MA 65: Poster 2

Time: Friday 9:30–13:00 Location: P2-OG1

MA 65.1 Fri 9:30 P2-OG1

Behavior of silica-based magneto-optical fluids influenced by dynamically changing magnetic stray field landscapes — •Iris Koch[1], Karl Sebastian Mandel[2], Tim Granath[2], and Arno Ehresmann[1] — [1]Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel — [2]Fraunhofer Institute for Silicate Research ISC, Neunerplatz 2, D-97082 Würzburg

The microscopic motion of silica-based superparamagnetic rods (SR) in aqueous solution and their resulting macroscopic magneto-optical behavior were manipulated by using specially designed magnetic field landscapes (MFL). These MFL originate from a superposition of magnetic stray fields emerging from micromagnetically stripe-patterned exchange bias (EB) bilayer systems [1] and time-dependent external magnetic fields. The SR were found to arrange in parallel rows above the respective domain walls emerging from the EB substrate's surface. By applying defined external magnetic field pulses, the orientation and localization of these rows can be varied and, thereby, cause significant changes of the macroscopical optical properties of the fluid. The obtained results are promising for the future development of remotely switchable optical filter systems.

[1] D. Holzinger et al., J. Appl. Phys. 114, 1 (2013)

MA 65.2 Fri 9:30 P2-OG1

Magnetic properties of porphyrin magnetite nanocomposites — •Apoorva Sharma[1], Chalathan Saengruengrit[2], Patrick Matthes[3], Numpon Insin[2], Patchanita Thamyongkit[2], Dietrich R.T. Zahn[1], Georgeta Salvan[1], and Setfan Krause[1] — [1]Institute of Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany — [2]Department of Chemistry, Chulalongkorn University, 10330 Bangkok, Thailand — [3]Fraunhofer Institute for Electronic Nano Systems, 09126 Chemnitz, Germany

Since the advent of superparamagnetic nanoparticles, their properties have been vastly exploited by both industries and the scientific community. However, very few investigations are so far focused on the integration of such magnetic nanoparticles in an organic matrix for bio-medical applications. We hereby present our work conducted on porphyrin magnetite nanocomposites. The binding of magnetite particles to porphyrin was confirmed by fluorescence microscopy. The magnetic properties of nanoparticles with different geometries (cubes and spheres), sizes (10 nm and 25 nm), and cladding was investigated with superconducting quantum interference device - vibrating sample magnetometry (SQUID-VSM). These properties were observed to be insignificantly influenced by the addition of porphyrin. Furthermore, a comprehensive study of the interaction behaviour among these nanoparticles was performed using the first order reversal curve measurement technique (FORC) [1].

[1]C. R. Pike et al., J. Appl. Phys., vol. 85, no. 9, 1999.

MA 65.3 Fri 9:30 P2-OG1

Controlling the magnetic anisotropy of adsorbed Fe porphyrins by a ring-closure reaction — •Lucas M. Arruda[1], Md. Ehesan Ali[2], Matthias Bernien[1], Fabian Nickel[1], Jens Kopprasch[1], Peter M. Oppeneer[2], and Wolfgang Kuch[1] — [1]Institut für Experimentalphysik, Freie Universität Berlin, 14195 Berlin, Germany — [2]Department of Physics and Astronomy, Uppsala University, Box 516, 75120 Uppsala, Sweden

Metalloporphyrins' stability and tunability make them well-suited candidates for use in molecular spintronics. In this context, the understanding of the on-surface properties and reactions of such systems is of great relevance. In this work we investigate the intramolecular reaction mediated by thermal stimulation undergone by iron octaethylporphyrin adsorbed onto a Au(111) single crystal substrate. Through a ring-closure process, the molecule turns into iron tetrabenzoporphyrin when subjected to an annealing temperature of 550 K [1]. Near-edge x-ray absorption fine structure, x-ray magnetic circular dichroism, and density-functional-theory-calculated density of states (DOS) results are presented to display the modifications resulting from this process. We find the magnetic anisotropy of the molecule after ring closure is reduced by a factor of six, while the iron magnetic moment is substantially increased. — Financial support by project VEKMAG (BMBF 05K13KEA) and CAPES is gratefully acknowledged.

[1] B. W. Heinrich *et al.*, Nano Lett. 13 (10), 4840 (2013).

MA 65.4 Fri 9:30 P2-OG1

The Emegence of Cooperativity in the Coverage-Dependent Temperature and Light-Induced Spin-State Switching of an Fe(II) Complex Adsorbed on a Graphite Surface — •Lalminthang Kipgen[1], Holger Naggert[2], Matthias Bernien[1], Fabian Nickel[1], Lucas M. Arruda[1], Andrew J. Britton[1], Sascha Ossinger[2], Felix Tuczek[2], and Wolfgang Kuch[1] — [1]Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Institut für Anorganische Chemie, Christian-Albrechts Universität zu Kiel, 24098 Kiel, Germany

The spin-state manipulation from high-spin state (HS, S=2) to low-spin state (LS, S=0) or vice versa of spin crossover molecules adsorbed on a surface has been of much interest due to its potential for applications in spintronic devices. We report on the complete spin-state switching from the sub-monolayer to multilayer coverage of an Fe(II) complex deposited on a highly oriented pyrolytic graphite surface with temperature and light. For a sub-monolayer coverage, the thermal spin transition is rather gradual between 300 K to 70 K and can be fitted well as a system of non-interacting molecules along the Vant Hoff's model. With the increased in coverage, the transition becomes more abrupt, which is attributed to increase cooperativity between the molecules.

