MA 37: Micro- and Nanostructured Magnetic Materials

Time: Wednesday 9:30–12:30 Location: HSZ 401

MA 37.1 Wed 9:30 HSZ 401

Ferromagnetic resonance spectroscopy of magnetotactic bacteria — •Sara Ghaisari[1], Michael Winklhofer[2], Stefan Klumpp[3], and Damien Faivre[1] — [1]Department of Biomaterials, Max Planck Institute of Colloids and Interfaces, Potsdam, Germany — [2]School of Mathematics and Science, University of Oldenburg, Oldenburg, Germany — [3]Institute for Nonlinear Dynamics, Georg-August University Göttingen, Göttingen, Germany

Magnetotactic bacteria represent an example of a simple biomineralizing organism that synthesizes inorganic nanoparticles called as magnetosomes. Magnetosomes consist of a lipid membrane surrounding a ferrimagnetic crystal, which typically is magnetite Fe3O4 or greigite Fe3S4, with a size (40-100 nm). The particles are organized by some protein structures in a chain form inside the cells. Genetic manipulations enable the cell to produce other particle arrangements like e.g. clusters. Due to unique magnetic and morphologic properties, magnetosome particles and their functionality are attracting broad interest in many interdisciplinary areas.

Ferromagnetic Resonance (FMR), as a powerful tool for determining the magnetic anisotropies, is used in this study to explore the magnetic properties of the magnetosomes in different strains. Magnetic uniaxial and crystalline anisotropies of the different morphologies are calculated. Besides, by modeling the chain imperfections and alignment statistics through a Fisher distribution function, along to analyzing the geometry of magnetosome configuration, statistical interpretations of the bulk sample have been achieved.

MA 37.2 Wed 9:45 HSZ 401

Magnetization dynamics of a single Fe-filled carbon nanotube detected by ferromagnetic resonance — •Kilian Lenz[1], Ryszard Narkowicz[1], Christopher F. Reiche[2], Attila Kákay[1], Thomas Mühl[2], Bernd Büchner[2], Dieter Suter[3], Jürgen Fassbender[1,4], and Jürgen Lindner[1] — [1]HZDR, Institute of Ion Beam Physics and Materials Research, Bautzner Landstr. 400, 01328 Dresden — [2]Leibniz Institute for Solid State and Materials Research IFW Dresden, Helmholtzstr. 20, 01069 Dresden — [3]Department of Physics, TU Dortmund, 44221 Dortmund — [4]TU Dresden, 01062 Dresden

The precise magnetic characterization of a single nanostructure by e.g. ferromagnetic resonance is an experimental challenge as they lack the necessary sensitivity to measure single sub-micron-sized structures. Measurements of arrays of such elements are no alternative due to inhomogeneity. Microresonator FMR [1] can overcome these limitations boosting the FMR sensitivity by several orders of magnitude. Thus a single Fe-filled carbon nanotube (Fe-CNT) of 42 nm diameter [2] can be measured. A focused ion beam was used to shorten little-by-little the length of the Fe-CNT after each FMR measurement. Angle-dependent FMR measurements were performed to extract the anisotropy contributions. The narrow linewidth suggests that the Fe-filling is a well ordered crystal as confirmed by TEM. Supported by DFG MU1794/3-2. [1] A. Banholzer et al., Nanotechnology **22**, 295713 (2011) [2] P. Banerjee et al., Appl. Phys. Lett. **96**, 252505 (2010).

MA 37.3 Wed 10:00 HSZ 401

Magnetic nanoparticles as building blocks for hierachically designed samples to investigate collective magnetic phenomena — •Alexander Fabian[1], Matthias T. Elm[1,2], Detlev M. Hofmann[1], and Peter J. Klar[1] — [1]I. Physikalisches Institut, Heinrich-Buff-Ring 16, 35392 Giessen — [2]Physikalisch-Chemisches Institut, Heinrich-Buff-Ring 17, 35392 Giessen

