MA 25: Micro- and Nanostructured Magnetic Materials II

Time: Wednesday 14:45–19:15 Location: HSZ 403

MA 25.1 Wed 14:45 HSZ 403

Anisotropy of the Curie temperature in ultrathin epitaxial Fe(001) wire arrays — Roland Meier and •Günther Bayreuther — Universität Regensburg, 93040 Regensburg, Germany

According to Mermin and Wagner [1] long-range ferromagnetic order in isotropic 2D systems with short-range magnetic interactions is destroyed by spin fluctuations at any temperature $T > 0$. Curie temperatures, T_C, above 200 K in single atomic layers can be understood by considering magnetic anisotropies and long-range dipolar interactions. The relevance of dipolar interaction was verfied in ultrathin Fe(001) dot arrays epitaxially grown on GaAs(001) by variation of dot diameter and dot separation. By assuming that magnetization fluctuations in space and time close to T_C are partially suppressed by combined exchange and dipolar interactions in the same way as purely spatial magnetization fluctuations in polycrystalline films ("magnetization ripple"), the result of a Green's function approach [2] predicts that T_C should be higher in a long wire magnetized perpendicular to the wire axis compared to a parallel magnetization and to a circular dot. This was confirmed by exploiting the strong uniaxial interface magnetic anisotropy in Fe/GaAs(001). Compared to the extended film a reduction of T_C by 3% was observed for perpendicular magnetization versus 8% for the parallel case; for a dot with the same dimension the reduction was indeed the sum of both, i.e.11%. This means that in epitaxial ultrathin ferromagnetic wires the Curie temperature is indeed anisotropic. [1] N. D. Mermin and H. Wagner, Phys. Rev. Lett 17 (1966) 1133 [2] W. Maass, PhD thesis, University of Regensburg, 1984

MA 25.2 Wed 15:00 HSZ 403

Magnetization Reversal of Electrochemically Synthesized Nanowires — •Judith Moser, Tim Böhnert, Kristina Pitzschel, Robert Zierold, Lars Bocklage, Michael Martens, Shadyar Farhangfar, Ulrich Merkt, Kornelius Nielsch, and Guido Meier — Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg

We suggest novel nanostructures for spin momentum transfer studies. The electrodeposition of ferromagnetic materials in self-organized pores of an Al_2O_3-membrane provides the unique ability to process ultrathin wires of complex shape and with reproducible properties [1]. For both fundamental research and technological applications it is of interest to understand the pinning and the dynamics of domain walls as well as the interaction between domain walls and spin-polarized currents in such nanostructures [2]. We synthesize Ni nanowires with diameters between 30 nm and 300 nm and aspect ratios up to 500. The magnetization reversal of single wires is studied by magnetic-force microscopy (MFM), X-ray microscopy, and anisotropic magnetoresistance measurements in straight wires, in bent wires, and in wires with diameter modulations serving as tailored pinning sites. The angle dependence of the switching field is proportional to $1/cos(\theta)$ and the MFM images support the idea of magnetization reversal via domain-wall motion.

[1] K. Nielsch et al., Handbook of Magnetism and Adv. Magnet. Mat., Vol. 4, John Wiley and Sons (2007). [2] G. Meier et al., Phys. Rev. Lett. 98, 187202 (2007).

MA 25.3 Wed 15:15 HSZ 403

Iron filled carbon nanotubes studied with the Magnetic Force Microscope under applied magnetic fields — •Matthias Lutz, Uhland Weissker, Christian Müller, Franziska Wolny, Martin Bauch, Thomas Mühl, Albrecht Leonhardt, Rüdiger Klingeler, and Bernd Büchner — Leibniz Institute for Solid State and Materials Research (IFW) Dresden, Germany

We present MFM (Magnetic Force Microscopy) studies of ferromagnetic nanowires formed inside carbon nanotubes (CNT) during the CVD (Chemical Vapour Deposition) growth process. The single domain configuration of the nanowires as well as their predominantly single crystal nature render them promising candidates for novel magnetic applications. The remanent magnetization states of the CNT encapsulated α-iron and iron carbide nanowires are contrasted as well es their switching behavior studied with the aid of applied magnetic fields. Measuring vertical arrays of α-Fe nanowires reveals a tip triggered switching, indicating a nucleation based magnetization reversal mechanism. Despite the extreme aspect ratio in Fe_3C nanowires the magnetization is aligned perpendicular to the long axis which is discussed in terms of the magnetocrystalline anisotropy in combination with a preferred crystal orientation.

