance between them. We have considered special cases of parallel wires on a rigid substrate. The system is located in air or in a neutral environment, there are no capillary effects.

The approach itself is of a general nature and can be used for other agglomeration options. For a system of fixed parallel NW, the formula for the radius of curvature of bending of two adjacent fused wires contain only the values of the elastic modulus E, the surface tension of the NW material in the medium α and the radius r of the wires. By the value of R*, the non-fused length of the NW L*is found by the graphical method. The wires stick together near the vertex if their non-stuck length L*, corresponding to the radius of curvature R*, is approximately equal to the entire length L_0. If $L^*>L_0$, there is no sticking at all. The theoretical estimates according to the method gave for Fe and Ni NW the value L_0 equal to 2.1 and 2.2 microns, respectively, which corresponds well to the experimental data.

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Numerical modelling of FORCs of magnetoactive elastomers based on ferromagnetic and ferroelectric particles

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Magnetoacive elastomers (MAE) with the mixture of ferromagnetic and ferroelectric particles with soft polymer matrix become more and more popular in recent years. Recently it was shown that such elastomers show multiferroic properties. Such multiferroic materials are significantly more flexible and can be biocompatible for different biomedical and engineering applications.

First-Order Reversal Curves (FORCs) [1] is effective tool to characterize hysteretical behavior of material and analyze its magnetic intrinsic interactions, local switching fields, coercivity distribution and local interaction fields. FORC approach is widely used experimentally to analyze properties of MAE [2].

In this work we present results of numerical simulations of FORCs of MAE with ferroelectric filler. We analyze properties, FORCs and switching field distributions (SFD) of the material by simulating "bulk" systems containing 10^4 particles. The effect of external constant electric field was investigated.

MAE are well known for their properties to be strong depended on particles distribution in the elastic matrix. The presented model is based on the assumption about the displacement of magnetic particles inside the elastic matrix under the external magnetic field and the formation of chain-like structures.

To calculate particle redistribution in the system molecular dynamic approach was used. To calculate particles positions Verlet integration [3] was used. We considered dipole-dipole model for particle-particle interaction and "springs" model for particle-matrix elastic interaction.

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

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FORC-approach for magnetoactive polymer-based composites

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Magnetoactive elastomers (MAE) refer to composite materials that consist of polymer matrix and magnetic micro- or nanoparticles. Properties of MAE strongly depend on the type of particles and elastic modulus of polymer matric as well as particles distribution inside the matrix affecting their interaction. MAE properties, namely magnetodeformation, magnetorheology etc. [1,2] allow the use of these composites in various fields of engineering [3,4] and biomedicine [6]. MAE macrocharacteristics, such as Young's modulus, the magnitude of deformation in a magnetic field, magnetic properties are associated with their microcharacteristics, namely, with the distribution and interaction of FM particles inside the polymer matrix. Various methods are used to study the distribution of particles, such as force and optical microscopy [7], 3D microtomography [8], etc.

In this work, method of First Order Reversal Curve (FORC)-analysis [9,10] is used for providing information of the number of magnetic phases and origin of their interaction, values of local switching fields, interaction fields and coercivity distribution for all the phases that contribute to the hysteresis loop for the elastomers. The elastomers with ferromagnetic (Fe-based) particles of different concentration and preparation conditions are used. FORC approach shows the influence of magnetic anisotropy on the interaction between different magnetic phases and their switching parameters. MAE with the particles with different anisotropy is the example of flexible composite that can be used in engineering and biomedical areas.

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Stress and temperature sensitivity of magnetization process of magnetic microwires for structural health monitoring

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The possibility of controlling the electromagnetic properties of composites materials through the external influence such as magnetic field, stress and temperature is of particular interest for various applications including reconfigurable devices and non-destructive tests. Such tunable electromagnetic behavior has been demonstrated in polymer composites with ferromagnetic amorphous microwires with ultra-soft magnetic properties [1-3].