Almost all magnetic phenomena are based on collective interaction of the electrons of the material. The magnetic characteristics of a material such as its hysteresis behavior, is determined by the macroscopic shape of the ferromagnet or the formation of domains. To deepen the understanding of magnetic interactions on different length scales we use nanoparticles as larger building blocks than atoms, which are ordered in hierachically assemblies. Besides from a fundamental view this is interesting for applications, e. g. in high density storage media and spin tronic devices. We describe how spherical magnetite nanoparticles with a diamater of $d = 20$ nm can be assembled in hierachical structures. For this purpose we use a top-down lithographic method combined with the meniscus force deposition method. Characterization is done by angle-dependent ferromagnetic resonance measurements. The results show that on the chosen length scales only the shape of the nanoparticle assemblies determine the magnetic behavior. Moreover the experimental results are accompanied by a theoretical model based on the Smit-Suhl formalism and by micromagnetic calculations to characterize the possible formation of domains in the assemblies.

MA 37.4 Wed 10:15 HSZ 401

Dimension and shape dependence of magnetization reversal mechanisms and magnetic anisotropies in four-fold nanomagnets — •Andrea Ehrmann[1] and Tomasz Blachowicz[2] — [1]Bielefeld University of Applied Sciences, Faculty of Engineering and Mathematics, Bielefeld, Germany — [2]Silesian University of Technology, Gliwice, Poland

Magnetic nanoparticles are intensively investigated due to their intriguing magnetic properties, such as a broad variety of magnetization reversal mechanisms and unusual anisotropies. Especially fourfold nanowire structures were shown to exhibit technologically interesting magnetic properties - they may show a step in the hysteresis loop correlated with a stable intermediate state at remanence which can be utilized in quaternary memory cells. Magnetization reversal mechanisms and the possible existence of such stable intermediate states, however, depend strongly on the materials, dimensions, and exact shapes of the nanoparticles under investigation.

In a recent project, fourfold nanoparticles of different dimensions and shape modifications were modeled using typical properties of permalloy, iron, and cobalt. In these systems, different numbers of stable intermediate states were found in different angular orientations. For cobalt, the largest number of steps was simulated, while coercive fields showed an irregular and unpredictable behavior.

In all cases, comparisons with previous calculations underlined that common mathematical descriptions of fourfold magnetic systems are no longer valid in the investigated nanoparticles.

MA 37.5 Wed 10:30 HSZ 401

Influence of dipolar coupling on microstructured multilayer giant magnetoimpedance (GMI) sensors in the high frequency regime — •Gregor Büttel and Uwe Hartmann — Institute of Experimental Physics, Saarland University, P. O. Box 151150, D66041, Saarbrücken, Germany

We have fabricated microstructured GMI sensors integrated into a coplanar waveguide consisting of a Cu core layer (250nm thickness) surrounded by magnetic Permalloy single and multilayers. This leads to different and complex coupling behavior of the layers and strongly influences important parameters like maximum GMI ratio, sensitivity and it creates additional peaks in the GMI curve which is in contrast to thin film devices in the mm regime about which was reported so far. To better tune and analyze such devices we have combined MOKE microscopy and micromagnetic simulations to understand the role of dipolar coupling and multi-domain switching. We discuss the complex phenomenology of domain structures for such GMI Py multilayer microstructures. This could so far not be supported by high-resolution domain-imaging techniques. Additionally we fabricated arrays of such microstructured multilayers that allow for recording of the hysteresis curve in a vibrating sample magnetometers and full magnetic characterization in order to understand the coupling behaviour in multilayers with odd and even number of magnetic layers.

MA 37.6 Wed 10:45 HSZ 401

Structural and magnetic characterizations of highly ordered arrangements of magnetic nanoparticles — •Asmaa Alhroob[1], Emmanuel Kentzinger[1], Marina Ganeva[2], Dominique Dresen[3], Sabrina Disch[3], Juergen Moers[4], Jun Xu[5], Giuseppe Portale[5], Xiao Sun[1], Oleg Petracic[1], Ulrich Ruecker[1], and Thomas Brueckel[1] — [1]Jülich Centre for Neutron Science (JCNS) and Peter Grünberg Institute (PGI), JARA-FIT, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [2]Jülich Centre for Neutron Science, Forschungszentrum Jülich, Outstation at MLZ, 85748 Garching, Germany — [3]Departments of Chemistry, University of Cologne, 50939 Cologne, Germany — [4]Helmholtz Nanoelectronic Facilities (HNF) and Peter Grünberg Institute (PGI) Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [5]Zernike Institute for Advanced Materials, Nijenborgh 4, 9747 AG Groningen, The Netherlands

Long range ordering between magnetic nanoparticles in two and three-dimensions is obtained by assisted self-assembly using pre-patterned substrates with feature size of the same order of magnitude as the diameter of the nanoparticles.