MA 25.4 Wed 15:30 HSZ 403

Magnetic properties and applications of ferromagnetic nanowires inside carbon nanotubes — •Thomas Mühl[1], Franziska Wolny[1], Uhland Weissker[1], Markus Löffler[1], Matthias Lutz[1], Rüdiger Klingeler[1], Palash Banerjee[2], Denis Pelekhov[2], Chris Hammel[2], Albrecht Leonhardt[1], and Bernd Büchner[1] — [1]IFW Dresden, Dresden, Germany — [2]Ohio State University, Columbus, USA

A short overview comparing the magnetic properties of iron-filled and cementite-filled carbon nanotubes is presented. Thereafter, their potential as novel probes for magnetic force microscopy and for magnetic resonance force microscopy will be shown. In addition, the nearly 100 years old Einstein-de-Haas experiment will be discussed in terms of spectacular scaling effects when applied to self supported magnetic nanowires.

MA 25.5 Wed 15:45 HSZ 403

Magnetization switching in α-Fe filled Carbon nanotubes using micro-Hall gradiometry — •Pintu Das[1], Jens Müller[1], Steffen Wirth[1], Kamil Lipert[2], Franziska Wolny[2], Thomas Mühl[2], Rüdiger Klingeler[2], and Bernd Büchner[2] — [1]Max Planck Institute of Chemical Physics of Solids, Nöthnitzer Str. 40, 01187 Dresden, Germany — [2]Leibniz Institute for Solid State and Materials Research (IFW), Helmholtz Str. 20, 01069 Dresden, Germany

Using the Hall response of a two-dimensional electron gas (2DEG) in GaAs/AlGaAs heterostructures, we employed a micro-Hall gradiometry technique to quantitatively study the magnetization behavior of α-Fe cylinders of diameter ~ 20 nm, which are filled into Carbon nanotubes ($\sim 10\,\mu$m long). A Hall cross size of $800 \times 800\,\mathrm{nm}^2$ has been used for the measurements. From the measurements of a single α-Fe-filled nanotube placed in the active area of the Hall cross (see talk of K. Lipert *et al.*), clear magnetization switching has been observed. The dependence of the switching field on the angle between the nanotube and the applied magnetic field has been studied in order to identify the switching mode. At certain magnetic fields, we also have observed switching which is not symmetric with respect to the direction of the field. A detailed calculation of the perpendicular stray field due to the α-Fe-filled nanotube at the location of the 2DEG has been carried out to analyze the experimental data. We discuss the results and the analysis to understand the possible mode of the magnetization switching.

MA 25.6 Wed 16:00 HSZ 403

Magnetization behaviour of perpendicular magnetized particles and nanostructures — •Matthias Jacobi[1], Daniel Stickler[1], André Kobs[1], Simon Hesse[1], Holger Stillrich[1], Andreas Frömsdorf[2], and Hans Peter Oepen[1] — [1]Institut für Angewandte Physik, Universität Hamburg, Jungiusstr. 11, 20355 Hamburg, Germany — [2]Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, 20146 Hamburg, Germany

We have investigated the magnetization reversal of submicron Co/Pt structures using anomalous Hall effect (AHE). Two different methods have been used to create the structures from films. The first method is based on highly focused ion beam (FIB), which has been used to pattern the film magnetically. A dose of $5\cdot 10^{14}Ga^+/cm^2$ has been applied which destroys ferromagnetism due to intermixing of Co and Pt [1]. Ordered arrays of submicron, ferromagnetic squares are generated. The magnetisation curves obtained by AHE show stepwise reversal, while the homogeneous films exhibit single jump behaviour. The second method is based on the self assembly of diblock-copolymer micelles with silica cores. The cores act as shadow masks during Ar^+ sputtering. Hence, arrays of nanometre-sized dots with diameters of about 12 nm and 18 nm are created [2]. In the AHE measurements we can identify the magnetisation curves of the dots although the area filling factor is about 15%. The 12 nm particles show superparamagnetism at room temperature.