In the present work, we are presenting a new method of monitoring internal stresses. The method can be referred to as embedded sensing technique, where the sensing element is a glass-coated ferromagnetic microwire with a specific magnetic anisotropy. The microwire of composition $Co_{71}Fe_5B_{11}Si_{10}Cr_3$ show abrupt transformation of the magnetization process under applied tensile stress. Ferromagnetic microwires with positive magnetostriction are characterized by almost rectangular hysteresis loop measured in a magnetic field along the microwire axis. The magnetization takes place by axial domain propagation which generates a sharp voltage signal producing high harmonics. Enhanced stress sensitivity is seen in the case when the magnetostriction constant can change a sign under stress effect. Therefore, these wires can be used as wireless sensors with remote interrogation and can be placed on the surface or inside materials. We demonstrate that the ratio of harmonic amplitude may also sensitively depend on tensile stress which can be used directly for structural health monitoring. The advantage of using magnetic microwires as embedded sensors is related with the tunability of the response, small cost and relatively simple signal processing.

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Magnetic properties of $CoFe_2O_4/SiO_2$ nanocomposites

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The magnetic properties of nanocomposites of cobalt ferrite nanoparticles in silica matrix ($CoFe_2O_4/SiO_2$), synthesized by a sol–gel auto-combustion method, have been investigated by DC magnetometry and AC susceptibility measurements at different frequencies [1]. The control of the particle size was achieved by varying the nanoparticles concentration (from 5 to 15 %) in the matrix and the temperature (from 700 °C to 900 °C). The particle size increases (from ~2.5 to ~7 nm) with increasing the annealing temperature as observed by high-resolution transmission electron microscopy (HRTEM) images.

The M_S increases with the annealing temperature. Its value depends on the combined cation distributions, canted spin fractions and surface effects. In ref. [2], where the N15T900 (6.7 nm particle size) and N5T900 (2.8 nm particle size) samples were compared, an increase of M_S with decreasing the particle size associated with an increase in canted spins as a result of an increased fraction of Fe^{3+} in octahedral sites was reported. The non-saturated susceptibility decreases with increasing annealing temperature and particle size. The contribution to the non-saturated susceptibility (χ_{SAT}) should be attributed to the magnetically disordered or canted spins in the core of the particles, playing an important role on the magnetization process. The value of the effective magnetic anisotropy constant (K_{eff}) increases with the decrease of particle size, being two times higher than the bulk value for ~3 nm particles, as the result of the increasing surface contribution. Moreover, for particles of the same size, but annealed at different temperatures, we observed a significant variation of K_{eff} due to the change in the cation distribution, strongly affecting the magnetocrystalline anisotropy. The results show that the anisotropy comes from a complex balance of surface and magnetocrystalline contributions of the core closely related to the particle size and to the cation distribution.

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Obtaining of calibrated nickel nanoparticles for local drug delivery

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It is known that magnetic particles are actively used in biology and medicine. So, an urgent and actively solved problem at the present time is called “Targeted drug delivery”.

There are a large number of methods for using magnetic nanoparticles for local drug delivery, for example, applying a drug to the surface of magnetic nanoparticles or introducing magnetic particles into the shell of drug capsules to further bring them to the desired location using a magnetic field. Also, the magnetic nanoparticles delivered to the desired location can provide local heating due to the subsequent application of a high frequency magnetic field.

In this work, it is proposed to use elongated magnetic particles with a sufficient magnetic moment to rupture a polymer microcapsule with a drug.

We have developed a method for obtaining nanoparticles with strictly specified geometric parameters. For this purpose, arrays of layered nickel / copper nanowires were fabricated using the matrix synthesis method, by electrochemical filling of the pores of track membranes. The modes of alternate deposition of separate layers of nickel and copper layers were selected. Nickel layers were then isolated in the form of single nanoparticles due to selective chemical dissolution of intermediate copper layers (sacrificial). This mode made it possible to synthesize a large amount of nanoparticles in each pore channel.

Suspensions of nanoparticles with a diameter of 100 nm and lengths of 50, 100, 200, or 400 nm were obtained. The geometry control was carried out by the SEM method. The first experiments on the introduction of nanoparticles into the shell of polymer microcapsules have been carried out. To study this process, their zeta potential was measured, the value of which was -8 ± 2 and -4 ± 1 mV. It has been proven that particles can be introduce into the surface of the capsule-shell during their synthesis, however, the efficiency of this process is low. This is because the magnetic particles stick together to form agglomerates in solution.