MA 65.5 Fri 9:30 P2-OG1

Atomistic simulation of finite temperature magnetism of nanoparticles — •András Lászlóffy, László Udvardi, and László Szunyogh — Budapest University of Technology and Economics, Budapest, Hungary

Recent experimental efforts focus on scaling down the size of spintronics and magnetic logics devices to atomic scales to maintain technological development, which requires also intensive theoretical studies. By combining the spin-cluster expansion with the relativistic local moment scheme we developed a technique to determine suitable spin models for small embedded clusters of arbitrary geometry. We calculated the spin model of uncovered and covered hexagonal Co clusters on Au(111) surface and show that the parameters strongly depend on the local environment, especially on the coordination number of the magnetic atoms. In particular, the Co clusters capped by Au atoms display strong out-of-plane magnetic anisotropy. We performed Monte Carlo simulations to calculate the temperature dependent magnetization of the systems. We found that the blocking temperature of the covered clusters with perpendicular magnetic anisotropy can be determined by calculating the variance of the magnetization in the easy direction, since its inflection point is related to the magnetic anisotropy energy of the system. The average time of the spin reversals satisfy the Néel–Arrhenius law with an energy barrier slightly higher than the magnetic anisotropy energies of the clusters.[1]

[1] A. Lászlóffy, L. Udvardi, L. Szunyogh: arXiv: 1611.09199 (2016)

MA 65.6 Fri 9:30 P2-OG1

Monte-Carlo simulation studies on the superspin structure of 3D nanoparticle supercrystals — •Mauricio Cattaneo, Michael Smik, Oleg Petracic, and Thomas Brückel — Jülich Centre for Neutron Science JCNS and Peter Grünberg Institut PGI, JARA-FIT, Forschungszentrum Jülich GmbH, 52425 Jülich

The assembly of magnetic nanoparticles into large 3D structures constitutes a novel way of fabricating artificial materials that show properties that are not found in conventional systems. A detailed understanding of the magnetic properties is impeded by the huge number of contributing parameters as well as the difficulty in probing the internal magnetic structure in situ. Monte-Carlo simulations offer the possibility to predict numerically possible magnetic ground states. Sufficiently small nanoparticles can be considered as single domain which may be modelled as an effective superspin. In contrast to atomic spins, the dominating inter-particle interaction is the dipole-dipole interaction. We simulated regularly arranged supercrystals of iron oxide nanoparticles with diameters between 10-20nm with various supercrystal structures and with various easy-axis orientations. Using the Metropolis scheme, we simulated the temperature dependent magnetization and ac susceptibility at various applied magnetic fields. The results are compared to measurements of experimental nanoparticle supercrystals.

MA 65.7 Fri 9:30 P2-OG1

Magnetic properties of wet-chemically prepared nanoparticles — •Adrian Jaspers, Maryam Youhannayee, and Mathias Getzlaff — Institute of Applied Physics, Heinrich-Heine-Universität, Düsseldorf, Germany

The magneto-optical Kerr effect (MOKE) is a convenient method to investigate the magnetic properties of magnetic systems such as ferromagnetic thin film and magnetic nanoparticles. In our research, a transverse magneto-optic Kerr effect (TMOKE) setup has been constructed in order to measure magnetic hysteresis loops by the intensity of a laser beam reflected of its surface. The magnetic particles consist of magnetite which have a wide application spectrum in biology and medicine. They have been prepared in a wet-chemical way (coprecipitation) using Iron(II) sulfate and Iron(III) chloride which were mixed thoroughly initially. Subsequently, ammonium has been added for formation of magnetite nanoparticles. In the following step, a few drops of nanoparticle solution have been applied on silicon wafer and dried under vacuum condition to obtain non-oxidized homogenous samples. The measuring procedure was run by a LabVIEW program which operated a bipolar power supply attached to the magnetic coils. The setup delivered results with a good signal-to-noise ratio even without utilizing any amplification devices.

MA 65.8 Fri 9:30 P2-OG1

Magnetization behavior and interactions of single magnetic nanodots — •Stefan Freercks[1], Philipp Staeck[1], Carsten Thönnissen[1], Eva-Sophie Wilhelm[1], Alexander Neumann[1,2], and Hans Peter Oepen[1] — [1]Institut für Nanostruktur- und Festkörperphysik, Universität Hamburg, Germany — [2]Institut für Medizintechnik, Universität zu Lübeck, Germany

We use the anomalous Hall-effect to measure the magnetization behavior of single magnetic nanodots with a uniaxial anisotropy perpendicular to the film plane in the blocked and the superparamagnetic state [1]. The nanodots and Hall bars are created by electron beam lithography and ion milling from thin Pt/Co/Pt multilayers. The diameter of the dots can be tuned down to 20 nm. Single nanodots as well as ensembles of a few nanodots have been investigated from 2.5 K to room temperature. The switching behavior of a single blocked nanodot has been studied as a function of field direction in three dimensions and differences to the model of Stoner-Wohlfarth are found [2]. In previous experiments interactions between nanodots were found [3]. Here the influence of the stray field of two blocked dots on the superparamagnetic switching behavior of a third dot is examined. Residual fields of the nanodots can be determined and give information on the internal dot structure. Funding by DFG via SFB 668 is gratefully acknowledged. [1] A. Neumann *et al.* Nano Letters. **13**, p2199-2203, (2014). [2] E. C. Stoner and E. P. Wohlfarth, Philos. Trans. R. Soc. London, Ser. A **240**, 599 (1948). [3] A. Neumann *et al.* New J. Phys. **16**, 083012 (2014).

