MA 35: Magnetic Particles / Clusters

Time: Wednesday 9:30–12:45 Location: HSZ 101

MA 35.1 Wed 9:30 HSZ 101

Direct correlation of microscopic structure and magnetic properties of individual cobalt nanoparticles — •T. M. Savchenko[1], A. Béché[2], M. Timm[1], D. M. Bracher[1], G. Khadra[3], A. Tamion[3], F. Tournus[3], C. Albin[3], V. Dupuis[3], J. Verbeeck[2], F. Nolting[1], and A. Kleibert[1] — [1]Swiss Light Source, Paul Scherrer Institut, CH-5232 Villigen, Switzerland — [2]Electron Microscopy for Materials Science (EMAT), University of Antwerp, Groenenborgerlaan 171, B-2020 Antwerp, Belgium — [3]Institut Lumière Matière, UMR5306 Université Lyon 1-CNRS, Université de Lyon, 69622 Villeurbanne cedex, France

Ever increasing data volumes demand memory devices with higher data storage density. In case of magnetic memory this requires nano-sized units with uniform magnetic properties. However, at the nanoscale a rich structural variety and defects are frequently found in materials which may cause significant dispersion of magnetic properties. A direct correlation of magnetism and atomic composition of nanostructures is so far achieved in spin-polarized scanning tunneling microscopy on surfaces. Here, we present a unique combination of magnetic and microstructural characterization of individual magnetic nanoparticles by means of X-ray photo-emission electron microscopy and high resolution scanning transmission electron microscopy. Distinct magnetic properties are found in cobalt nanoparticles with sizes ranging between 12 and 19 nm irrespective of size and actual microstructure. The results are discussed with respect to defects and morphology.

MA 35.2 Wed 9:45 HSZ 101

Determining anisotropy and magnetic moment of single nanodots from switching time measurements — •Stefan Freercks, Carsten Thönnissen, Eva-Sophie Wilhelm, Philipp Staeck, and Hans Peter Oepen — Institut für Nanostruktur- und Festkörperphysik, Universität Hamburg, Germany

We use the anomalous Hall-effect to investigate the magnetization reversal in single Pt/Co/Pt nanodots (diameter <40nm, Co thickness < 1nm) with perpendicular magnetization. The dots are fabricated by electron beam lithography and ion milling out of thin multilayers [1]. We have investigated the time dependent switching in the superparamagnetic regime and determine the temperature dependence of the switching frequency. The Néel-Arrhenius plot reveals attempt frequencies that deviate from the expected values in the GHz regime [2]. Measuring the occupation as a function of field along the easy axis gives access to the magnetic moment. In the blocked regime a magnetic field is applied perpendicular to the easy axis, which reduces the energy barrier and causes thermal switching. In accordance to experiments in the superparamagnetic regime the switching times are determined as a function of field strength. The field dependent switching times allow for the determination of the dot moment and total anisotropy as a function of temperature. Dots and film reveal a similar temperature behavior. Funding by DFG via SFB 668 is gratefully acknowledged. [1] A. Neumann *et al.* Nano Letters. **13**, p2199-2203, (2014). [2] Bean and Livingston, J. Appl. Phys. **30**, 120S, (1959)

MA 35.3 Wed 10:00 HSZ 101

Structural and magnetic properties of self-assembled iron oxide nanoparticle films — •Xiao Sun[1], Michael Smik[1], Emmanuel Kentzinger[1], Aladin Ullrich[2], Ulrich Rücker[1], Oleg Petracic[1], and Thomas Brückel[1] — [1]Jülich Centre for Neutron Science JCNS and Peter Grünberg Institut PGI, JARA-FIT, Forschungszentrum Jülich GmbH, Jülich — [2]Lehrstuhl für Experimentalphysik II, Universität Augsburg, Augsburg

2D self-assembled iron oxide nanoparticles (NPs) with various sizes (11-20nm) have been studied using magnetometry and Grazing Incidence Small Angle X-ray Scattering (GISAXS). Self-assembled NP films have been fabricated using various methods (e.g. drop-casting/liquid-air-interface) and characterized by scanning electron microscopy and GISAXS. The GISAXS patterns are compared with the simulation results from the software BornAgain[1]. Magnetometry results show an exchange bias effect in hysteresis loops. By comparing hysteresis loops cooled at different magnetic fields, a hardening effect can be observed, i.e. the squareness and hardness of hysteresis loops is significantly enhanced with increasing magnetic cooling field. Due to the antiferromagnetic wustite component, the spins of the ferromagnetic magnetite/maghemite components are exchange biased and an anisotropy axis is induced. The influence of the induced anisotropy onto the magnetic correlations of the magnetic superspins was investigated. The hardening effect of diluted iron oxide NPs is compared to self-assembled NP films. [1]http://bornagainproject.org/