Various methods have been used to eliminate this effect. Demagnetization of nanoparticles on a demagnetizer led to a slight decrease in agglomeration. Also, a method was developed for a controlled increase in copper impurity in magnetic layers to lower the Curie temperature. For bulk alloys, it is known that the ad of $\approx$ 30% copper will lead to a decrease in the Curie temperature to 50-80 ° C. In this work, this will make it possible to controllably “turn on and off” the magnetic properties of nanoparticles by a slight heating. In this work, the first results were obtained on reducing the agglomeration of nanoparticles due to the controlled addition of a copper impurity into nickel nanoparticles during electrodeposition. The paper evaluates the influence of the parameters of the electrodeposition process on the amount of copper in nickel particles. Estimated calculations of the magnetic moment of cylindrical nanoparticles are carried out.

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Scanning probe microscopy as a multifunctional tool to study polymer-based composites

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Polymer-based magnetoelectric composite materials have attracted a lot of attention due to their high potential in various types of applications as magnetic field sensors, energy harvesting, and biomedical devices [1]. One new strategy to increase the value of the desired effects in the composites is to prepare materials with the differently distributed magnetic and / or piezoelectric particles inside the polymer matrix [2]. This strategy may help to increase the magnetoelectric effect of such composites and to make them applicable as bioactive surfaces for neural crest stem cell cultures [3,4].

Scanning probe microscopy, which includes atomic-force, magnetic-force, piezoelectric-force, etc. microscopy turned out to be a multifunctional tool to study the properties of the composite materials. The main advantage is that the desired properties can be examined not only separately but also in conjunction which is undoubtedly helpful for the multiferroics where each of the components (magnetic, electric or elastic) can be strongly dependent on the other one and vice versa. Another valuable advantage is the possibility to plot the mapping of the studied properties across the sample surface. If one can see the different regions, for example, with and without nano- and microparticles, it is possible to differentiate which region gives the impact to the magnetic or piezoelectric response of the whole sample [5].

In this work we studied the sample of the piezoelectric elastic composite, consisting of the PVDF-TrFE polymer matrix with $Zn_{0.25}Co_{0.75}Fe_2O_4$ magnetic nanoparticles, distributed in it. On the first step we studied the mechanical properties on this composite using NTEGRA scanning probe microscope (НТ-МДТ, Russia) in the hybrid scanning mode. In this mode the probe retracts from the surface in each single point of the scan and then reaches the surface again, while the software mathematically fits the obtained force versus distance to the surface curves, extracting the values of the Young modulus, mechanical stiffness and adhesion force in the same time with the roughness. Due to this method we visualized the distribution of the magnetic nanoparticles across the surface and studied the way it affects the mechanical properties of the sample. The obtained mapping was in the good agreement with the previously achieved X-ray computer tomography 3D-scans. Afterwards we investigated the magnetic properties of the polymer using magnetic-force microscopy. We obtained the pictures of the magnetic dipoles, corresponding to the zinc-cobalt-ferrite nanoparticles, distributed inside the diamagnetic matrix and observed their motion when the external magnetic field was applied. The obtained results let us conclude on the mechanisms of the interaction between the particles and the matrix and gave us the important insights about the formation of the properties in the studied class of composites.

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Conjugated oligomers and polymers for gas sensing via organic field-effect transistors

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Monitoring and quantitative analysis of various gas mixtures including indoor and outdoor air atmosphere, food aromas, exhaled breath etc., are becoming more and more important for both safety and personal medicine points of view. One of the perspective techniques for creation low-cost, portable device with low energy consumption is based on usage of the ultrathin-film (monolayer) organic field-effect transistors (OFETs) as sensor devices for detection of different gases (analytes) in the atmosphere. Such detection is possible due to strong dependence of the OFETs electrical properties on the environment while direct contact between the thin current-carrying layer and the analyte in the monolayer OFETs determines their ultrahigh sensitivity to the presence of toxic gases in the atmosphere.[1]