MA 65.9 Fri 9:30 P2-OG1

Magnetic and morphological characterization of magnetite nanoparticles with ligand shell — •Stanislav Emelianov, Maryam Youhannayee, and Mathias Getzlaff — Institute of Applied Physics, Heinrich-Heine-Universität, Düsseldorf, Germany

Magnetic properties of nanoparticles are of big interest for scientists due to its wide application in different field such as medicine. In our research, magnetic nanoparticles are obtained by wet chemical synthesis (coprecipitation) using the following procedure: Ammonium hydroxide drop wised in Ferric Chloride and Ferrous Sulphate mixed solution. All procedures of synthesis were carried out in the presence of nitrogen. In order to increase the biocompatibility and to decrease the toxicity of them, the particles have been coated with Aminosilane shell. We investigated magnetic properties of iron oxide nanoparticles by means of the transverse magneto-optic Kerr effect (TMOKE) which is based on the analysis of p-polarized laser beam intensity after interaction with magnetic samples. To evaluate physical and morphological characterization of the particles, DLS (Dynamic Light Scattering) and TEM (Transmission Electron Microscopy) techniques are involved, in order to determine shape, size and structure of the particles and to observe particle-cluster formation.

MA 65.10 Fri 9:30 P2-OG1

Dilatometry in very high magnetic fields ... an overview — •Mathias Doerr[1], Sergey Granovsky[1], Martin Rotter[1,2], Thomas Stöter[1], Sergey Zherlitsyn[3], and Zhaosheng Wang[3] — [1]Technische Universität Dresden, Institut für Festkörperphysik, D-01062 Dresden, Germany — [2]McPhase-project (www.mcphase.de) Dresden, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf, Hochfeld-Magnetlabor (HLD-EMFL), PF 510119, D-01314 Dresden, Germany

Investigations of the changes in lattice constants or crystal symmetries of solids complement macroscopic measurements of electronic properties and often accompany ultrasound experiments. We give an overview on how the dilatometric methods have been developed in the last decade. The capacitive dilatometry can be used in steady fields with a resolution better than 10^{-8}. Especially for the highest available (pulsed) fields of about 100 T, optical methods, such as for example the FBG (fibre bragg grating) technology, were developed with a resolution better than 10^{-6}. Modern dilatometer constructions with a diameter of 5 mm allow to measure longitudinal and transversal components of the general striction tensor. Additionally, techniques to measure magnetostriction under pressure up to the highest fields are tested by scientific groups now. New results (GdSb, $CeCu_2Ge_2$, $Ho_2Ti_2O_7$ etc.) are discussed. The data are important to determine magnetic phase diagrams or show how lattice distortions influence the high-field properties of solids.

MA 65.11 Fri 9:30 P2-OG1

Quantitative Imaging of Magnetic Nanostructures Using Magneto Optical Indicator Film Techniques — •Manuela Gerken[1], Sascha Gorny[1], Sandra Lindner[2], Sibylle Sievers[1], and Hans Werner Schumacher[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [2]Matesy GmbH, Otto-Schott-Straße 13, 07745 Jena

The magneto-optical indicator film (MOIF) technique is a versatile tool for imaging magnetic domain structures. Optimized sensor films combined with correction schemes to compensate the influence of the finite sensor thickness allow to measure perpendicular stray field components with a spatial resolution down to the sub μm scale. However, present calibration schemes neglect in-plane stray field components. Therefore, a quantitative analysis of stray field data above micropatterned magnetic materials creates additional difficulties, since the closure of the flux lines leads to a rapidly spatially varying direction of the magnetic field H(x). To understand the sensor response on such arbitrary stray fields the full anisotropy tensor and the magnetic history of the sensor material have to be known. We will present results on the FMR based analysis of sensor materials and a thereon based sensor calibration scheme for vectorial stray fields. But, even if the sensor response function is understood, the inversion from contrast to stray field in gereral is not unique. Conditions which allow a reconstruction of the magnetic field and the underlying domain pattern will be discussed.

MA 65.12 Fri 9:30 P2-OG1

Microwave interferometry for high sensitivity VNA-FMR measurements — •Taras Holoyad, Joschua Kurda, Sibylle Sievers, and Hans Werner Schumacher — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Vector network analyzer ferromagnetic resonance (VNA-FMR) using coplanar waveguides (CPW) is widely used to analyze ferromagnetic film parameters. This is of particular interest in the area of patterned magnetic nanostructures, where, however, due to the small volume, the absorption inn FMR is low and the FMR signal is superimposed by the excitation signal, limiting the sensitivity. Here, a promissing approach is microwave interferometry [1]. In the present work, we compare two techniques to generate the reference signal to interfere with the signal of the measurement path:

(I) A reference signal is generated in a second microwave path with the same geometry as the measurement path, including an identical but empty CPW. It is, however, extended by 0.5 m of an rf coaxial cable. This path length difference leads to a frequency dependent phase difference of the two paths in regular frequency intervals. (II) The second technique uses a fully synthetic reference signal generated by a second phase coherent microwave source with adjustable attenuation.

Our experiments reveal an improvement of the sensitivity by up to 2 orders in magnitude. The feasibility of both techniques is discussed.

[1] S. Tamaru et al, Ultrahigh Sensitivity Ferromagnetic Resonance Measurement based on Microwave Interferometer, IEEE Magn. Lett., Volume 5 (2014).

MA 65.13 Fri 9:30 P2-OG1

Element specific magnetometry of buried layers by HAXPES

— •Andrei Gloskovskii[1], Gerhard H. Fecher[2], and Wolfgang Drube[1] — [1]Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Max Planck Institute for Chemical Physics of Solids, Dresden

The electronic properties of buried magnetic nano-layers were studied using the linear magnetic dichroism (LMD) in the angular distribution of photoemitted Fe, Co, and Mn $2p$ electrons from a CoFe-IrMn multi-layered sample. The buried layers were probed using hard X-ray photoelectron spectroscopy, HAXPES, at the undulator beamline P09 of the 3^{rd} generation storage ring PETRA III.

