MA 25: Magnetic Imaging

Time: Wednesday 9:30–11:45 Location: H 1012

MA 25.1 Wed 9:30 H 1012

Detecting magnetic flux distributions in superconductors with magnetic scanning x-ray microscopy — •Claudia Stahl[1], Stephen Ruoss[1], Patrick Audehm[1], Markus Weigand[1], Gisela Schütz[1], and Joachim Albrecht[2] — [1]Max Planck Institut für Intelligente Systeme, Heisenbergstr. 3, 70569 Stuttgart — [2]Forschungsinstitut für Innovative Oberflächen, Hoschschule Aalen, Beethovenst. 1, 73430 Aalen

The magnetic flux distribution arising from a high-Tc superconductor is detected and visualized using polarized x rays. Therefore, we introduce a sensor layer, namely, an amorphous, soft-magnetic $Co_{40}Fe_{40}B_{20}$ cover layer, providing a large x-ray magnetic circular dichroism (XMCD). CoFeB is directly deposited on top of high-Tc superconducting YBCO structures [1]. The magnetic stray fields of the supercurrents lead to a local reorientation of the magnetic moments in the ferromagnet. Using polarized x-rays it is possible to measure the local magnetization via the XMCD effect.

We show that the XMCD contrast in the sensor layer corresponds to the in-plane magnetic flux distribution of the superconductor [2] and can hence be used to image magnetic structures in superconductors with high spatial resolution.

The measurements are carried out at our scanning x-ray microscope MAXYMUS and our own dedicated reflectometry endstation at Bessy II at HZB in Berlin.

[1] C. Stahl et al., EPL 106, 27002 (2014). [2] C. Stahl et al., PRB 90, 104515 (2014).

MA 25.2 Wed 9:45 H 1012

X-ray imaging of curved magnetic nanomembranes — •Denys Makarov[1], Robert Streubel[1], Peter Fischer[2], Florian Kronast[3], and Oliver G. Schmidt[1] — [1]Institute for Integrative Nanosciences, IFW Dresden, 01069 Dresden, Germany — [2]Center for X-ray Optics, Lawrence Berkeley National Laboratory, Berkeley CA 94720, USA — [3]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, 12489 Berlin, Germany

Conventionally magnetic films and structures are fabricated on flat surfaces. The topology of curved surfaces has only recently started to be explored and leads to new fundamental physics and applied device ideas. Advancing in this field calls for the understanding of the magnetic responses of thin films on curved surfaces. Here, two basic geometries, i.e. hemi-spherical [1,2] and tubular [3-5], will be addressed. To enable the microscopic characterization of 3D architectures, we put forth the concept of magnetic soft x-ray tomography. This concept will be introduced and the angle- and layer-resolved imaging of 3D shaped tubular architectures [4,5] will be presented.

[1] T. C. Ulbrich et al., Phys. Rev. Lett. 96, 077202 (2006). [2] D. Makarov et al., Appl. Phys. Lett. 93, 153112 (2008). [3] E. J. Smith et al., Phys. Rev. Lett. 107, 097204 (2011). [4] R. Streubel et al., Nano Lett. 14, 3981 (2014). [5] R. Streubel et al., Adv. Mat. 26, 316 (2014).

MA 25.3 Wed 10:00 H 1012

High-Resolution Soft X-ray Holographic Microscope — Kai Bagschik[1], Judith Bach[1], Robert Frömter[1], •Jochen Wagner[1], Leonhard Müller[2], Stefan Schleitzer[2], Jens Viefhaus[2], Christian Weier[3], Roman Adam[3], Gerhard Grübel[2], Claus M. Schneider[3], and Hans Peter Oepen[1] — [1]Institut für Nanostrukturund Festkörperphysik, Universität Hamburg, Germany — [2]DESY, Hamburg, Germany — [3]Peter Grünberg Institut, Forschungszentrum Jülich, Germany

X-ray Fourier transform holography has become a competitive technique to investigate magnetic samples with sub-20 nm spatial resolution exploiting the x-ray magnetic circular dichroism [1]. The obtainable resolution depends on the maximum recorded scattering angle and the size of the reference hole of the optics mask.

Our X-ray holographic microscope, equipped with a large-area CCD camera of 4k × 4k pixels, accepts scattering angle of up to 10°. This corresponds to a maximum $q = 0.66$ nm^{-1} for the L-edge of Cobalt (778 eV). Separated sample and optic mask allow a free movement across the sample [1]. A permanent-magnet assembly enables application of in- and out-of-plane magnetic fields of up to 140 mT [2].

