Project logo

Project website

Leader **E. Lahderanta**, Finland
Lappeenranta University of Technology
Magnetometry

Leader **A. Chuvilin**, Spain
CIC nanoGUNE
TEM for Nanocarbon Materials

Leader **M. Ricco**, Italy
Parma University, Carbon Nanostructures Laboratory
Hydrogenated graphene

Leader **T. Makarova**, Sweden
Umeå University
MagNonMag Roadmap

Leader **A.V. Okotrub**, Russia
Nikolaev Institute of Inorganic Chemistry, Siberian Branch of RAS
Fluorographite

Leader **J. Stride**, Australia
University of New South Wales
Graphene and Molecular Magnets

Leader **A.G. Zabrodskii**, Russia
Ioffe Physical Technical Institute
Magnetism and Metal-Insulator Transition
WP1 Synthesis of novel magnetic semifluorinated graphite/graphene systems

Work package Leader: NIC (A. V. Oktubasid)   Involved Partners: NIC, Umi, UNIPR, UNISW

There is a strong interest in the synthesis of new magnetic materials for the development of novel electronic devices. The use of magnetic graphene has been shown to have potential applications in spintronic devices, information storage, and field-effect transistors. In this project, we propose to synthesize novel magnetic graphene materials using various techniques, including chemical vapor deposition (CVD) and epitaxial growth. The objective is to develop graphene materials with tunable magnetic properties and high electrical conductivity. This work will be conducted in collaboration with UNIPR and UNISW.

WP2 Magnetism in the vicinity of the metal-insulator transition in the IV group elements

Work package Leader: PTH (A. G. Zabrodskii)   Involved Partners: PTH, Umi, NanoCUNIE

In this work package, we aim to investigate the magnetic properties of IV group elements in the vicinity of the metal-insulator transition. The study will focus on elements such as Ge, Sn, and Pb, which exhibit a transition from a metallic to an insulating state. The project will involve experimental investigations using techniques such as magnetotransport measurements and magnetic susceptibility measurements. The results will help in understanding the role of magnetic interactions in these materials and their potential applications in spintronics and quantum computing.

These phenomena are insufficiently studied, mainly due to their weakness at normal conditions. They become noticeable in special conditions: in the vicinity of MIT for electronic semiconductors, where the carrier concentration becomes critical, the role of spin coupling becomes rather strong. In contrast, in the Coulomb gap, the spin gap disappears at the transition point and affects the very phenomenon of the MIT. The nature of the spin gap may be due to the Peierls model [R. E. Peierls, Quantum Theory of Solids, Oxford, 1955]. In low-dimensional systems, it is energetically more preferable to move in the insulating state by doubling the lattice parameter, while remaining in the metallic state in the distilled lattice. The unit cell contains two atoms in which electron spins are antiparallelly coupled, and the electron energy spectrum acquires a gap of spin origin. In the compensated n-Ge internal electric fields lead to a broadening of the resonance line rather than its splitting as occurs in uncompensated and weakly compensated n-Ge [A. V. Voinov, B. A. Zabrodskii, S. I. Gelashchagov, Semiconductors, 42 (2008) 1301]. A spontaneous lattice distortion of Ge has been explained on the basis of the Peierls effect. [A. V. Voinov, A. G. Zabrodskii, T. Timosh, S. I. Gelashchagov, Izvestiya, a series of physics, 73 (2008) 1944]. The WP is aimed at further development of
WP3

**Workprograms**

**WP3 Ion-beam induced magnetic nano-patternning of graphite**

Work package Leader Ph.D. T. V. Timok

Involved Partners PTI, Umii, UNIFR, NIC

In recent years intense research is being pursued to the development of novel methods for the fabrication of magnetic nanostructures. This is motivated not only by technological applications but also by fundamental scientific interest since magnetic behaviour of materials on the nanoscale differs significantly from the bulk. Carbon has a unique combination of magnetic and structural properties which turns it into a potential candidate for magnetic patterning. Whereas atomically ordered carbon is diamagnetic at room temperature, skilfully and knowingly disordered carbon becomes ferromagnetic. Theory predicts plenty of ferromagnetic scenarios for carbon, i.e. graphite, diamond, nanotubes, fullerenes or graphene. There are plenty of random experimental publications about observation of metal-free magnetism found in or on carbon allotropes. PTI and Umii are experienced in systematic and reproducible production of magnetic carbon [1].