In general, the intensity and shape of photoelectron lines of magnetic materials depend on the relative orientation of the sample magnetisation, the X-ray beam polarisation and the spectrometer axis, i.e. the electron emission direction. The highest LMD value was obtained for the Fe $2p_{3/2}$ line measured with the polarisation vector $\vec{\mathbf{E}} \parallel \vec{\mathbf{M}}$ versus $\vec{\mathbf{E}} \perp \vec{\mathbf{M}}$. The dichroism value obtained for Fe $2p_{3/2}$ is 5.5%, for Co $2p_{3/2}$ it is 4.5%.

It is demonstrated that magnetic dichroism and spin-resolved HAXPES is an effective and powerful technique to perform element specific magnetometry of deeply buried ferromagnetic and antiferromagnetic magnetic materials and multilayered spintronics devices, which are inaccessible with conventional soft X-ray photoelectron spectroscopy. It allows to determine the relative orientation of the magnetisation in different layers in a complex nano-structured sample.

MA 65.14 Fri 9:30 P2-OG1

The quadratic magnetooptic tensor of cubic materials without inversion symmetry — •Robin Silber[1,2], Jan-Oliver Dreessen[2], Jaromír Pištora[1], Günter Reiss[2], Martin Veis[3], Jaroslav Hamrle[3], and Timo Kuschel[2,4] — [1]VSB - Technical University of Ostrava, Czech Republic — [2]CSMD, Physics Department, Bielefeld University, Germany — [3]Charles University, Prague, Czech Republic — [4]University of Groningen, The Netherlands

The permittivity tensor of a magnetized crystal could be described by a Taylor series: $\varepsilon_{ij} = \varepsilon_{ij}^{(0)} + \varepsilon_{ij}^{(1)} + \varepsilon_{ij}^{(2)} + \ldots$, where the superscript denotes the order in magnetization (**M**). The shape of $\varepsilon_{ij}^{(2)}$ is determined by the so-called quadratic magnetooptic (MO) tensor G_{ijkl} [1]. This quadratic MO tensor for cubic materials with and without inversion symmetry differ in the parameter $\Delta\Gamma = (G_{12} - G_{21})$ [2], being zero for cubic material with inversion symmetry as $G_{12} = G_{21}$. The $\Delta\Gamma$ parameter was predicted by symmetry arguments of the structure, but no experimental determination method exists so far. Here, we propose a new measurement procedure of magnetooptic Kerr effect (MOKE), allowing us to separate contribution of $\Delta\Gamma$ to overall MOKE signal.

[1] Š. Višňovský, Czech. J. Phys. B 36, 1424 (1986)
[2] J. Hamrlová et al., Phys. Status Solidi B 250, 2194 (2013)

MA 65.15 Fri 9:30 P2-OG1

FMR identification of skyrmionic states in confined helimagnetic nanostructures — •Marijan Beg[1], David I. Cortés-Ortuño[1], Weiwei Wang[1,2], Rebecca Carey[1], Mark Vousden[1], Ondrej Hovorka[1], and Hans Fangohr[1] — [1]Faculty of Engineering and the Environment, University of Southampton, Southampton, SO17 1BJ, United Kingdom — [2]Department of Physics, Ningbo University, Ningbo, 315211, China

One of the challenges in the study of skyrmionic states in confined helimagnetic nanostructures is the detection of which state emerged in the studied sample. In this work, we explore how measuring resonance frequencies can contribute to the identification of the emergent state. We compare the power spectral densities of an incomplete Skyrmion (iSk) (also called the quasi-ferromagnetic or edged vortex state) and isolated Skyrmion (Sk) states in a 100 nm diameter FeGe disk sample with 10 nm thickness at different external magnetic field values using our full three-dimensional micromagnetic model. In this sample size and at all simulated external magnetic field values, the Sk state is metastable and the iSk state is the ground state. We discuss the comparison between iSk and Sk power spectral densities and observe several key differences in power spectral densities that can contribute to the experimental identification of the state present in the studied sample by measuring the resonance frequencies. This work was supported by the EPSRC's EP/G03690X/1 and EP/N032128/1 grants and the Horizon 2020 European Research Infrastructure project (676541).

MA 65.16 Fri 9:30 P2-OG1

Quantitative Analysis of Magnetic Nanoparticles by Means of the Magnetic Force Microscopy — •Runbang Shao[1], Adrian Schillik[2], Benjamin Riedmüller[1], Ulrich Herr[1], and Berndt Koslowski[2] — [1]Institut für Mikro- und Nanomaterialien, Universität Ulm, Ulm, Deutschland — [2]Institut für Festkörperphysik, Universität Ulm, Ulm, Deutschland

Magnetic force microscopy (MFM) is a powerful tool to analyze magnetic structures down to the nano-scale. Unlike macroscopic magnetic characterization techniques such as SQUID and VSM, which only reveal average magnetic properties of a large ensemble of nanoparticles, MFM is able to characterize a single nanoparticle with respect to magnitude and orientation of magnetization. The recently proposed pseudo-pole model [1], which assumes that the tip can be represented by an infinitely high cone covered homogeneously with dipoles pointing to the tip of the cone, allows quantitative analysis of the cantilever frequency shift versus tip-sample distance curves. Nano-composites of ferromagnetic Co nanoparticles made by inert gas condensation and SiOx cover layers with different layer thicknesses have been investigated. The frequency shift-distance curves agree well with the predictions from the pseudo-pole model, yielding detailed information about size and magnetization of the nanoparticles, as well as their depth below the film surface. It is further demonstrated that superparamagnetic nanoparticles can also be analyzed by this method. [1] Häberle, Thomas, et al. "Towards quantitative magnetic force microscopy: theory and experiment." New Journal of Physics 14.4 (2012): 043044.