We imaged the domain pattern of Co/Pt and Fe/Pd multilayer films and determined a spatial resolution of (16 ± 1) nm. With this resolution, we could successfully image Co/Pt nanodots with diameters between 30 - 100 nm.

[1] D. Stickler, et al., Appl. Phys. Lett. 96, 042501 (2010). [2] D. Nolle, et al., Rev. Sci. Instrum. 83, 046112 (2012).

MA 25.4 Wed 10:15 H 1012

Quantification of microscopic magnetic and/or electric fields by calibrated DPC measurements — •Felix Schwarzhuber, Johannes Wild, Ralph Schregle, and Josef Zweck — Institute of Experimental and Applied Physics, University of Regensburg

Differential phase contrast microscopy (DPC) in a scanning transmission electron microscope (STEM) allows to obtain detailed information about microscopic electric and/or magnetic field distributions within a specimen. The deflection of the electron beam due to those fields leads to a shift of the diffraction disk in the detector plane, which can be detected using a direction sensitive detector.

In order to retrieve quantitative information about those electric and/or magnetic fields a calibration of the beam deflection as a function of field strength is necessary. We present a simple calibration method which is based on the defined deflection of the convergent electron beam after passing the electric field of a parallel-plate capacitor that is built in a TEM holder. The diffraction disk shift caused by a well known capacitor field at a certain set of microscope parameters allows to derive device specific calibration factors. With this calibrated DPC system it is possible to quantitatively measure fields that cause deflections in the order of microradians.

MA 25.5 Wed 10:30 H 1012

Quantitative measurement of magnetic fields and magnetic moments of nanoparticles by off-axis electron holography — •Zi-An Li[1], Andras Kovcas[2], Alexandra Terwey[1], Rafal E. Dunin-Borkowski[2], and Michael Farle[1] — [1]Faculty of Physics and Center for Nanointegration (CENIDE), University Duisburg-Essen, Germany — [2]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons and Peter Grünberg Institute, Research Centre Jülich, Germany

The quantitative mapping of magnetic fields and the measurement of magnetic moments of individual nanoparticles is critically important, both for the fundamental understanding of nanoscale magnetism and for practical applications. Off-axis electron holography provides direct access to the magnetic field within and around an object of interest in the transmission electron microscope. Here, we use off-axis electron holography to map local variations in magnetic induction within and around individual nanoparticles with close to 2 nm spatial resolution. We apply a contour integration method developed by Beleggia et al. [1] to measure their magnetic moments with an estimated accuracy of better than 1%. The origins of possible statistical and systematic errors in such measurements are discussed [2].

References 1.*M. Beleggia, K. Takeshi, R. E. Dunin-Borkowski. Ultramicroscopy, 110, 425-432, (2010) 2.*Financial support by the European Research Council Grant *IMAGINE* is gratefully acknowledged.

MA 25.6 Wed 10:45 H 1012

Relaxometry imaging of superparamagnetic magnetite nanoparticles using a single qubit — •Dominik Schmid-Lorch[1], Thomas Häberle[1], Andrea Zappe[1], Friedemann Reinhard[1,2], Amit Finkler[1], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut und Forschungszentrum SCoPE, Universität Stuttgart, Germany — [2]Walter Schottky Insititut, Technische Universität München, Germany

We present a novel technique to image superparamagnetic iron oxide nanoparticles via their fluctuating magnetic fields. The detection is based on the nitrogen-vacancy (NV) color center in diamond, which allows optically detected magnetic resonance (ODMR) measurements on its electron spin structure. In combination with an atomic-force-microscope, this atomic-sized color center maps ambient magnetic fields in a wide frequency range from DC up to several GHz [1], while retaining a high spatial resolution in the sub-nanometer range [2].

We demonstrate imaging of single 10 nm sized magnetite nanoparticles using this spin noise detection technique. By fitting simulations (Ornstein-Uhlenbeck process) to the data, we are able to infer additional information on such a particle and its dynamics, like the attempt frequency and the anisotropy constant. This is of high interest to the proposed application of magnetite nanoparticles as an alternative MRI contrast agent or to the field of particle-aided tumor hyperthermia [3].