Objectives of this WP are: (1) To investigate the ion-beam induced PM and correlate structural ( lattice parameter, crystal size, microstrain and magnetic (saturation magnetization, Curie temperature, ferromagnetic/antiferromagnetic) properties. (2) To study the generation of ferromagnetism and antiferromagnetism by ion irradiation applying the effect of different species, their energy and dose, process temperature and time on the induced magnetism. (3) To demonstrate the feasibility to produce periodic arrays of isolated ferromagnetic structures in the micro and nanoscale range by selective ion irradiation, i.e. using ion irradiation through shadow masks or focused ion beam. (4) To perform a systematic study of the induced transformation aimed at tailoring and correlating the induced structural and magnetic properties.

WP4

**Workprograms**

**WP4 Advanced quality control**

Work package Leader nanoGUNE (A. Chouvilli)

Involved Partners nanoGUNE, Umii, UNIFR, PTI, NIC, UNIV

Scanning Electron Microscopy (SEM), and atomic force microscopy (AFM) are used to analyze with sub-nanometer spatial resolution the morphology, structure, and chemical composition of the nanostructures. Depending on the chosen preparation route specific crystallographic orientations, shapes, and chemical compositions of the graphene-based structures will be determined.

**Surface chemistry**

The crystalline quality (deep centers, localized states, fluorine related disorder effects due to different nearest neighbour configurations, impurities) of the structures are studied by high resolution X-ray diffraction and X-ray photoelectron spectroscopy (XPS) is pursued as well, since defects introduce modifications in the frontier valence electronic structure and, if containing heteroatoms, also appear in XPS spectra. XPS provides additional information concerning nanostructure, heteroatomic bonds, intercalated and adsorbed atoms and molecules. The XPS system at Umii University is used to analyze surface composition (3-10 nm in depth). Identify and quantify oxidation states, and elemental-depth distribution. The device is equipped with small spot XPS imaging facility, ion gun which provides depth profiling up to 0.3 µm, and angle resolved XPS. XPS and TML are used in combination to determine the site-specific chemical bonding and defect diffusion on an atomic scale.

**Specroscopy**

Raman spectroscopy and carbon provides essential information due to peculiar dispersion of the FF electrons in graphene. The shape, intensity, and position of the peaks gives us much information as that obtained by a combination of other lengthy and destructive approaches.

Time-resolved electron- and photo-luminescence is used for the detection of possible impurities via the modification of the integral or time resolved optical spectra.

The present defects, can for example, significantly modify the singlet-triplet transition, induce quenching effects and even generate new peaks. The impact of such defects on deep centers, localized states, fluorine related disorder effects due to different nearest neighbour configurations, impurities on the optical properties (non-radiative recombinetion processes, emission peak broadening) are measured by time-resolved photoluminescence experiments.
WP5

Workprograms

WP5 Magnetic characterization

Magnetometry: SQUIDs, AC magnetometry

Superconducting Quantum Interference Device (SQUID) magnetometry. Vibrating Sample Magnetometer (VSM).

AC/DC susceptibility are used for a full characterization of bulk and surface magnetism. The features of ferromagnetism, superparamagnetism, and superconductivity are identified from the analysis of temperature and field dependencies of magnetic moment.

EMF is made on the reduced dimensionally effects.

This is a sub-dimensionally dimensioned area which is expected to produce fundamentally new knowledge. Directional measurements of the dependencies of magnetic moment as well as the electron paramagnetic resonance signals will be performed.

BPM: Kohler probe / Magnetic force microscopy. This allows for the detailed and precise investigation of homogeneity and local electrical properties. Using a conductive-tip AFM (CT-AFM) an electrical mapping with resolution down to the nanometer scale will be provided. The application of local probes will permit us to relate the magnetic properties to the structural defects and topology of the materials in the investigated areas.

The detected features of the ARMs are in the graphene. Measurements are performed in the atmosphere of dry nitrogen to avoid the effect of water absorption.

Resonance techniques: Electron spin resonance, Ferromagnetic Resonance, Muon Spin Rotation

Resonance methods provide a fingerprint of the magnetic unit. The pronounced manifestations of the spin interaction were found in the insulating states in the vicinity of the metal-insulating transition. In this region of concentrations, binding of spins into antiferromagnetic pairs lead to a decrease in the intensity of the ESR signal with decreasing temperature, a reduction of the g-factor with increasing impurity concentration, and changes in the line shape and width. SQUID measurements in the field cooled and zero field cooled regimes will be simultaneously performed. Temperature dependencies of the linewidth of the ferromagnetic resonance magnetic field at the center of the ferromagnetic resonance, double integrated interferometer for irradiated graphene will be compared to those for fluorinated graphite. Thus, an important conclusion will be made on whether the magnetic structural units are identical for different types of magnetic carbon materials.

Muon Spin Rotation (μSR) offers a valuable instrument for probing local magnetic fields. Unlike other resonance techniques it does not require any application of external fields which could perturb the magnetic system.