[1] P. Warin et al., J. Appl. Phys. **90**, 3850 (2001)
[2] H. Stillrich et al., Adv. Funct. Mat. **18**, 76 (2008)

MA 25.7 Wed 16:15 HSZ 403

Critical behaviour of nanocrystalline gadolinium — •Adrian Ferdinand[1], Frank Döbrich[1], Anne Catherine Probst[1], Andreas Michels[1], Sharika Nandan Kaul[2], and Rainer Birringer[1] — [1]Technische Physik, Universität des Saarlandes, Saarbrücken, Germany — [2]School of Physics, University of Hyderabad, Hyderabad, India

For single crystalline gadolinium (Gd), Srinath, Kaul, and Kronmüller [1] have demonstrated that Gd belongs to the uniaxial dipolar universality class with a Curie temperature T_c = 292.77 K. For polycrystalline Gd, the critical behaviour seems to be strongly affected by the microstructure when the crystallite size D is reduced to the nanometer regime. The most striking feature in this context is the continuous reduction of T_c with decreasing D which yields T_c-shifts of 10 K and more for grain sizes below 30 nm [2]. Here, we report on the critical behaviour of inert-gas condensed nanocrystalline Gd (with 8 nm < D < 21 nm) which has been studied by means of ac-susceptibility and small-angle neutron scattering.

[1] S. Srinath, S.N. Kaul, H. Kronmüller, Phys. Rev. B 59, 1145 (1999) [2] D. Michels, C.E. Krill III, R. Birringer, J. Magn. Magn. Mater. 250, 203 (2002)

MA 25.8 Wed 16:30 HSZ 403

The effect of the tapered shape on the magnetostatic anisotropy of magnetic elements — •Sabine Pütter, Nikolai Mikuszeit, Holger Stillrich, Elena Vedmedenko, and Hans Peter Oepen — Institut für Angewandte Physik, Universität Hamburg, Jungiusstr. 11, 20355 Hamburg, Germany

Magnetic nano– and microstructures are commonly fabricated by mask techniques. At first glance, the size of the structure depends only on the holes in the mask. However, due to the finite size of the evaporation source and the finite distance of mask and substrate the structure has a certain edge profile. In general, a tapered shape is produced.

In this paper the influence of the tapered shape on the magnetostatic anisotropy is studied for elements with rectangular base. Based on the approach of Rhodes and Rowlands [1] and on straight forward integration of the Poisson equation the demagnetizing energy of uniformly magnetized elements is calculated. We find that the shape anisotropy is drastically reduced due to the modified shape.

When two rectangular elements are aligned parallel to their long axes there is a critical distance at which the easy axis of magnetization switches from the single element's easy axis to the direction of the connecting line due to the magnetostatic interaction. This distance is increased significantly in case of elements with tapered shape.

The theoretical predictions are compared with the results for micron sized permalloy elements studied by the magneto-optical Kerr effect.

[1] P. Rhodes and G. Rowlands, Proc. Leeds Phil. Liter. Soc. 6 (1954), 191.

MA 25.9 Wed 16:45 HSZ 403

Hall micromagnetometry of domain walls in permalloy nanostructures — •Peter Lendecke[1], Lena Breitenstein[1], Stellan Bohlens[2], Guido Meier[1], and Ulrich Merkt[1] — [1]Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg — [2]I. Institut für Theoretische Physik, Universität Hamburg

We investigate domain-wall depinning in permalloy nanowires and the hysteresis of micron-sized square platelets by ballistic Hall micromagnetometry. The technique allows to measure the stray field of individual nanostructures between liquid helium temperature and 50 K. The pinning and depinning of single domain walls at constrictions is detected non-invasively by sensing the stray field of the walls [1]. Results on the temperature dependence of depinning fields at constrictions of different sizes as well as experiments on current-assisted depinning are presented. By measuring the stray field of square thin-film platelets we are able to investigate their hysteresis loop at low temperatures. Nucleation of a Landau pattern, displacement of the vortex in its centre by an in-plane external field, and vortex annihilation are clearly identified by analyzing minor loops and return branches [2]. These results are corroborated by magnetic-force microscopy images and micromagnetic simulations.

