MA 1: Magnetic nanoparticles (joint session MA/CPP)

Time: Monday 9:30–12:15 Location: H 0112

MA 1.1 Mon 9:30 H 0112

Temperature dependence of the magnetic anisotropy of Pt/Co/Pt nanodots — •Stefan Freercks, Eva-Sophie Wilhelm, Carsten Thönnissen, Philipp Staeck, and Hans Peter Oepen — Center for Hybrid Nanostructures, Universität Hamburg, Germay

We use the anomalous Hall-effect to investigate the magnetization reversal of single Pt/Co/Pt nanodots (diameter <35nm, Co thickness< 1.5nm) with perpendicular magnetization. The dots are fabricated by electron beam lithography and ion milling out of thin multilayers[1]. Our technique allows for measuring from room temperature, where the nanodots are usually superparamagnetic, down to low temperatures, where the magnetization is blocked. Measuring the switching times, we find that the attempt frequencies given by the Néel-Arrhenius law are some orders of magnitude higher than the expected GHz regime. Simple considerations show that a temperature dependent anisotropy can very well explain such deviations, which gave the motivation for our investigation. We determined the anisotropy of the initial film and of nanodots as a function of temperature. The anisotropy shows a non-linear temperature dependence in films and dots, which proves our point that temperature effects cannot be neglected in the Néel-Arrhenius law. Furthermore, the temperature dependence varies for different nanodots. The latter variation reveals that generalizations in ensemble measurements have to be handled with care. Funding by DFG via SFB 668 is gratefully acknowledged. [1] A. Neumann et al. Nano Letters. 13, p2199-2203, (2013)

MA 1.2 Mon 9:45 H 0112

Non-coherent reversal of magnetization in single Pt/Co/Pt nanodots with diameter below 100nm — •Eva-Sophie Wilhelm, Stefan Freercks, Philipp Staeck, Carsten Thönnissen, and Hans Peter Oepen — Center for Hybrid Nanostructures, Universität Hamburg, Germany

We investigate magnetization reversal behavior of single Pt/Co/Pt nanodots with a diameter of 35nm and a Co thickness of 1nm using anomalous Hall-effect magnetometry [1] at temperatures from 2.5K to 270K. The samples were fabricated from polycrystalline films by electron beam lithography and ion milling.

For nanodots with uniaxial anisotropy and a diameter below 100nm single domain behavior and coherent rotation reversal according to the Stoner-Wohlfahrt model is expected [2] [3]. However non-coherent switching with two jumps in the hysteresis is observed for some of the dots with out-of-plane magnetization at low temperatures. Comparison of the reversal of two different dots from the same film material and micromagnetic simulation using Mumax3 [4] gives hints that this finding is caused by different local magnetic properties of the initial films. The differences presumably originate from the distribution of grains of different crystal orientation in the nanodots. Funding by DFG via SFB 668 is gratefully acknowledged. [1] A. Neumann et al. Nano Letters. 13, p2199-2203, (2013) [2] A. Neumann, Ph.D thesis, Universität Hamburg, (2015) [3] E. C. Stoner and E. P. Wohlfarth, Philos. Trans. R. Soc. London, Ser. A 240, 599 (1948) [4] A. Vansteenkiste et al. AIP Advances 4 107133 (2014)

MA 1.3 Mon 10:00 H 0112

Chemical and magnetic characterizations of ordered arrangements of magnetic nanoparticles — Asmaa Qdemat[1], Emmanuel Kentzinger[1], •Jin Xu[2], Giuseppe Portale[2], Marina Ganeva[3], Stefan Mattauch[3], Oleg Petracic[1], Ulrich Rücker[1], and Thomas Brückel[1] — [1]Jülich Centre for Neutron Science (JCNS) and Peter Grünberg Institute (PGI), JARA-FIT, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [2]Herzog-Wilhelm-Allee — [3]Jülich Centre for Neutron Science, Forschungszentrum Jülich, Outstation at MLZ, 85748 Garching, Germany

a.qdemat@fz-juelich.de Keywords: magnetic nanoparticles, grazing incidence small angle scattering, interparticle interactions

Magnetic nanoparticles and their assembly in highly ordered structures are principally interesting regarding the understanding of magnetic interactions and for future applications in information technology as e.g. magnetic data storage media or as material for spintronics.