MA 65.17 Fri 9:30 P2-OG1

Design of a vector magnetometer for three dimensional magnetization measurements — •Markus Kleinhans, Marco Halder, Christopher Duvinage, and Christian Pfleiderer — Physik-Department, Technische Universitaet Muenchen, 85748 Garching, Germany

In magnetically ordered systems, the fundamental order parameter is the magnetization which is, in general, a three dimensonal vector quantity. Conventional magnetometers, however, typically are limited to the projection of the moment along the applied magnetic field hence missing key informations of systems such as Ising ferromagnets in transvers fields [1]. We report the design of a bespoke set of pickup coils for a vibrating sample magnetometer allowing for the simultaneous determination of all three components of the magnetization for temperatures down to 3 K and in fields up to 9 T. We demonstrate the potential of this technique by studying the anisotropic ferromagnets Co and $Nd_2Fe_{14}B$.

[1] Coldea *et al.*, Science **327**, 5962 (2010).

MA 65.18 Fri 9:30 P2-OG1

Spontaneous and field-induced magnetic phase transitions in $Dy_2Co_3Al_9$ — •D.I. Gorbunov[1], M.S. Henriques[2], C. Salazar Mejía[1], J. Gronemann[1], A.V. Andreev[2], M. Uhlarz[1], Y. Skourski[1], and J. Wosnitza[1,3] — [1]Dresden High Magnetic Field Laboratory (HLD-EMFL), Helmholtz-Zentrum Dresden-Rossendorf, D-01314 Dresden, Germany — [2]Institute of Physics, Academy of Sciences, Na Slovance 2, 182 21 Prague, Czech Republic — [3]Institut für Festkörperphysik, TU Dresden, D-01062 Dresden, Germany

In the crystal structure of $Dy_2Co_3Al_9$, there are various Dy-Dy interatomic distances with similar values. Due to the poorly compensated exchange and anisotropy interactions acting on the Dy spins, a magnetically stable state is difficult to achieve and the system displays a number of spontaneous and field-induced magnetic phase transitions as revealed by means of magnetization, specific-heat, and electrical-resistivity measurements. Antiferromagnetic ordering sets in at the Néel temperature, $T_N = 6.2$ K, followed by two additional phase transitions at 5.2 and 3.7 K in zero field. In applied magnetic fields, new phases emerge. The field-dependent magnetization exhibits multiple jumps accompanied by large magnetoresistance changes. The magnetoresistance can be explained by modified conduction-electron spectra since the conduction electrons interact with the localized magnetic moments.

MA 65.19 Fri 9:30 P2-OG1

Chiral magnetism of Fe intercalated $TaSe_2$ and $NbSe_2$ — •Hemza Kouarta[1,2], Jonathan Chico[2], Hafid Belkhir[1], and Samir Lounis[2] — [1]Faculty of Science, Department of Physics, Laboratory Studies of Surfaces and Interfaces of Solid Materials (LESIMS), University of Badji Mokhtar, P.O. Box 12, Annaba 23000, Algeria — [2]Peter Grünberg Institut and Institute of Advanced Simulation, Forschungszentrum Jülich & JARA, D-52428, Jülich, Germany

Transition metal dichalcogenides have been extensively studied due to the quasi two dimensional structure of the trilayers that compose it. The intercalation of Fe in the Ta(Nb)Se_2 compounds, has been observed to give rise to ferromagnetic (antiferromagnetic) order, and in the case of Ta a large magnetrocrystalline anisotropy energy (MAE) has been measured[1].

We perform fully relativistic first-principles simulations on these two materials considering alloying Nb and Ta at different concentrations, i.e. $Fe_{1/4}Ta_{1-x}Nb_xSe_2$. We investigate the Heisenberg magnetic exchange interactions, Dzyaloshinkii-Moriya interactions and the MAE and shine light on their microscopic origins. All of that with the objective of studying the impact of substitutional disorder in the magnetic properties of these compounds, while also allowing the exploration of the phase transition between the ferromagnetic and antiferromagnetic states present in the stochiometric compounds.

[1] K.-T Ko et al.*Phys. Rev. Lett.*, **107**, 247201 (2011)

MA 65.20 Fri 9:30 P2-OG1

Microscopic View of Magnetic Anisotropy in Permalloy — •Debora C M Rodrigues[1,2], Angela B Klautau[2], Alexander Edström[1], Jan Rusz[1], Lars Nordström[1], Manuel Pereiro[1], Björgvin Hjörvarsson[1], and Olle Eriksson[1] — [1]Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden — [2]Faculty of Physics, Federal University of Pará, Belém, Brazil

Permalloy (Py) is the common name for Fe-Ni alloys, with concentration of 80 % Ni and 20 % Fe, and known due to its vanishingly low magnetic anisotropy energy (MAE) and low damping parameter. Py may be viewed as a huge ensemble of interconnected clusters of Fe-Ni atoms distributed on an fcc lattice. Therefore, by means of relativistic first principles calculations, we investigated the microscopic origin of the vanishingly low magnetic anisotropy of Py. The study was focus on evaluating the orbital moment anisotropy of clusters composed by Fe and Ni, with different configurations, embedded in an effective medium of Py. The MAE is obtained by relating the orbital moment anisotropy and local magnetic anisotropy. As result, we found that the local MAE can be much larger than that of the Py bulk sample, and at least the same order order of magnitude than of Fe or Ni bulk. We discuss these results in terms of local symmetries of the alloy and conclude that the vanishingly small MAE would be the result of a proper configurational average.