[1] P. Lendecke, R. Eiselt, U. Merkt, and G. Meier, J. Appl. Phys. **103**, 073909 (2008).
[2] L. Breitenstein, P. Lendecke, S. Bohlens, G. Meier, and U. Merkt, J. Appl. Phys. **104**, 083909 (2008).

MA 25.10 Wed 17:00 HSZ 403

Freezing dynamics of magnetite ferrofluids studied by time-resolved Small Angle Neutron Scattering — •Sylvain Prévost[1], Albrecht Wiedenmann[2], Uwe Keiderling[3], Dirk Wallacher[3], Michael Meissner[3], and Joachim Kohlbrecher[4] — [1]Stranski Lab., TU Berlin, Berlin, Germany — [2]Institut Laue Langevin, Grenoble, France — [3]Helmholtz-Zentrum Berlin, Berlin-Wannsee, Germany — [4]Laboratory for Neutron Scattering, ETH Zurich & PSI, Villigen, Switzerland

The dynamics of particle ordering in ferrofluids has been studied by time-resolved stroboscopic SANS. Two samples are compared, with nearly monodisperse Co and Fe3O4 nanoparticles of similar magnetic moments, dispersed in oil and stabilized by surfactant. The SANS scattering response was measured stroboscopically in an oscillating applied magnetic field, with an optional static field superimposed, the temperature ranging from 100 to 300K.

As long as the magnetic moments follow the applied field, the 2D scattering patterns alternate between fully isotropic and strongly anisotropic. Oscillating behavior with decreasing amplitudes is clearly observed down temperatures lower than the melting point of the pure solvent. Scattered intensities can be successfully fitted in terms of the Langevin statistics. The dynamics of field-induced ordering in the ferrofluid systems is governed by the fast Brownian rotation of individual nanoparticles and small aggregates while the magnetic relaxation of longer dipolar chains and local hexagonal domains is much slower.

15 min. break

MA 25.11 Wed 17:30 HSZ 403

(001) textured FePt thin films on spherical SiO_2 nanoparticle template — Christoph Brombacher[1], •Christian Schubert[1], Andreas Teichgräber[1], Sara Romer-Urban[2], Mireille Maret[3], Denys Makarov[4], Michael Hietschold[1], and Manfred Albrecht[1] — [1]Institute of Physics, TU Chemnitz, Chemnitz, Germany — [2]Nanoscale Materials Science, Empa, Dübendorf, Switzerland — [3]Laboratoire de Thermodynamique et Physico-Chimie Métallurgiques, ENSEEG, Saint Martin d'Heres, France — [4]Department of Physics, University of Konstanz, Konstanz, Germany

Due to its high magnetocrystalline anisotropy and excellent corrosion resistance, FePt is considered one of the most promising candidates for future magnetic data storage devices. In this study, densely-packed arrays of SiO_2 nanoparticles have been used as a template to create regular FePt nanostructures suitable for application as patterned media. The sputter deposited FePt film displays a chemically disordered fcc phase. Postannealing in a commercial RTA setup yields both a high ordering parameter and the desired (001) texture as shown by XRD and TEM. The heating rate, heating time and heating temperature have been optimized on planar SiO_2 substrates, obtaining perpendicular magnetic anisotropy and coercivities of up to 2 T. Furthermore, the FePt films exhibit a strong dewetting behavior on both planar substrates and spherical nanoparticles. By tuning the thickness of the FePt layer, the characteristic length scales of the dewetting process can be controlled. This was used to create isolated FePt nanostructures on SiO_2 particle arrays with periodicities down to 50 nm.

MA 25.12 Wed 17:45 HSZ 403

Magnetic single-phase behaviour of die-upset magnets made from μm-sized $Nd_2Fe_{14}B$ and Fe-particles — •Juliane Thielsch, Dietrich Hinz, Konrad Gueth, Oliver Gutfleisch, and Ludwig Schultz — IFW Dresden, Institute for Metallic Materials, P.O. Box 27 01 16, D-01171 Dresden, Germany

