MA 46: Magnetic Measurement Methods

Time: Thursday 15:00–18:30 Location: H33

Invited Talk MA 46.1 Thu 15:00 H33

Advanced magneto-optical microscopy: Magnetoelectric sensors, spin-waves, and beyond — •Jeffrey McCord[1], Necdet Onur Urs[1], Mikhail Kustov[1], Babak Mozooni[1], Cai Müller[1], Matic Klug[1], Volker Röbisch[2], Patrick Hayes[2], Dirk Meyners[2], Eckhard Quandt[2], Roland Mattheis[3], Robin John[4], and Markus Münzenberg[4] — [1]Nanoscale Magnetic Materials - Magnetic Domains, Institute for Materials Science, Kiel University, Kiel, Germany — [2]Inorganic Functional Materials, Institute for Materials Science, Kiel University, Kiel, Germany — [3]IPHT Jena, Jena, Germany — [4]Ernst.Moritz-Arndt Universität Greifswald

Recent developments of the observation of magnetic domains and domain walls by wide-field optical microscopy based on the magneto-optical Kerr, Faraday, and Voigt effect are reviewed. Special emphasis is given to the imaging using higher order magneto-optical effects. Fundamental concepts and advances in methodology are discussed that allow for imaging of magnetic domain formation on a wide span of length and time scales, including time-resolved imaging of spin-wave propagation and electric field induced domain wall rotation, and optical induced magnetization reversal. Magneto-optical multi-effect domain imaging techniques are presented. Beyond domain imaging, the use of magneto-optical techniques for local temperature sensing is demonstrated.

15 min. break

MA 46.2 Thu 15:45 H33

Incorporating Nanosecond Time Resolution into Scanning Electron Microscopy with Polarization Analysis — •Fabian Kloodt, Robert Frömter, Susanne Kuhrau, Philipp Staeck, and Hans Peter Oepen — Institut für Nanostruktur- und Festkörperphysik, Universität Hamburg, Jungiusstraße 11, 20355 Hamburg, Germany

The Scanning Electron Microscope with Polarization Analysis (SEMPA) is well established to investigate the magnetic microstructure at surfaces and in ultrathin films. Up to now only stationary measurements over several minutes of acquisition time were feasible. Our instrument is using a LEED-based spin-polarization analyzer, where the intensity of four LEED beams is monitored via single-electron counting and analyzed to calculate the magnetic contrast. Making use of modern fast electronics, the arrival time of each single electron can be determined. In this way the obtained magnetic information can be split up into distinct time slices with respect to the phase of an external periodic voltage that drives the magnetization dynamics at the sample. Results of field-driven excitations of 60nm thick FeCoSiB rectangles in the diamond state as well as squares in the Landau state will be shown and the dynamics of coupled and uncoupled vortex gyration is extracted. A temporal resolution of 700ps is achieved. The present state of the method, limitations and the development potential will be discussed.

MA 46.3 Thu 16:00 H33

Magnetization and Spin Sensitive Real and Momentum Space Imaging in Laser-based Photoemission — •Maximilian Staab[1,2], Dima Kutnyakhov[1], Robert Wallauer[1], Hans Joachim Elmers[1,2], Mathias Kläui[1,2], and Gerd Schönhense[1,2] — [1]Johannes Gutenberg-Universität Mainz — [2]Graduate School Materials Science in Mainz

On the quest to faster magnetic imaging we exploit the magnetic circular dichroism in threshold photoemission (TPMCD) in the excitation by a laboratory-based Ti-sapphire laser, providing circularly polarized light of 1.6 eV and 3.2 eV. The corresponding asymmetries are based on different probabilities of transitions between spin-dependent electronic bands in the near photoemission threshold region. We show spatially resolved PEEM images of the magnetic domain pattern of epitaxially grown ultrathin Co/Pt(111) films. By utilizing time-of-flight momentum microscopy we investigate the electronic transitions that are responsible for the TPMCD effect. The time-of-flight momentum microscope allows for an efficient acquisition of angular-resolved photoemission spectra [1]. Additionally, we perform spin-resolved measurements with this method by reflecting the imaging electron beam at an Ir(001) spin filter crystal. While maintaining the band structure pattern they show an overall high spin asymmetry with a pronounced maximum in a flat band slightly below the Fermi level. The spin polarization and the magnetic circular dichroism are compared with theoretical calculations [2]. [1]G. Schönhense, K. Medjanik, H.-J. Elmers, JESRP, 200, 84-118,(2015) [2]K. Hild et al., Phys. Rev. B 82, 195430,(2010)