In this talk a new, simple and fast method of fabricating of reusable gas sensors based on monolayer Langmuir-Schaeffer (LS) OFETs for real-time detection of various polar gases will be presented. The devices investigated demonstrate the limit of detection of 50-70 ppb for ammonia, hydrogen sulfide and nitrogen dioxide in air atmosphere with relative humidity up to 60%. The response and recovery times were found to be within a few minutes and 10-20 minutes, respectively. We have demonstrated two suitable approaches of selectivity achieving for such devices. The first approach is based on the fact that direct current response of such sensors can be splitted into the variation of different OFET parameters, which are responsible for the interactions with different toxic gases. The sensor response estimation routine developed allows complete distinguishing of three different gases mentioned above with a single sensing device.[2] The main disadvantage of such approach is strict limitation of analytes which can be distinguished by it. The second approach is more universe and based on the idea of the device modification by an additional metal-containing porphyrin receptor layer. Such modification increases the sensitivity of the device, as well as allows the sensor selectivity adjustment while keeps response and recovery times at the same level comparing with non-modified OFETs.[3] Finally combining our knowledge we successfully fabricate an array of 20 semi-selective sensors on one chip, whose response can be collected simultaneously with portable analyzer forming "electronic nose" system. Such system are able to distinguish ammonia, hydrogen sulfide, nitrogen dioxide and ethanethiol in concentration range of 40-1500 ppb in humid air with relative humidity up to 95%.[4]

In addition, we have demonstrate that sensor devices with almost the same limit of detection can be fabricated by inkjet printing what allows device cost decreasing.

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Tensoresistive effect of silicon polymer nanocompositions in transformed structures

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Introduction

To assess the change in the geometry of the transformed structures, the strain-resistive effect of the material is used. Silicone rubbers have low internal friction and are capable of stretching over large values makes these materials an interesting and promising matrix for creating tensoresistive nanocomposites [1, 2]. Carbon nanotubes are a versatile additive that modifies the properties of a material while maintaining its quality. In particular, when carbon nanotubes are added to polymers, their strength increases and conductivity appears, which can be varied within wide limits. They are directly embedded inside the material from the manufacturing stage also allows to perform real-time monitoring of element.

Methods

The objects of study were samples based on Elastosil RT 604 silicone rubber manufactured by Wacker (Germany) with various concentrations (1, 2, 3, 5 wt.%) of concentrate based on single-wall carbon nanotubes manufactured by OCSiAl (Russia). The resistance of composites with different concentrations of carbon nanotubes was measured by the strip probe method under different loads and depending on the number of loading cycles. To study the strain-resistive effect in the samples during bending deformation, an installation was assembled.

Results and discussion

In previous studies, we have shown that for single-walled carbon nanotubes, the composite has a resistivity, which indicates a change in the substructure of carbon nanotubes in the composite. This is determined by the presence of semiconductor nanotubes in the material of single-walled carbon nanotubes. In this work, the coefficient of resistance to bending deformation was determined in the range from 0.5 to 2.

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Polymer composite materials with shape memory effect based on polylactide for adaptable medical structures

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Biopolymers are increasingly used in medicine today. In addition, the number of scientific studies aimed at creating polymer composites with various specified properties is constantly growing.

One of the most common polymers already used in medicine is polylactide (PLA). It has some already proven important characteristics, such as biocompatibility and biodegradation by hydrolysis, as well as less studied, but no less interesting properties, such as the shape memory effect. The shape memory effect of this polymer is a promising object of research, relevant for the creation of various adaptive medical structures and self-installing implants in the focus of reconstructive medicine.

An important task of this work was to reduce the activation start temperature and the apparent activation energy of the memory effect of the polylactide form to ensure the possibility of safer and easier use of this effect in biomedical applications. Thus, a composite material based on polylactide with a content of 10 wt was developed. % polycaprolactone (PCL), the activation temperature was reduced from 55-60 °C to 45 °C, and the apparent activation energy was reduced by 85 kJ.

One of the effects realized in the human body is the piezoelectric effect. It consists in the occurrence of electrical potentials under mechanical stress. Mechanical stresses induce electrical signals that can stimulate cell growth and division, that is, promote tissue repair.

Polylactide has piezoelectric properties, which makes it an even more promising material for use in tissue engineering. However, the piezoelectric response is quite low, which requires the introduction of electrically conductive fillers into the polylactide matrix, in this study reduced graphene oxide (rGO) was used in amounts of 0.7, 1.0 and 1.5%. The introduction of dispersed particles also affects the morphological structure and crystallinity of the polymer matrix. Thus, the addition of rGO particles to the polymer composite has a positive effect not only on the piezoelectric response, but also on the characteristics of the shape memory effect.

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