Textured composite magnets containing hard magnetic NdFeB and soft magnetic α-Fe were produced by hot pressing and subsequent die upsetting. As starting material NdFeB melt spun ribbons (MQU-F) and μm-sized Fe-particles were blended in varying compositions from a NdFeB:Fe-weight ratio of 100:0 to 70:30. The addition of Fe leads to a drastic decrease in coercivity from 13.20 kOe for pure NdFeB ribbons to 1.54 kOe for a sample with 30 wt-% Fe but has surprisingly almost no influence on the remanence. In contrast values for saturation magnetisation increase with larger amounts of Fe. The diameter of the Fe-particles exceeds by far the maximum length of effective exchange interactions. Therefore magnetostatic coupling between the two phases is proposed to explain the magnetic single-phase hysteresis behaviour when measured along the nominal easy direction of magnetisation. Measurements along the hard direction of magnetisation show two-step curves. SEM and Kerr investigations were carried out to investigate phase distribution and coupling.

MA 25.13 Wed 18:00 HSZ 403

Microresonator fabrication for lower sensitivity limit for ferromagnetic resonance measurements — •Anja Banholzer[1], Ryszard Narkowicz[2], Sven Stienen[1], Jürgen Lindner[1], Dieter Suter[2], and Michael Farle[1] — [1]Universität Duisburg-Essen, Standort Duisburg, Institut für Physik und CeNIDE, AG Farle, Lotharstr. 1, 47048 Duisburg — [2]Universität Dortmund, Institut für Physik, Otto-Hahn-Str. 4, 44227 Dortmund

By measuring Ferromagnetic Resonance (FMR) there is a minimum number of spins which can be detected, depending on the measurement device used. We are currently developing a microresonator from which higher sensitivity can be expected. Therefore, it would be possible to measure FMR even for a small amount of sample material. We process the microresonator using Electron Beam Lithography on Silicon. For the measurement we use an external magnetic field, while the microwave field is generated inside the microresonator. The frequency of the microwave depends on the layout of the microresonator. By varying the layout, it is possible to optimise the quality factor and the signal to noise ratio. Our test measurements are performed on Permalloy nanostructures.

MA 25.14 Wed 18:15 HSZ 403

Local setting of magnetic anisotropy in FeCoSiB thin films by means of indirect ion implantation — •Norbert Martin[1], Jeffrey McCord[1], Andreas Gerber[2], Thomas Strache[3], Thomas Gemming[1], Ingolf Mönch[1], Rudolf Schäfer[1], Jürgen Fassbender[3], Eckhard Quandt[2], and Ludwig Schultz[1] — [1]Leibniz Institute for Solid State and Materials Research IFW Dresden, P.O. Box 270116, 01171 Dresden, Germany — [2]Chair for Inorganic Functional Materials, CAU Kiel, Kaiserstrasse 2, 24143 Kiel, Germany — [3]Forschungszentrum Dresden Rossendorf e.V., P.O. Box 510119, 01314 Dresden, Germany

The magnetic anisotropy direction and strength of amorphous FeCoSiB thin films was modified locally by masked ion implantation without alteration of the magnetic material's structure and the intrinsic magnetic properties of the ferromagnetic film. The changes were introduced by local ion implantation in a SiO2 covering and protection layer, inducing additional stress-induced magnetic anisotropy to the magnetostrictive ferromagnetic layer. Hybrid hysteresis curves combining switching and rotational processes were measured and the underlying local variation of magnetic anisotropy was confirmed by magnetic domain observations. A good agreement between the calculated stress distribution and the experimentally obtained magnetic data was found. The described indirect method, relying purely on magneto-elastics, introduces a new path to the creation or alteration of magnetic properties subsequent to magnetic film preparation in structured magnetic samples without introducing any structural changes to the ferromagnetic layers.

MA 25.15 Wed 18:30 HSZ 403

Structure and magnetic properties of HDDR $Nd_2Fe_{14}B$ powders — •Konrad Güth, Juliane Thielsch, Oliver Gutfleisch, and Ludwig Schultz — IFW Dresden, Institute for Metallic Materials, Postfach 270116, D-01171 Dresden, Germany