MA 46.4 Thu 16:15 H33

Study of Magnetic Vortex Oscillations in Permalloy Disks by Lorentz TEM and Differential Phase Contrast Microscopy — •Johannes Wild, Michael Vogel, Michael Mueller, Christian Back, and Josef Zweck — Institute of Experimental and Applied Physics, University of Regensburg

In a cylindrical nanodisk with a thickness of a few ten nanometers the magnetic ground state is a vortex. The magnetization curls in the plane of the disk either in clockwise or counterclockwise circulation and points out of the plane at the center. The center is called vortex core and there the magnetization can point either up or down.

We structured Permalloy ($Ni_{80}Fe_{20}$) disks on SiN_3 membranes and investigated them in the transmission electron microscope (TEM) while applying an AC spin-polarized current. The quantitative in-plane induction of the disks is imaged in Lorentz TEM mode and with differential phase contrast microscopy (DPC). To our knowledge we show the first DPC measurements of oscillating vortices.

We investigated the behavior of the vortex core oscillation on the applied frequencies and the temperature dependence of the resonance frequency.

MA 46.5 Thu 16:30 H33

Magnetic force microscopy sensors based on nanowire mechanical resonators — •Thomas Mühl[1], Christopher F. Reiche[1], Julia Körner[1], Clemens Gütter[1], and Bernd Büchner[1,2] — [1]Leibniz-Institut für Festkörper- und Werkstoffforschung IFW Dresden — [2]Institut für Festkörperphysik, Technische Universität Dresden

Magnetic force microscopy (MFM) employing monopole-type probes allows for quantitative measurements of derivatives in space of magnetic field components. Furthermore, the concept of bidirectional MFM enables a direct, fast, and quantitative real space mapping of field component derivatives in both the perpendicular and a lateral direction [1, 2]. It relies solely on multiple-mode flexural cantilever oscillations.

Here, we present a new quantitative approach that enables the mapping of one component of the magnetic stray field in real space. This technique is based on the integration of field derivative maps measured at different scan heights. Furthermore, we combine the ease-of-detection and stability of standard cantilevers with the high sensitivity of nanowire mechanical resonators by applying our recently developed co-resonant sensor concept [3] to MFM. The basis of our MFM probes are iron-filled carbon nanotubes that constitute both nanoscale mechanical resonators and monopole-type magnetic probes.

[1] T. Mühl et al., Appl. Phys. Lett. 101, 112401 (2012).
[2] C. F. Reiche et al., New J. Phys. 17, 013014 (2015).
[3] C. F. Reiche et al., Nanotechnology 26, 335501 (2015).

MA 46.6 Thu 16:45 H33

Ultra-thin Magnetic Angle Sensor for On-Skin Interactive Electronics — •Gilbert Santiago Cañón Bermúdez, Dmitriy Karnaushenko, Daniil Karnaushenko, Denys Makarov, and Oliver G. Schmidt — Institute for Integrative Nanosciences, IFW Dresden, Dresden, Germany

Next generation flexible electronic devices aim to become fully autonomous and will require ultra-thin[1] and flexible navigation modules which often rely on magnetic angular sensors for position tracking. Unfortunately, current angle sensors are too thick and rigid, limiting their direct applicability in flexible electronics. In addition, their reliance on magnetically oriented sensing elements complicates their fabrication. Here, we address these challenges by introducing a novel ultra-thin angle sensor, which uses a puzzle-like approach to selectively orient and bond inorganic spin valve stacks onto ultra-thin polymeric films. This method allows us to produce angle detecting devices with thicknesses below 10 um. Furthermore, due to the excellent thermal stability of the polymer film, it is even possible to directly solder to the sensor contacts. Our experiments show that this ultra-thin sensor can withstand harsh treatment conditions while keeping its angle detection functionality. Moreover, it can be mounted on any curved surface or integrated directly on skin as an imperceptible sensoric aid. This feat opens a new door for interactive devices with magnetic cognition which could enhance the perceptual experience of both visually impaired and non-impaired individuals.