The work to be presented focuses on the chemical and magnetic characterization of monolayer of CoFe2O4 nanoparticles on silicon substrate. Using Grazing Incidence Small Angle X-ray Scattering (GISAXS) we deduce the height profile of the nanoparticle, and a hexagonal ordering between those nanoparticles. Macroscopic magnetization measurement and polarized neutron reflectometry were used to deduce that the nanoparticles are weakly magnetized with respect to bulk CoFe2O4 and that a random in plane relative orientation of the nanoparticle magnetizations is obtained at zero applied field.

MA 1.4 Mon 10:15 H 0112

Magnetic behavior of single- and polycrystalline nanoparticle superlattices — •Michael Smik[1], Genevieve Wilbs[1], Mauricio Cattaneo[1], Elisa Volkmann[1], Emmanuel Kentzinger[1], Stefan Mattauch[2], Ulrich Rücker[1], Oleg Petracic[1], and Thomas Brückel[1] — [1]Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science (JCNS-2) and Peter Grünberg Institut (PGI-4), JARA-FIT, 52425 Jülich, GERMANY — [2]Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science at MLZ, Lichtenbergstr. 1, 85747 Garching, Germany

Magnetic nanoparticle (NP) assemblies form a novel type of artificial material which hold the promise to display 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 NP. The assembly of polycrystalline samples up to 300 μm in size was possible, as well as a the realization of a nearly ideal macrocrystal. Using small angle x-ray scattering at our in-house instrument GALAXI the supercrystalline structure and quality of ordering could be characterized. The magnetic properties were investigated by a variety of magnetometric methods. Additional samples of nearly non-interacting NP were prepared to characterize the magnetic behavior of the individual NP. A comparision between the polycrystalline, single crystal and dispersed samples was performed. For a microscopic investigation of the magnetic ordering in the supercrystals, small angle neutron scattering was employed.

MA 1.5 Mon 10:30 H 0112

Structural and magnetic characterization of Pd-decorated cobalt ferrite multifunctional nanoparticles — •Seyedeh Fatemeh Shams[1], Detlef Schmitz[2], Alevtina Smekhova[1], Nataliya Svechkina[1], Konrad Siemensmeyer[2], Amir Hossein Tavabi[3], Rafal E. Dunin-Borkowski[3], and Carolin Schmitz-Antoniak[1] — [1]Peter Grünberg Institute (PGI-6), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Department for Quantum Phenomena in Novel Materials (EM-IQM), Helmholtz-Zentrum Berlin für Materialien und Energie, 12489 Berlin, Germany — [3]Ernst Ruska Centre for Microscopy and Spectroscopy with Electrons and Peter Grünberg Institute, Forschungszentrum Jülich, 52425 Jülich, Germany

Pd-decorated CoFe2O4 multifunctional nanoparticles have been synthesized as a hybrid platform for simultaneous magnetic hyperthermia and photothermal therapeutic applications. Elemental and microstructural analyses have been conducted using TEM, HAADF STEM, EDS and ICP-OES. Experimental results confirm successful homogeneous Pd decoration on highly crystalline CoFe2O4 nanoparticles. Cations distributions, which have been inferred from XANES and XRD measurements, suggest the presence of considerable cation disorder, which increases with decreasing particle size for all of the samples. Magnetic properties of the nanoparticles have been investigated using XMCD and magnetometry. Intriguingly high-field XMCD reveals significantly enhanced total magnetic moments for both Fe and Co ions after Pd decoration. This substantially increased magnetization could lead to improved magnetic hyperthermia performance of the nanoparticles.