The HDDR process (Hydrogenation Disproportionation, Desorption, Recombination) is a unique method to produce highly coercive powders for bonded permanent magnets. The starting material is a Nd-rich $Nd_2Fe_{14}B$ alloy. The first step starts with the absorption of hydrogen atoms at room temperature which fill the vacancies and cause expansion of the lattice. This large stress causes decrepitation of the alloy resulting in a powder with a particle size of several micrometers. An additional heating of the alloy at 840°C under 0.3 bar hydrogen pressure leads to the disproportionation of the $Nd_2Fe_{14}B$ phase into a very fine mixture of neodymium hydride, α-iron and Fe-boride. Desorption of hydrogen and recombination can be induced at high temperatures, leading to the recovering of the original $Nd_2Fe_{14}B$ phase but with a dramatically refined grain size (200-300 nm). Phase analysis and grain size determination of the powders are characterized by XRD using Rietveld analysis. High resolution scanning electron microscopy (HR SEM LEO 1530 GEMINI) was used to study the microstructure. Magnetic properties were investigated by vibration sample magnetometry (VSM) with a maximum magnetic field of 9 T at room temperature. Prior to the VSM measurement the $Nd_2Fe_{14}B$ powders were aligned applying a magnetic field of 2 T during cold compaction.

MA 25.16 Wed 18:45 HSZ 403

High resolution *in-situ* MOKE and STM setup with all optical components in UHV — •Anne Lehnert, Philipp Buluschek, Nicolas Weiss, Johannes Giesecke, Matthias Treier, Stefano Rusponi, and Harald Brune — Institute of the Physics of Nanostructures, EPF-Lausanne, Switzerland

A surface magneto-optic Kerr effect (MOKE) setup fully integrated in an ultra high vacuum chamber is presented [1]. The system has been designed to combine high resolution *in-situ* MOKE and variable temperature scanning tunnelling microscopy. The coverage detection limit is 0.5 ML for transverse MOKE and 0.1 ML for polar MOKE. For island superlattices, the latter limit corresponds to islands composed of about 50 atoms. Magnetic fields up to 0.3 T can be applied at any angle in the transverse plane allowing the study of the in-plane and out-of-plane magnetization. The setup performance is demonstrated for a continuous film of 0.9 ML Co/Rh(111) with in-plane easy axis and for a superlattice of nanometric double layer Co islands on Au(11,12,12) with out-of-plane easy axis. For Co/Au(11,12,12) we demonstrate that the magnetic anisotropy energies (MAE) deduced from thermally induced magnetization reversal by measuring the zero field susceptibility and from applying a torque onto the magnetization by turning the field are the same. Assuming the MAE to be proportional to the perimeter length 0.95 ± 0.01 meV/perimeter atom and 0.87 ± 0.01 meV/perimeter atom have been inferred.

[1] A. Lehnert *et al.*, submitted to Rev. Sci. Instrum.

MA 25.17 Wed 19:00 HSZ 403

Quasi-Antiferromagnetic 120° **Néel-State in 2D Clusters of Dipole-Quadrupole-Interacting Particles Arranged on a Hexagonal Lattice** — •Nikolai Mikuszeit[1], Larysa Baraban[2], Elena Y. Vedmedenko[1], Artur Erbe[2], Paul Leiderer[2], and Roland Wiesendanger[1] — [1]Institute of Applied Physics, University of Hamburg Jungiusstr. 11, 20355 Hamburg, Germany — [2]Department of Physics, University of Konstanz, Universitätsstr. 10, Konstanz, 78457, Germany

Recent experiments on colloidal particles, capped with Co/Pt multilayers, have shown a 120° Néel-state [1], which was unexpected for particles interacting via stray field. The state, where all particles are reversed, is not observed. In the framework of multipole expansion [2] this asymmetry requires not only odd but also even parity moments (e.g. a quadrupole (**q**)). The even parity moments significantly alter the dipolar ordering of the presumably dominant dipole (**d**).

We performed Monte Carlo simulations of particle clusters taking into account a **d**- and a **q**-moment. Although the symmetries of the pure dipolar (vortex) or pure quadrupolar (pinwheel) ground states strongly differ from the observed Néel-state, the latter one can be established by competing **d** and **q** interactions. The relative strength of **d**-**d**- and **q**-**q**-interaction as well as the cluster size was varied. A small region was found, where the 120° Néel-state is formed.

[1] L. Baraban, et al. Phys. Rev. E **77**, 031407 (2008)
[2] E. Y. Vedmedenko and N. Mikuszeit, ChemPhysChem, **9**, 1222 (2008)