[1] M. Melzer et al., Nat. Commun. 6, 6080 (2015).

15 min. break

MA 46.7 Thu 17:15 H33

All-Electric Access to the Magnetic-Field-Invariant Magnetization of Antiferromagnets — •Tobias Kosub[1,2], Martin Kopte[1,2], Oliver G. Schmidt[1], and Denys Makarov[1,2] — [1]IFW Dresden, 01069 Dresden, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, 01239 Dresden, Germany

The rich physics of thin film antiferromagnets can be harnessed for prospective spintronic devices given that all-electric assessment of the tiny uncompensated magnetic moment is achieved. On the example of magnetoelectric antiferromagnetic Cr2O3, we prove that spinning-current anomalous Hall magnetometry serves as an all-electric method to probe the field-invariant uncompensated magnetization of antiferromagnets [1].

We obtain direct access to the surface magnetization of magnetoelectric antiferromagnets providing a read-out method for ferromagnet-free magnetoelectric memory. Owing to the great sensitivity, the technique bears a strong potential to address the physics of antiferromagnets in pristine environments. Exemplarily, we apply the method to access the criticality of the magnetic transition for a Cr2O3 thin film and we reveal the presence of field-invariant uncompensated magnetization even in 6-nm-thin IrMn films clearly distinguishing two contributions. This measurement technique is likely to advance the fundamental understanding of the anomalous Hall and magnetic proximity effects.

Supported by the EU FP7 (ERC Grant No. 306277) and the EU FET Programme (Grant No. 618083).

[1] T. Kosub et al., Phys. Rev. Lett. 115 097201 (2015).

MA 46.8 Thu 17:30 H33

Neutron depolarization imaging of the pressure dependence of $HgCr_2Se_4$ — •Pau Jorba[1], Philipp Schmakat[1], Michael Wagner[1], Alexander Regnat[1], Michael Schulz[2], Vladimir Tsurkan[3], Alois Loidl[3], Peter Böni[1], and Christian Pfleiderer[1] — [1]Technische Universität München, Physik Department, Garching, Germany — [2]Technische Universität München, Forschungsneutronenquelle Heinz Maier Leibnitz, Garching, Germany — [3]University of Augsburg, Center for Electronic Correlations and Magnetism, Augsburg, Germany

The isostructural family of the Chromium spinels (ACr_2X_4) show diverse magnetic ground states due to an interesting variety of competing magnetic interactions between the chromium ions. We report the magnetization of ferromagnetic mercury chromium spinel $HgCr_2Se_4$ up to 1.7 GPa. To extend these data we used high pressure neutron depolarization measurements, allowing us to quantify the evolution of ferromagnetic domains up to 4 GPa and down to very low temperatures. Surprisingly, the critical temperature displays a complex phase diagram, pointing to a loss of ferromagnetism above 3 GPa. Our results demonstrate, on a proof of principle level, the feasibility of combining miniaturized moissanite anvil cells, with neutron depolarization imaging. This paves the way for studies of ferromagnetic and superconducting phases up to very high pressures in a rather simple manner.