The detection of the precession signal (which originates solely from the magnetic region) and the measurement of its decay, will allow a fundamental characterization of the magnetic system. This method provides information about internal magnetic field distributions and it provides information about magnetic fluctuations and spin-dynamics, even above the magnetic transition temperature.

WP6

Workprograms

WP6 Theory and design

Despite several recent publications introducing the ways towards graphene spintronics, there still is a need for understanding the possibilities of spin injection in graphene-based materials. Intrinsically magnetic regions created by induced magnetization may help solving this problem. Advanced multilayer computational methodologies combining data from the art and in situ and real binding approaches will be developed to tackle with spin transport and spin-bit coupling in modified forms of graphene. The modelling strategy will be aimed at using graphene-based magnetic or future building block for engineering coherent spintronic. The usage of magnetic structural units produced by the methods of induced magnetization and creates preconditions for new approaches to employ spin manipulation at room temperature.

Theoretically, these localized electronic states can form a ferromagnetically ordered structure [S. Bolognesi, V.B. Shenoy “Edge states magnetism of single layer graphene nanostuctures”, The Journal of Chemical Physics 126, (2007) 244710]. The presence of magnetism in graphene islands on undifferfluoridated C2F matrix is supported by the ever-increasing growing number of theoretical publications predicting the magnetism of small islands of graphene.

Theory predicts a band magnetism in graphene due to a defect-induced localized states [O.V. Yazyev, L. Helm, Phys. Rev. B 79 125404 (2009)], whereas even on a single defective atom can lead to a ferromagnetic ground state. Short-range magnetic ordering is peculiar to the homogeneous lattice with vacancies, and hydrogen chemisorbed or defects [H. Kurasaki, D. S. Hirashima, J. Phys. Soc. Jpn., 78, 034707 (2009)]. Magnetic susceptibility of graphene depends on temperature, unlike conventional metal [H. Kurasaki, D. S. Hirashima, J. Phys. Soc. Jpn., 78, 044712 (2009)]. Spin susceptibility decreases with temperature in the absence of impurities but tends to a finite value in the presence of impurity atoms, which may increase the tendency to ferromagnetic ordering [M. R. Penas et al “Electronic properties of disordered two-dimensional carbon” Phys.Rev.B 73, 125411 (2006)]. In the biased bilayer graphene [N. Stadler et al “First-order ferromagnetic phase transition in the low electronic density regime of a biased graphene bilayer” J. Phys.: Condens. Matter 20 323201 (2008)] there is a tendency to ferromagnetic ground state, while the phase transition between paramagnetic and ferromagnetic phase transition is of the first order. Proposed low nanoscale spintronic devices employ the phenomenon of polarization of the spins localized on one-dimension [99] along edges of graphene [C. Y. Yazyev, N. I. Kostromin, Phys. Rev. Lett. 100, 047209 (2008)]. The objectives of the WP is to provide the theoretical foundation for the schemes considered and to support the various experimental activities within the project.
WP7 Corrective actions and knowledge transfer

Work package Leader: Umut T. Makarenko
Involved Partners: Umut, nanoGune, PTL, NHC, UNIPR, UNSW

Kick-off meeting: 14-16 June 2012

The kick-off meeting of the EU FP7 project MagicMag, 2012-2016, (Magnetic Order Induced in Nonmagnetic Solids) was held in June in Ulf’s institute, St. Petersburg, Russia. The meeting was opened by the Director of Inter PT, Andrei Zabolotnyi, who participated in the project with his own topic. Russia, Spain, Italy, France and Australia are the Project Members, and the Institute of Physics, Umeå University is the Project Coordinator.

The representatives of H2020, (Research Executive Agency of FP7 program, Brussels), the Project Officer Oliver Nation and the Acting Head of REA Unit Frank Male attended the meeting.

The Joint European Magnetic Symposium are the most important and comprehensive conference on magnetism in Europe. JEMS was Padua, Italy, from September 9th to 14th, 2012.

Mauro Ricco, Padua: organizer

Tatiana Tesnik, St. Petersburg: Low temperature antiferromagnetism and ferromagnetism in Ce-As near the phase transition insulator – metal

Tatiana Makarenko, Umeå: Self-organized antiferromagnetic floccing chains in graphene planes

Erik Liidsiranta, Lappeenranta: Irreversible Magnetic Properties of Carbon Nanoparticles

The dissemination, exploitation and the protection of the intellectual property of the Project results will be organized in this work package which has two major objectives: scientific (corrective actions) and administrative (knowledge transfer). The work will be carried out mainly by the Steering Committee (consisting of representatives for each partner and headed by a Coordinator)