MA 65.21 Fri 9:30 P2-OG1

Field-free manipulation of spin structure in perpendicularly magnetized thin films — •Mariia Filianina[1], Samridh Jaiswal[1,2], Tetsuya Hajiri[3], Alexander Kronenberg[1], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany. — [2]Singulus Technologies AG, Kahl am Main, 63796, Germany. — [3]Department of Crystalline Materials Science, Nagoya University, Nagoya 464-8603, Japan

Recently there has been an immense interest for efficient methods of magnetization reversal, in particular by means of electric fields, as recently realized in multiferroic systems. This approach is advantageous because of the low power required without any power-hungry constant current flow. It utilizes so called magnetostrictive coupling, which is the effect of lattice strain on magnetic properties resulting from spin-orbit interaction, such as anisotropy but also the Dzyaloshinskii-Moriya interaction (DMI). The DMI stabilizes chiral spin structures, in particular skyrmions, and possible applications can be facilitated by the control of this interaction [1,2].

In this contribution we report on manipulation of magnetization via electric field induced strain, observed for thin Co20Fe60B20 perpendicularly magnetized film, fabricated on top of the piezoelectric substrate with a W seed layer. The modification of the direct spin structure by strain was imaged by x-ray microscopy to reveal the impact of the strain on the anisotropy and DMI.

1. A. Fert et al., Nat. Nanotechnol. 8, 152 (2013).
2. S. Woo et al., Nat. Mater. 15, 501 (2016).

MA 65.22 Fri 9:30 P2-OG1

Quantifying the electric field induced change of magnetic anisotropy in ultrathin Fe layers — •Mirko Ribow, Liane Brandt, and Georg Woltersdorf — Martin Luther University Halle-Wittenberg, Institute of Physics

The recent discovery of magneto-electric coupling in ultrathin ferromagnet-dielectric heterostructures has opened new ways to control the magnetic properties via electric fields. A possible application of this effect is magnetization control in ultra low power consumption spintronic devices. Here, we report on the quantitative evaluation of the electric field induced change of magnetic anisotropy (ECMA) in Au/MgO/Fe/Au(001) layers grown by molecular beam epitaxy. Fe layers in a thickness range of t = 0 - 7 monolayers were studied. In the analysis special care has been taken to exclude charge trapping effects, which can lead to an overestimation of the ECMA effect. In contrast to an expected 1/t dependence of the effect, our results demonstrate an increasing ECMA as function of thickness. This finding cannot be explained based on a modification of the electronic structure only at the surface of the Fe layer, instead it may be attributed to the electric tuning of quantum well states [1].

[1] U. Bauer et al., Phys. Rev. B., 89, 174402 (2014)

MA 65.23 Fri 9:30 P2-OG1

Probing the Spin Hall Effect of β-Tungsten by Terahertz Emission Spectroscopy — •Oliver Gückstock[1], Tom Seifert[1], Sebastian Dapper[2], Satya Prakash Bommanaboyena[2], Markus Meinert[2], and Tobias Kampfrath[1] — [1]Fritz Haber Institut, MPG, Berlin, Deutschland — [2]Universität Bielefeld, Bielefeld, Deutschland

The efficient conversion of spin into charge currents driven by spin-orbit interaction (SOI) will be highly important for future spin-based electronics [1]. Recently, much effort has been devoted to the identification of new large-SOI materials. One promising material is β-tungsten, for which large spin Hall angles (SHA) have been reported [2]. However, it remains unclear to which extent such a large SHA is caused by an increased SOI or by a decreased longitudinal conductivity. In our experiments, we employ femtosecond optical pulses to trigger ultrafast spin transport in magnetic thin-film stacks. Due to SOI, this spin current is partially converted into a transverse charge current which is monitored by detecting the concomitantly emitted THz electromagnetic radiation [3,4]. In particular, we study THz emission from bilayers of ferromagnetic cobalt-iron-boron and nonmagnetic β-tungsten with varying oxygen concentration. By additionally measuring the THz conductivity of these films, we are able to separate the influence of the spin-Hall conductivity and the longitudinal conductivity to the SHA.

References: [1] S.A. Wolf et al., Science 294.5546 (2001), [2] K. Demasius et al., Nature Comm. 7, 10644 (2016), [3] T. Kampfrath et al., Nature Nanotech. 8, 256 (2013), [4] T. Seifert et al., Nature Phot. 10, 483 (2016)

MA 65.24 Fri 9:30 P2-OG1

Doping of perpendicularly magnetized ferrimagnetic Mn_3Ge thin films — •Jan Balluff, Markus Meinert, and Günter Reiss — Center for Spinelectronic Materials and Devices, Physics Department, Bielefeld University, Germany

The Mn_3Ge compound[1] is interesting for spintronic applications in several ways. It combines a low saturation magnetization of $1\mu_B$ per unit cell with a high coercivity of more than 2T. Furthermore, it shows perpendicular anisotropy, which is preferable, e.g, for spin transfer torque switching in magnetic tunnel junctions. We report on a study of doping the compound to improve the magnetic properties. Using density functional theory we calculate defect formation energies for $Mn_{3-x}Y_xGe$, where Y are different dopants occupying either one of the two inequivalent Mn sites. In the case of Y=Ni, a reduction in the saturation magnetization is predicted.We prepared epitaxial thin films of Ni-doped Mn_3Ge on $SrTiO_3$ substrates using magnetron co-sputtering for different Ni concentrations. Magnetization measurements using a vibrating sample magnetometer reveal the predicted reduction in the magnetization for low Ni concentrations $x \approx 0.2$.