In this contribution, we will report on the first steps of this program, that are the structural characterization of patterned silicon substrates by Grazing Incidence Small Angle X-ray Scattering (GISAXS) on the laboratory high brilliance GALAXI instrument with data analysis using the BornAgain software and the structural and magnetic characterizations of monolayers of CoFe2O4 nanoparticles.

15 min. break.

MA 37.7 Wed 11:15 HSZ 401

Influence of domain wall substructures on magnetic energies of patterned Permalloy films — •Sukhvinder Singh, Haibin Gao, and Uwe Hartmann — Institute of Experimental Physics, Saarland University, Germany

Substructures of domain walls (such as Bloch points, Bloch lines, Neel lines and vortex-antivortex pairs) significantly affect the magnetic characteristics of patterned magnetic materials [1, 2]. We have investigated the influence of domain wall substructures on magnetic energies of Permalloy (Ni80Fe20) patterned thin films. The microstructured patterned films in the thickness range of 20 nm to 150 nm were investigated. The single-vortex state was observed as the lowest energy state for square patterns, while various lowest energy states for rectangular patterns were observed for different film thicknesses. Energy density for the lowest energy configuration decreases with an increase of the patterned structure thickness.

[1] A. Hubert and R. Schäfer, Magnetic domains, Springer (1998)
[2] V.V. Zverev et al., Phys. Solid State, 56, 1785 (2014)

MA 37.8 Wed 11:30 HSZ 401

Collective oscillations of magnetic vortices — •Max Hänze[1,2,3], Benedikt Schulte[1,3], Christian F. Adolff[3,4], Markus Weigand[5], and Guido Meier[1,3,4] — [1]Max-Planck-Institut für Struktur und Dynamik der Materie, Hamburg — [2]Max-Planck-Institut für Festkörperforschung, Stuttgart — [3]Institut für Angewandte Physik, Universität Hamburg — [4]The Hamburg Centre for Ultrafast Imaging, Hamburg — [5]Max-Planck-Institut für Intelligente Systeme, Stuttgart

Tailored ferromagnetic structures on micro- to nanometer length scales are promising candidates for future storage and logic devices based on spin-wave excitations. We study collective oscillations of coupled magnetic vortices emerging in micron-sized permalloy disks using two complementary measurement techniques, i.e., scanning transmission X-ray microscopy and ferromagnetic resonance spectroscopy.

Coupled magnetic vortices can exhibit crystal properties, e.g. a dispersion relation and a group velocity [1]. The manipulation of such properties is demonstrated on nanosecond time scales [2] using the excitation of coupled gyrotropic motions and coupled spin-wave modes in closely packed vortex arrangements [3,4].

[1] C. Behncke, M. Hänze, C. F. Adolff, M. Weigand, and G. Meier, Phys. Rev. B 91, 224417 (2015) [2] M. Hänze, C. F. Adolff, M. Weigand, and G. Meier, Phys. Rev. B 91, 104428 (2015) [3] M. Hänze, C. F. Adolff, B. Schulte, J. Möller, M. Weigand, and G. Meier, Sci. Rep. 6, 22402 (2016) [4] M. Hänze, C. F. Adolff, S. Velten, M. Weigand, and G. Meier, Phys. Rev. B 93, 054411 (2016)

MA 37.9 Wed 11:45 HSZ 401

Programmable magnetization configurations in Co-antidot lattices of optimized geometry — Tobias Schneider[1,2], Manuel Langer[1,3], Julia Alekhina[1,4], Ewa Kowalska[1,3], Antje Oelschlägel[1,3], Anna Semisalova[1,4], Andreas Neudert[1], Kilian Lenz[1], Mikhail P. Kostylev[5], Jürgen Fassbender[1,3], Adekunle O. Adeyeye[6], Jürgen Lindner[1], and •Rantej Bali[1] — [1]Helmholtz-Zentrum Dresden - Rossendorf, Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany — [2]Technische Universität Chemnitz, Germany — [3]Technische Universität Dresden, Germany — [4]Lomonosov Moscow State University, Russia — [5]University of Western Australia, Australia — [6]National University of Singapore, Singapore