MA 46.9 Thu 17:45 H33

The Magnonic Heat Capacity measured by Ferromagnetic Resonance in Metastable Magnetic States — •Benjamin Zingsem, Sabrina Masur, Paul Wendtland, Michael Winklhofer, Markus Ernst Gruner, Ruslan Salikhov, Florian M. Römer, Ralf Meckenstock, and Michael Farle — Faculty of Physics and Center for Nanointegration (CENIDE), University Duisburg-Essen, 47057 Duisburg, Germany

We report on ferromagnetic resonance (FMR) in metastable states and show experimentally that resonant absorption in such magnetic states can be achieved via unconventional angular dependent FMR measurements. Calculations of such an unconventional FMR are compared to experimental results obtained from a 10 nm Fe thin film measured in X-band at temperatures ranging from 50 K to 300 K. In this comparison we find a difference between the critical field and angle configurations at which the metastable states spontaneously decay. We interpret this difference in terms of thermal fluctuations in the real physical system. By applying spin wave theory to calculate the magnonic heat capacity [1] we show that the temperature derivative of the Zeeman energy at these critical points in the experiment is proportional to the magnonic heat capacity, while the difference in the applied field strength at a given angle is given by the thermal fluctuation field [2]. [1] S. M. Rezende et al. Phys. Rev. B, 91 (2015) 104416 [2] S. Bance et al. Applied Physics Letters, 105 (2014)

MA 46.10 Thu 18:00 H33

A co-resonantly coupled sensor for cantilever magnetometry — •Julia Körner[1], Christopher F. Reiche[1], Bernd Büchner[1,2], and Thomas Mühl[1] — [1]Leibniz-Institut für Festkörper- und Werkstoffforschung IFW Dresden — [2]Institut für Festkörperphysik, Technische Universität Dresden

Cantilever magnetometry as a technique to study magnetic properties of samples requires advances due to continuously decreasing sample size. We are presenting a novel approach based on the coupling of a micro- and a nanocantilever with matched resonance frequencies which induces a strong interplay between the two cantilevers [1]. This leads to the possibility of detecting very small magnetic interactions between a sample attached to the highly sensitive nanocantilever and an external magnetic field by measuring the oscillatory state of the microcantilever. We validated the concept by using a commercially availabe silicon cantilever as micrometer sized oscillator and an iron filled carbon nanotube as nanocantilever. Our measurements show an increase in signal strength by several orders of magnitude compared to cantilever magnetometry experiments with similar nanomagnets. With this experiment we do not only demonstrate the functionality of our sensor design but also its potential for very sensitive magnetometry measurements while maintaining a facile oscillation detection with a conventional microcantilever setup [2].

[1] Reiche, Körner et al., Nanotechnology 26 (335501), 2015
[2] Körner et al., submitted to Nanotechnology

MA 46.11 Thu 18:15 H33

Identical wavelength-dependent magnetooptical response of ultrathin permalloy films in multilayer structures on different substrates — Rajkumar Patra[1], Danilo Bürger[1], Roland Mattheis[2], Hartmut Stöcker[3], Fangbin Han[4], Bin Peng[4], Wenxu Zhang[4], Manuel Monecke[5], Georgeta Salvan[5], Stefan Pofahl[6], Rudolf Schäfer[6], Oliver G. Schmidt[1,7], and •Heidemarie Schmidt[1] — [1]Fakultät ETIT, TU Chemnitz — [2]IPHT Jena — [3]TU BA Freiberg — [4]UESTC, China — [5]Fakultät Physik, TU Chemnitz — [6]Metallic Materials, IFW Dresden — [7]Integrative Nanosciences, IFW Dresden

The multilayer systems discussed in this work consist of Ru/permalloy (Py)/Ta stacks on different substrates, namely SiO2/Si and ZnO. The wavelength-dependent on-diagonal elements of the dielectric tensors of all layers in the multilayer systems have been determined from standard ellipsometry measurements and modelling. Below Curie temperature, the wavelength-dependent off-diagonal elements of the dielectric tensor of the Py films are non-zero and odd functions of magnetization. Therefore, we applied vector magnetooptical generalized ellipsometry with a 0.4 T octupole magnet [1] to study the optical anisotropy of the multilayer structures and employed the 4x4 matrix algorithm to characterize the directly measured 4x4 Mueller matrix and to extract the thickness-independent dielectric tensor [2] of the Py thin films. [1] K. Mok, N. Du, H. Schmidt, Rev. Sci. Instr. 82 (2011) 033112; [2] K. Mok, H. Schmidt et al. J. Appl. Phys. 110 (2011) 123110; Phys. Rev. B 84 (2011) 094413