MA 35.4 Wed 10:15 HSZ 101

Structural and magnetic properties of self-assembled 3D nanoparticle macrocrystals — •Michael Smik[1], Genevieve Wilbs[1], Mauricio Cattaneo[1], Elisa Volkmann[1], Emmanuel Kentzinger[1], Stefan Mattauch[2], Jörg Persson[1], Ulrich Rücker[1], Oleg Petracic[1], and Thomas Brückel[1] — [1]Jülich Centre for Neutron Science JCNS and Peter Grünberg Institut PGI, JARA-FIT, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [2]Jülich Centre for Neutron Science JCNS, Heinz Maier-Leibnitz Zentrum, 85747 Garching, Germany

Magnetic nanoparticle assemblies form a novel type of artificial material with properties that are not found in nature. We have succeeded in fabricating large 3D nanoparticle 'macrocrystals' using a novel centrifuge assisted sedimentation technique from commercially available spherical iron oxide nanoparticles. The assembly of macrocrystals up to 300-1000 μm in size was possible. Using small angle x-ray scattering (SAXS) at the new in-house instrument 'GALAXI' (Gallium Anode Low-Angle X-ray Instrument) the supercrystalline structure and quality of ordering could be characterized. The magnetic properties were investigated by a variety of magnetometric methods including zero field cooled and field cooled curves as well as AC susceptibility. For a microscopic investigation of the magnetic ordering, small angle neutron scattering (SANS) was employed at the neutron reflectometer MARIA (MAgnetic Reflectometer with high Incidence Angle) at the Heinz Meier-Leibnitz Zentrum.

MA 35.5 Wed 10:30 HSZ 101

Highly ordered 3D nanoparticle superlattices investigated by microresonator ferromagnetic resonance — •Elisabeth Josten[1,2], Ryszard Narkowicz[1], Attila Kákay[1], Doris Meertens[2], Lennart Bergström[3], Thomas Brückel[2], Kilian Lenz[1], and Jürgen Lindner[1] — [1]Helmholtz-Zentrum Dresden Rossendorf, Dresden, Germany — [2]Forschungszentrum Jülich, Jülich, Germany — [3]Stockholm University, Stockholm, Sweden

Magnetic nanoparticles and their assembly into highly correlated superstructures are of great interest for future applications, e.g. as material for magnon-spintronic. These systems are not only distinguished by the obvious miniaturization but by their novel physical properties. Recently, single micrometer-sized three-dimensional magnetic nanoparticle assemblies became available, exhibiting a high degree of structural order close to that of an atomic crystal. These systems provide a good basis for the magnetic investigation of nanoparticle superstructures. Novel microresonators, provide the necessary sensitivity for the investigation of magnetic properties of nano-objects using ferromagnetic resonance. Due to the much higher filling factor as compared to conventional microwave cavities, they offer several orders of magnitude increased sensitivity gain. A focused ion beam was used to isolate an individual 3D mesocrystal from an ensemble and to transfer it into the microresonator loop. The FMR study reveals the magnetic anisotropy of the single mesocrystal, which is corroborated by micromagnetic simulations. It was possible for us to functionalize the system and to set the magnetic easy axis of the mesocrystal via pre-defining their shape.

MA 35.6 Wed 10:45 HSZ 101

Magnetic properties of Pd and Fe ions in a polyoxopalladate crystal field — •Nataliya Svechkina[1], Natalya Izarova[1], Alevtina Smekhova[1], Detlef Schmitz[2], and Carolin Schmitz-Antoniak[1] — [1]FZ Jülich (PGI-6) — [2]HZB, Berlin

Polyoxometallates (POMs) represent a large class of nanosized, polynuclear metal-oxo anions with a wide compositional and structural variety. Cuboid shaped polyoxopalladates (POPs) shells can incorporate various transitions metal ions placed in the cubic crystal field for studying their magnetic properties. Two types of POPs, Fe-POP (with Fe ion in the center) and Pd-POP (with Pd ion in the center), have been

investigated by x-ray absorption spectroscopy (XAS) at the $L_{2,3}$ absorption edges of Fe and at the $M_{2,3}$ absorption edges of Pd. Spin and orbital magnetic moments were quantified by an integral sum-rules analysis of the x-ray magnetic circular dichroism (XMCD).

For Fe-POP, the derived magnetic moments of Fe correspond with the values expected from a simple atomic model. A small XMCD at Pd was found only for the Pd-POP sample. For Fe-POP it is considerably smaller or even absent. This assumes that the magnetism of Pd arises only from the central Pd ion and it is very sensitive to the coordination environment.