Programmable stable magnetization configurations are of great interest for the emerging fields of spintronics and magnonics. Such devices might act as spinwave filters or spinwave logics. Here, we present a micromagnetic study of the reversal process in Cobalt antidot lattices. To achieve stable magnetization configurations we optimized the thickness and the inter-antidot distance, resulting in ≈ 50 nm and respectively ≈ 150 nm . The magnetization reversal in these antidots occurs via field driven transition between 3 elementary magnetization states - termed G, C and Q . These magnetization states can be described by vectors, and the reversal process proceeds via step-wise linear operations on these vector states. The reversal processes predicted by micromagnetic simulations were confirmed by experimental observations.

MA 37.10 Wed 12:00 HSZ 401

Collective dynamics in square artificial spin ice — •Spiridon D. Pappas[1], Mikael S. Andersson[2], Henry Stopfel[1], Agne Ciuciulkaite[1], Erik Östman[1], Aaron Stein[3], Per Nordblad[2], Roland Mathieu[2], Björgvin Hjörvarsson[1], and Vassilios Kapaklis[1] — [1]Department of Physics and Astronomy, Uppsala University, Box 516, SE-751 20 Uppsala, Sweden. — [2]Department of Engineering Sciences, Uppsala University, Box 534, SE-751 21 Uppsala, Sweden. — [3]Center for Functional Nanomaterials, Brookhaven National Laboratory, P.O. Box 5000, Upton, NewYork 11973, USA.

Recent advances in nanolithography allow the study of collective response and dynamics of interacting artificial assemblies of mesoscopic spins. In this work, we study the thermally induced magnetic relaxation process, as well as the temporal dynamics, in square Artificial Spin Ice (ASI) [1]. The time dependent magnetization of square ASI was recorded by using time-resolved magnetometry and the temporal dynamics were probed via MOKE susceptibility. The results provide: (a) a clear manifestation of cooperative behavior in the square ASI arrays, (b) proof that the relaxation behavior of the arrays can be tuned by adjusting the interaction strength between the magnetically interacting building blocks (c) a deep insight into the relaxation dynamics of mesoscopic nano-magnetic model systems, with adjustable energy and time scales, and (d) a clear demonstration that square ASI systems can be used as a new type of model system for the study of collective dynamics and relaxation phenomena in magnetic nanosystems. [1] M. S. Andersson et al., Scientific Reports 6, 37097 (2016).

MA 37.11 Wed 12:15 HSZ 401

Mesoscale Dzyaloshinskii-Moriya interaction — •Oleksii Volkov[1,2], Denis Sheka[3], Denys Makarov[1], Jürgen Fassbender[1], Volodymyr Kravchuk[2], and Yuri Gaididei[2] — [1]Helmholtz-Zentrum Dresden-Rossendorf e.V., Dresden, Germany — [2]Bogolyubov Institute for Theoretical Physics, Kyiv, Ukraine — [3]Taras Shevchenko National University of Kyiv, Kyiv, Ukraine

A broken chiral symmetry in a magnetic system can lead to the appearance of both periodical and localized magnetization structures. The spin-orbit driven Dzyaloshinskii-Moriya interaction (DMI), which is intrinsic to the crystal, is the origin of all those magnetic textures [1]. Recently, we reported [2,3] that geometrically broken symmetry in curvilinear magnetic systems also leads to the appearance of shape-induced effective DMI.

The combined intrinsic and shape-induced DMI can be reffered to as a mesoscale DMI, whose symmetry and strength depend on the geometrical and material parameters. The mesoscale DMI determines chiral properties of curved systems. We derive the general expression for the mesoscopic DMI terms and determined the conditions for periodical magnetisation structures to appear in one-dimensional ferromagnetic helix wires.

[1] A. Soumyanarayanan et. al., *Nature* **539**, 509-517 (2016).
[2] Y. Gaididei et. al, *Phys. Rev. Lett.* **112**, 257203 (2014).
[3] D. D. Sheka et. al., *J. Phys. A: Math. Theor.* **48**, 125202 (2015).