[1] H.Kurt et al., Appl. Phys. Lett. 101, 132410 (2012)

MA 65.25 Fri 9:30 P2-OG1

Magnetocrystalline anisotropy of ultrathin, epitaxial magnetite and iron films on MgO(001) — •Kristina Sprenger, Jari Rodewald, and Joachim Wollschläger — Fachbereich Physik, Universität Osnabrück, Barbarastraße 7, 49076 Osnabrück

Ferrimagnetic materials as magnetite are very important nowadays. Combined with the wide field of spintronics, it's an essential part of technological applications in many facets, for example in the development of non-decaying memories. For that it is very important to know the electric and magnetic properties of iron, magnetite and related materials.

In this work, the focus lies on the fabrication of Fe and Fe_3O_4 layers by reactive molecular beam epitaxy (RMBE) on MgO(001) and analyzing them towards their magnetic properties. For studying their chemical composition, x-ray photoelectron spectroscopy (XPS) is applied and the surface structure of the prepared films is characterized via low energy electron diffraction (LEED). The main focus lies on finding out about the magnetic properties of the thin films by vibrating sample magnetometry (VSM), ferromagnetic resonance (FMR) and the magneto-optical Kerr effect (MOKE).

The approach that is used focusses on the 360° in-plane orientation-dependent behaviour of all three measurement methods. Additionally, the dependency on the film thickness is evaluated. To do so, properties like remanence, coercivity and magnetocrystalline anisotropy, especially shifts in tetramerous and uniaxial anisotropy are analyzed in iron and magnetite films with different layer thicknesses.

MA 65.26 Fri 9:30 P2-OG1

Stripe domains in tetragonally distorted Fe-Co-C films with perpendicular anisotropy — •Volker Neu, Ludwig Reichel, Sebastian Fähler, Rudolf Schäfer, and Kornelius Nielsch — IFW Dresden, Institute for Metallic Materials

The tetragonal distortion of an epitaxially grown Fe-Co-C film introduces a significant perpendicular magnetic anisotropy into the otherwise cubic Fe-Co with low magnetocrystalline anisotropy. Unlike C-free films, which obtain their tetragonal distortion solely from lattice mismatch and which relaxes within a few nm, C-containing films maintain a crystallographic distortion of $(c/a)_{bct} = 1.03$ and a perpendicular magnetic anisotropy of ca. 0.4 MJ/m^3 even up to thicknesses of 100 nm [1]. We present the magnetic domain structure of such a $(Fe_{0.4}Co_{0.6})_{0.98}C_{0.02}$ film prepared on MgO(100) single crystal substrates. It has a thickness slightly above the critical stripe nucleation value, and hence the perpendicular anisotropy leads to a modulation of the out-of-plane magnetization in parallel stripes of 45 nm width, superimposed on large domains oriented in the film plane along the [110] and [1-10] direction. The analysis of such a multiscale domain pattern requires the combination of high resolution magnetic force microscopy (MFM) with its sensitivity to perpendicular stray fields and the large-view vectorial imaging capabilities of Kerr microscopy for inplane magnetization. The details of the 90° and 180° boundaries of the large in-plane domains are resolved by MFM on a sub-50 nm level. [1] L. Reichel *et al.* JAP 116 (2014) 213901.

MA 65.27 Fri 9:30 P2-OG1

Investigation of magnetic properties of epitaxial Fe_3O_4 and Fe_3O_4/NiO bilayers grown on MgO(001) and $SrTiO_3$(001) via VSM — •Kevin Ruwisch, Jari Rodewald, and Joachim Wollschläger — Fachbereich Physik, Universität Osnabrück, Barbarastr. 7, 49079 Osnabrück, Germany

Magnetite as a ferrimagnet has become more important for industrial applications in spintronics over the years. For instance, it is used in magnetoresistive random-access memory (MRAM) consisting of magnetic tunnel junctions (MTJ). Thus, improving the magnetic properties of ferrimagnetic films for spintronic devices is very important.

Hence, in this work Fe_3O_4 and Fe_3O_4/NiO bilayers, grown by reactive molecular beam epitaxy (RMBE) on MgO(001) and $SrTiO_3$(001), are investigated via vibrating sample magnetometry (VSM).

One approach of characterizing the magnetic features of Fe_3O_4 and Fe_3O_4/NiO is to evaluate the impact of NiO towards coercivity, remanence and magnetocrystalline anisotropy. Here, Fe_3O_4/NiO/MgO exhibits 45°-rotated magnetic easy axes in ⟨110⟩ directions while thin magnetite films deposited on MgO(001) have easy axes in ⟨100⟩ directions. Furthermore, the difference in the magnetic properties of magnetite on both substrates is evaluated. It shows that a 45°-rotation, including larger absolute values in coercivity and remanence, takes place on $SrTiO_3$(001) in contrast to MgO(001). Additionally, the influence of the layer thickness of magnetite towards the magnetic behaviour is investigated in in-plane and out-of-plane-orientation with respect to the applied magnetic field.