In addition, the influence of a hydrogen plasma treatment was investigated. The Fe ions were reduced from the initial $3d^5$ to $3d^6$ state, the crystal field was changed, and no XMCD for Pd was found in both samples.

MA 35.7 Wed 11:00 HSZ 101

Fabrication and characterization of spherical Janus particles with in plane anisotropy exchange bias caps — •Andreea Tomita, Rico Huhnstock, Dennis Holzinger, and Arno Ehresmann — Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel

The Janus particles are "dual-faced" particles that can serve multiple purposes at the same time, e.g. one face having magnetic properties, while the other can be functionalized with particular receptors, antibodies, or other enzymes for specific applications.

The system we propose makes use of the multifunctionality of Janus particles and complements them with the novelty of an exchange bias (EB) system deposited as a cap on one of the particle's "faces". The fabrication process is tailored so that the unidirectional anisotropy of the cap is oriented parallel to the surface of the particle. The particles are magnetically characterized via vibrating sample magnetometry (VSM), longitudinal magneto-optical Kerr magnetometry (L-MOKE) and magnetic force microscopy (MFM) and the topological features are investigated by scanning electron microscopy (SEM), respectively. These particles will be then introduced in a transport system for remotely controllable linear and rotatory motion.

MA 35.8 Wed 11:15 HSZ 101

Changing the magnetism of eightfold coordinated 3d transition metal ions in polyoxopalladates by hydrogen plasma — Nataliya Svechkina[1], Natalya V. Izarova[1], Detlef Schmitz[2], Alevtina Smekhova[1], and •Carolin Schmitz-Antoniak[1] — [1]FZ Jülich (PGI-6) — [2]HZB, Berlin

Cuboid-shaped polyoxopalladates hosting either Fe^{3+} ($3d^5$) or Co^{2+} ($3d^7$) ions in their centres have been studied by means of x-ray absorption spectroscopy at the $L_{3,2}$ absorption edges of the 3d elements. While the x-ray absorption near-edge structure (XANES) contains already important information on the valence state, the x-ray magnetic linear dichroism (XMLD) and x-ray magnetic circular dichroism (XMCD) were used to refine the quantification of the crystal field related to the eight oxygen ions surrounding the central ion by comparison with simulations using the CTM4XAS program. In addition, spin and orbital magnetic moments were derived by a sum-rule based analysis of the XMCD.

After a hydrogen plasma treatment, the Fe ions were reduced from the $3d^5$ to a $3d^6$ state while the Co $3d^7$ state remains unaffected. However in both cases, drastic changes of the crystal field and the magnetic properties were obtained pointing to a possible application in nanoscale hydrogen sensing or storage devices.

In addition, data of re-oxidised samples are presented and the influence of different heterogroups stabilising the polyoxopalladates is discussed.

MA 35.9 Wed 11:30 HSZ 101

Transport and rotational dynamics of exchange biased Janus particles in artificial magnetic stray field landscapes — •Rico Huhnstock, Andreea Tomiţa, Dennis Holzinger, and Arno Ehresmann — Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel

The investigation of remotely controlled transport of magnetic microparticles above topographically flat substrates is of particular interest for the design of Lab-on-a-chip (LOC) devices, which offer a variety of promising applications in medical diagnostics [1]. In addition to a directed two-dimensional translation of such particles, another degree of freedom for the movement can be found in their rotation properties. In the present study the controlled rotational and translational movement of Janus like colloidal magnetic particles was achieved by the superposition of a static magnetic stray field landscape and a time-dependent external magnetic field sequence. An investigation of the locomotion and the rotational dynamics of the Janus particles was carried out by using tracking and image analysis techniques. The obtained results encourage further experiments for implementing a rotational based transport of the particles and using this method for a biomolecular interaction screening in LOC-applications.

[1] Holzinger, D., Koch, I., Burgard, S., Ehresmann, A. (2015), Directed Magnetic Particle Transport above Artificial Magnetic Domains Due to Dynamic Magnetic Potential Energy Landscape Transformation. ACS Nano, 9: 7323-7331.

MA 35.10 Wed 11:45 HSZ 101

Electronic theory of multicenter complexes as logic elements — •Dibyajyoti Dutta[1], Debapriya Chaudhuri[1,2], Georgios Lefkidis[1], and Wolfgang Hübner[1] — [1]University of Kaiserslautern and Research Center OPTIMAS, Kaiserslautern, Germany — [2]SPINTEC CEA, Grenoble, France

We present a first-principles study of ultrafast spin dynamics on small magnetic Ni/Co clusters. The cooperative effects, due to the electronic correlations and the abundance of d electrons, allow the coherent spin manipulation controlled with femtosecond laser pulses [1]. Using already established spin flip and transfer scenarios, one can construct magnetic logic gates.