15 minutes break

MA 1.6 Mon 11:00 H 0112

Distributed heat production in clusters of magnetic nanoparticles — Paola Torche[1], David Serantes[2], Sergiu Ruta[3], Roy Chantrell[3], and •Ondrej Hovorka[1] — [1]University of Southampton, Southampton, UK — [2]Universidade de Santiago de Compostela, Santiago de Compostela, Spain — [3]University of York, York, UK

We address the issue of quantifying the heat produced by a single magnetic nanoparticle (MP) embedded within an interacting MP cluster.

This is relevant for MP hyperthermia considered as a modality for enhancing cancer therapies, where it becomes necessary to understand the distribution of heat production across a MP aggregate inside a living cell. The heat produced by MPs subject to time-varying external magnetic field can be determined from the area of the hysteresis loop. However, at the single-particle level of description, the magnetization of a MP undergoes a fluctuating stochastic process and the meaning of the hysteresis loop becomes ambiguous, as suggested also experimentally. It is then unclear how to quantify the heat production, especially if the interactions between MPs cannot be neglected.

We use the modern stochastic thermodynamics in combination with the Néel-Arrhenius theory of thermal relaxation of MPs to establish the relationship between the fluctuating work and entropy (heat) produced along the fluctuating magnetization trajectories of MPs. By considering the dipolar chains of MPs, we demonstrate a practical recipe for quantifying the heat produced by a single MP embedded within a chain, which then allows to map heat production distributions along the chains.

MA 1.7 Mon 11:15 H 0112

Determination of individual magnetic moments of trapped superparamagnetic particles — •Ulrich Herr, Meng Li, Benjamin Riedmüller, Florian Ostermaier, and Sruthi Sunder — Institute of Micro- and Nanomaterials, Ulm University, Ulm

Superparamagnetic nanoparticles are used in lab-on-chip devices for detection of bio-analytes, drug delivery, or in hyperthermia. Many of these applications would benefit from precise knowledge of the magnetic moment of the individual nanoparticle, which may vary significantly between particles due to the statistical nature of the production process. We have recently demonstrated that individual magnetic particles (Dynabeads M-280 and MyOne T1) can be trapped over long times in a micro-conductor ring combined with an additional homogeneous magnetic field [1], which allows precise determination of a variety of microscopic parameters. Here we demonstrate that capturing more than one particle inside the trap can lead to stable arrangement of the particles inside the magnetic potential landscape of the trap. By measuring the average distance between the nanoparticles in a known trap potential we are able to determine the actual magnetic moment of the trapped nanoparticles, which can not easily be obtained in other ways.

[1] B. Riedmüller, F. Ostermaier, F., U. Herr, Trapping of superparamagnetic particles with a single current-conducting microring, IEEE Transactions on Magnetics 53 (2017) 5300706 DOI: 10.1109/TMAG.2017.2697722

MA 1.8 Mon 11:30 H 0112

Studying the dynamic properties of pure cobalt ferrite nanoparticles and particles coated with silica in PEG-solution by magnetic AC-susceptometry — •Samira Webers[1], Melissa Hermes[2], Joachim Landers[1], Soma Salamon[1], Annette M. Schmidt[2], and Heiko Wende[1] — [1]Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen — [2]Institute for Physical Chemistry, University of Cologne

The particle-matrix interaction in complex viscoeleastic composites is determined by the characteristic length scales between the magnetic particles and matrix structures. In this work, we study the particle-matrix interaction of a polyethylene glycol (PEG) polymer solution with tailored complexity and the mobility of two types of particles. Pure cobalt ferrite nanoparticles with a hydrodynamic radius of $r_{h,CFO} = 23.2$nm and cobalt ferrite particles coated with silica resulting in $r_{h,CFO@SiO_2} = 42.3$nm are dispersed in various concentrated polymer solutions with different PEG length. The dynamic properties of the two particle systems in various polymer solutions are characterized by magnetic AC-susceptometry. Here the Brownian relaxation of the particles in complex fluids are investigated in the frequency regime from 0.001 Hz -250 kHz and compared to the relaxation of the coated particles, where a shift of magnetic susceptibility spectra to lower frequencies is observed. The frequency dependent viscosity is also determined by temperature dependent magnetic AC measurements. This work is supported by the DFG-Priority Programme SPP1681.