MA 65.28 Fri 9:30 P2-OG1

Magnetocrystalline anisotropy in the nanolaminated magnetic Mn2GaC MAX phase — •Iuliia Novoselova[1], Ruslan Salikhov[1], Arni S. Ingason[2], Johanna Rosen[2], Ulf Wiedwald[1], Hongbin Zhang[3], and Michael Farle[1,4] — [1]Faculty of Physics, University Duisburg-Essen, Duisburg, Germany — [2]Thin Film Physics Division, Department of Physics, Linköping University, Linköping, Sweden — [3]Institute of Materials Science, Theory of Magnetic Materials Group, TU Darmstadt, Darmstadt, Germany — [4]Center for Functionalized Magnetic Materials, IKBFU, Kaliningrad, Russia

MAX phases ($M_{n+1}AX_n$, n = 1, 2, etc.) are inherently nanolaminated hexagonal compounds composed of early transition metals M, A-group elements and X refers to C or N. Due to the unique structure these materials share properties usually associated with ceramics and metals [1]. Ternary Mn_2GaC magnetic compounds have been synthesized recently as hetero-epitaxial films containing Mn as the exclusive M-element [2]. Using ferromagnetic resonance (FMR) we have studied magnetic anisotropy in the Mn_2GaC in comparison with $(Cr_{0.5}Mn_{0.5})_2GaC$ MAX phase [3]. We find a significant magnetocrystalline anisotropy energy density of 0.5 MJ/m^3 at the temperature below 200 K with the easy axis perpendicular to the c-axis. Such observation can be understood using the perturbation theory based on the first-principles calculations. This work is supported by DFG Grant SA 3095/2-1 and DAAD Programm 57214224. [1] M. W. Barsoum, Prog. Solid State Chem. 28, 201 (2000). [2] A. S. Ingason et al., MRL, 2, 89 (2014). [3] R. Salikhov et al., MRL, 3, 156 (2015).

MA 65.29 Fri 9:30 P2-OG1

Magnetic Anisotropy of Layered Chromium Trihalides — •Nils Richter[1,2], Franziska Racky[1], Daniel Weber[3], Clemens Wuth[4], Bettina V. Lotsch[3,5], and Mathias Kläui[1,2] — [1]Institut für Physik, Johannes Gutenberg Universität, Mainz, Germany — [2]Graduate School of Excellence Materials Science in Mainz, Mainz, Germany — [3]Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany — [4]Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg, Hamburg, Germany — [5]Department of Chemistry and Center for NanoScience, Ludwig-Maximilians-Universität, München, Germany

We comprehensively determine the magnetic properties of single crystals of the isostructural series of the compounds CrI_3, $CrBr_3$ and $CrCl_3$ to obtain a systematic overview. We find a strong anisotropy of the magnetization along different directions. A detailed analysis of the uniaxial anisotropy as a function of temperature between 5K and their respective critical magnetic ordering temperature allows us to explain the temperature evolution of the magnetization along different crystallographic axes. The in-depth understanding of the bulk magnetic properties serves as a basis for the future exploration of few- and monolayer counterparts of these crystals. Such magnetic van-der-Waals materials are extremely important for spintronic and magnetoelectronic applications [1].

[1] Felser, C. et al., Angew. Chem., Int. Ed. 46 (2007).

MA 65.30 Fri 9:30 P2-OG1

Ferromagnetism in Silicon Single Crystals with Positively Charged Vacancy Clusters — •Yu Liu[1], Xinghong Zhang[2], Quan Yuan[2], Jiecai Han[2], Shengqiang Zhou[1], and Bo Song[2] — [1]Helmholtz-Zentrum Dresden-Rossendorf — [2]Harbin Institute of Technology

Defect-induced ferromagnetism provides an alternative for organic and semiconductor spintronics. Here, we investigated the magnetism in Silicon after neutron irradiation and try to correlate the observed magnetism to particular defects in Si. Commercially available p-type Si single crystal wafer is cut into pieces for performing neutron irradiations. The magnetic impurities are ruled out as they can not be detected by secondary ion mass spectroscopy. With positron annihilation lifetime spectroscopy, the positron trapping center corresponding to lifetime 375 ps is assigned to a kind of stable vacancy clusters of hexagonal rings (V6) and its concentration is enhanced by increasing neutron doses. After irradiation, the samples still show strong diamagnetism. The weak ferromagnetic signal in Si after irradiation enhances and then weakens with increasing irradiation doses. The saturation magnetization at room temperature is almost the same as that at 5 K. The X-ray magnetic circular dichroism further provides the direct evidence that Silicon is the origin of this ferromagnetism. Using first-principles calculations, it is found that positively charged V6 brings the spin polarization and the defects have coupling with each other.

MA 65.31 Fri 9:30 P2-OG1

Possible Polaron Percolation in the Diluted Magnetic Semiconductors (Ga,Mn)As and (Ga,Mn)P — •Martin Lonsky[1], Jan Teschabai-Oglu[1], Klaus Pierz[2], Hans Werner Schumacher[2], Ye Yuan[3], Shengqiang Zhou[3], and Jens Müller[1] — [1]Physikalisches Institut, Goethe-Universität, Frankfurt (M), Germany — [2]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

Diluted magnetic semiconductors combine the benefits of semiconducting and magnetic materials and therefore are promising candidates for spintronics applications. For instance, (Ga,Mn)As and (Ga,Mn)P exhibit long-range magnetic order between substitutional Mn ions mediated by holes. Despite intense research efforts, there is no consensus on the development of spontaneous magnetization. An intriguing theoretical concept is the percolation of magnetic polarons as a possible origin [1]. Motivated by results of a diverging 1/f-noise magnitude in the CMR material EuB_6, where the existence of percolating nanoscale magnetic clusters has been demonstrated [2], we study the low-frequency carrier dynamics by fluctuation spectroscopy. Besides insights into the defect physics of the materials, we find a power law scaling of the noise magnitude $S_R/R^2 \propto R^{\omega}$ at the percolation threshold p_c with a critical exponent $\omega = 3.7 \pm 0.3$ for (Ga,Mn)P, which we compare with the results for (Ga,Mn)As with delocalized carriers.

[1] A. Kaminski and S. Das Sarma, Phys. Rev. Lett. 88, 247202
[2] P. Das et al., Phys. Rev. B 86, 184425