Previously, we reported results on the synthesis, characterization and suggested laser-induced spin dynamics on ligand-decorated Co_3 and Ni_3 structures [2,3]. Here we extend our study to the $[Co_3Ni]^+$EtOH complex. A high-level *ab initio* calculation suggests a pyramidal structure of the $[Co_3Ni]$ part, in agreement with the spectroscopic data. Our findings suggest that optical spin manipulation in magnetic molecules can be used for future nanospintronic devices.

[1] W. Jin, F. Rupp, K. Chevalier, M. M. N. Wolf, M. Colindres-Rojas, G. Lefkidis, H.-J. Krüger, R. Diller, and W. Hübner, Phys. Rev. Lett. **109**, 267209 (2012)
[2] W. Jin, C. Li, G. Lefkidis, W. Hübner, Phys. Rev. B **89**, 024419 (2014)
[3] D. Chaudhuri, W. Jin, G. Lefkidis, and W. Hübner, J. Chem. Phys. **143**, 174303 (2015)

MA 35.11 Wed 12:00 HSZ 101

Transport of superparamagnetic particles on magnetically structured exchange bias layer systems in microfluidic devices with transversal flow — •Meike Reginka, Dennis Holzinger, Iris Koch, and Arno Ehresmann — Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel

The controllable movement of superparamagnetic particles above magnetically stripe-patterned exchange bias (EB) layer systems was used to transport such particles in a microfluidic structure.[1] Transversal flows of defined flux were used to affect the particles' movement perpendicular to the direction of their simultaneous transport. The particle velocities along the flow direction were shown to be 2 to 3 orders of magnitude smaller than the mean fluid velocity due to the transport being located close to the sample surface. The particles' trajectories remain almost unaffected, which allows the purification of biomolecules in microfluidic devices with transversal flow components. Besides that, the effect of the ferromagnetic layer thickness of the EB system was studied for further tailoring of the transport characteristics of superparamagnetic particles by a change of the intrinsic properties of the substrate material.

[1] D. Holzinger, I. Koch, S. Burgard, and A. Ehresmann, ACS Nano 9, 7323 (2015)

MA 35.12 Wed 12:15 HSZ 101

Tuning applied field characteristics to improve efficiency of magnetic hyperthermia — •Oliver Laslett, Hans Fangohr, and Ondrej Hovorka — Faculty of Engineering and the Environment, University of Southampton, Southampton, SO17 1BJ, United Kingdom

The effectiveness of magnetic hyperthermia therapy depends not only upon the material properties of magnetic particles but also on their interaction with one another and their environment. The applied magnetic field is limited in both amplitude and frequency to ensure patient safety and comfort. We investigate the ability of novel waveform shapes to overcome this limit and improve treatment effectiveness. We present

multiple theoretical and numerical approaches to simulating the induced power loss in heterogeneous ensembles of magnetic nanoparticles subjected to an arbitrary external field waveform. Crucially, we demonstrate the extent to which linear response theory and transition state theory accurately approximate full simulation of the Langevin dynamics. We also consider the filtering effect of hardware on high frequency switching fields. Subjecting magnetic nanoparticles to non-sinusoidal alternating fields affects the efficacy of treatment and the potential costs of material synthesis. We acknowledge financial support from the EPSRC grant EP/G03690X/1

MA 35.13 Wed 12:30 HSZ 101

The effect of clustering of magnetic nanoparticles on sensing and imaging in medicine — •Ondrej Hovorka — University of Southampton, UK

In this talk we discuss the role of aggregation of magnetic nanoparticles on performance of biosensing methodologies based on magnetorelaxometry (MRX) and of magnetic particle imaging (MPI). Employing the kinetic Monte-Carlo modelling of fractal clusters of magnetic nanoparticles such as typically observed in intracellular environments [1], we show that depending on the structure of aggregates the performance in MRX and MPI can be downgraded or enhanced. We also illustrate various memory effects emerging in the time scale range from superparamagnetic to hysteresis regime and discuss their potential utilisation for optimising the MRX and MPI applications [2, 3]. Understanding the effects of aggregation of magnetic nanoparticles is becoming an increasingly important issue because it implies that optimal designs of magnetic nanostructures need to take into account the considerations of realistic environments.

References: [1] Etheridge et al., Technology 2, 214 (2014). [2] O. Laslett, et al., Applied Physics Letters 106, 012407 (2015). [3] H. Mamiya, B. Jeyadevan, PLoS ONE 10, e0118156 (2015).