MA 1.9 Mon 11:45 H 0112

Intermediates and pH sensitive formation pathways of superparamagnetic Fe3O4 nanoparticles — •Mohammad Reza Ghazanfari[1], Seyedeh Fatemeh Shams[1,2], Mehrdad Kashefi[1], and Mahmoud Reza Jaafari[3] — [1]Department of Materials Science and Engineering, Ferdowsi University of Mashhad, 9177948974, Mashhad, Iran — [2]Peter Grünberg Institute (PGI-6), Jülich Research Centre, 52425 Jülich, Germany — [3]Biotechnology Research Center, Nanotechnology Research Center, School of Pharmacy, Mashhad University of Medical Sciences, Mashhad, Iran

In this work, by identification of reaction critical steps using study of pH variations trend and then investigation of structural, microstructural, and magnetic properties of each sample, the formation mechanism and reaction pathways of synthesis the nanoparticles of Fe3O4 (magnetite) phase by coprecipitation method were successfully recognized and presented. Based on the results, the formation mechanism and reaction pathways of magnetite nanoparticles synthesis during coprecipitation method can be explained in four critical steps as follows: (I) the formation of ferrous hydroxide phase from initial materials, (II) the transformation of ferrous hydroxide phase to lepidocrocite phase, (III) the transformation of lepidocrocite phase to goethite phase, and (IV) the transformation of goethite phase to magnetite target phase (or/and maghemite phase).

MA 1.10 Mon 12:00 H 0112

Magnetic properties of shell-ferromagnetic precipitates in decomposed off-stoichiometric Ni-Mn-based Heusler alloys, studied by ferromagnetic resonance (FMR) — •F. Scheibel[1,3], D. Spoddig[1], R. Meckenstock[1], T. Gottschall[2,3], M. Fries[3], A. Çakir[4], M. Farle[1], O. Gutfleisch[3], and M. Acet[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, 47057 Duisburg, Germany — [2]High Magnetic Field Laboratory, Helmholtz-Zentrum Dresden-Rossendorf, Germany — [3]Institut für Materialwissenschaft FG Funktionale Materialien, Technische Universität Darmstadt, 64289 Darmstadt, Germany — [4]Department of Metallurgical and Materials Engineering, Muğla Sitki Koçman University, 48000 Mugla, Turkey

Off-stoichiometric $Ni_{50}Mn_{25-y}X_y$ ($25 > y > 0$) Heusler alloys decompose into ferromagnetic (FM) $Ni_{50}Mn_{25}X_{25}$ and antiferromagnetic $Ni_{50}Mn_{50}$ components when annealed between 600 and 750 K [1]. In the case of $y = 5$ annealed at 650 K, shell-ferromagnetic $Ni_{50}Mn_{25}X_{25}$ nano-precipitates of about 3 nm are formed. High-field FMR measurements up to 12 T verify the existence of a strong coupling of the shell of the precipitates with the surrounding $Ni_{50}Mn_{50}$ matrix [2]. Magnetization measurements show a rotation of the shell-spins first above 5 T, while the core shows a soft FM behavior. The magnetic hysteresis is vertically shifted, which makes this material interesting for magnetic-field proof permanent memory application. Work supported by the Deutsche Forschungsgemeinschaft (SPP 1599).

[1] A. Çakir et al., Sci. Rep. 6 , 28931 (2016)
[2] F. Scheibel et al., AIP Adv. 7, 056425 (2017)