[1] E. Schäfer-Nolte et al., Phys. Rev. Lett. 113, 217204 (2014)
[2] P. Maletinsky et al., Nat. Nanotech. Vol. 7, 320-4 (2012)
[3] R. Hergt et al., J. Phys.: Condens. Matter 18 S2919-S2934 (2006)

MA 25.7 Wed 11:00 H 1012

Scanning probe magnetic resonance imaging with chemical contrast on the nanoscale — •Thomas Häberle[1], Dominik Schmid-Lorch[1], Friedemann Reinhard[1,2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut und Forschungszentrum SCoPE, Universität Stuttgart, Germany — [2]Walter Schottky Institut, TU München, Germany

We present a novel scanning probe imaging method that employs the nitrogen-vacancy (NV)-center in diamond as an atom-sized magnetic field sensor [1]. This technique extends the range of accessible quantities in scanning probe microscopy to nuclear magnetic spin noise imaging - on arbitrary samples and under ambient conditions. Moreover, the unique properties of different nuclear species allow chemical contrast imaging, while the sensitivity extends below the surface of a sample, thus revealing subsurface features.

We demonstrate NMR imaging with 20 nm resolution conducted on a benchmark sample. Furthermore, we present chemically specific contrast by separating fluorine from hydrogen rich regions, which additionally allows for the detection of subsurface features [2].

[1] Staudacher, T. et al. Science 339, 561-3 (2013)
[2] Häberle, T. et al. arXiv:1406.3324 [cond-mat] 25 (2014)

MA 25.8 Wed 11:15 H 1012

Simultaneous measurement of AMR and observation of magnetic domains with dual Kerr microscopy — •Julia Osten[1,2], Kilian Lenz[1], Jürgen Lindner[1], and Jürgen Fassbender[1,2] — [1]HZDR Institute of Ion-Beam Physics and Materials Research Bautzner Landstr.400 01328 Dresden, Germany — [2]TU Dresden , 01069 Dresden, Germany

Anisotropic magneto resistance (AMR) sensors are widely used in daily life. But the influence of magnetic domains on the AMR is still not fully understood. AMR depends on the direction of the magnetization. For the understanding of the AMR it is therefore important to know about the domain structure. Dual Kerr microscopy is used for the observation of the magnetic domains while at the same time the AMR is measured. Dual Kerr microscopy means that it is possible to measure two magnetization directions at the same time. These two sensitivity directions make it possible to calculate quantitative Kerr images for a complete loop. The investigated samples were magnetic stripe patterned permalloy. The patterning was archived with Cr-Implantation. In addition to the measured resistance the AMR is calculated from the quantitative Kerr images. We also compare the field dependence of the AMR by variation of the magnetic field angle.Our measurements show a clear dependence of the AMR on the magnetic domain types.

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Osten *et al.* Rev. Sci. Instrum. **85**(2014)

MA 25.9 Wed 11:30 H 1012

Investigation of magneto-optical anisotropy of epitaxial Bi-substituted rare-earth iron garnet films — •rajkumar patra[1], h. richert[2], n. du[1], m. lindner[3], r. holzhey[3], m. rabung[4], j. mccord[5], m. matczak[6], r. schäfer[7], o. g. schmidt[7], and h. schmidt[1] — [1]TU Chemnitz — [2]MATESY GmbH — [3]INNOVENT e.V. — [4]IZFP Saarbrücken — [5]University of Kiel — [6]IFMPAN, Poland — [7]IFW Dresden

Bi-substituted rare-earth iron garnet films were grown by liquid phase epitaxy [1]. Magnetooptical (MO) anisotropy of different garnet films was studied by VMOGE with a 0.4T octupole magnet [2]. The MO response is strongest in the composition dependent band gap region and has been modeled with a wavelength dependent, complex MO coupling constant [3]. The MO anisotropy of different garnet films with out-of-plane or in-plane easy axis of magnetization has been studied in the corresponding band gap region by VMOGE measurements by orbiting the magnetic field out-of-plane and in-plane. The differences in the observed MO anisotropy have been confirmed by Kerr microscopy and by Barkhausen Noise and Eddy Current Microscopy (BEMI) measurements. By modeling the VMOGE rotation data we can easily determine the direction of the saturation magnetization in dependence on the direction and amplitude of applied magnetic field. [1] P. Capper et al. (2010) Magneto-Optic Garnet Sensor Films: Preparation, Characterization, Application, in Crystal Growth Technology: Semiconductors and Dielectrics, Wiley, [2] K. Mok, H.S. et al. Rev. Sci. Instr. 82 (2011), [3] K. Mok, H.S. et al., J. Appl. Phys. 110 (2011)