MA 2: Focus Session: Nanomagnetism in the x-ray spotlight

X-ray microscopy allows the application of spectroscopic techniques on length scales far smaller than possible with optical microcopy. X-ray absorption contrast allows element and chemically sensitive imaging, while x-ray magnetic circular dichroism (XMCD) allows direct, highly sensitive detection of the sample magnetization. In x-ray microscopy, these contrast mechanisms can be employed at spatial resolutions below 15 nm, and even better using emergent coherent diffractive imaging techniques. Combining this with pump-and-probe imaging with time resolutions of <50 ps makes x-ray microscopy a universal and powerful tool. In this focus session, the fundamentals of x-ray microscopy, current developments of established and novel techniques and their applications to solve open questions in nanomagnetism are discussed.

Organized by: Joachim Gräfe, Markus Weigand, Eberhard Goering (MPI for Intellligent Systems, Stuttgart)

Time: Monday 9:30–12:45 Location: H 1012

Invited Talk MA 2.1 Mon 9:30 H 1012

Advanced X-ray Optics - Zone Plates, Kinoforms and Computer Generated Holograms — •Kahraman Keskinbora, Umut T. Sanli, Margarita Baluktsian, Gül Dogan, Iuliia Bykova, Markus Weigand, and Gisela Schütz — Max Planck Institute for Intelligent Systems, 70569 Stuttgart, Germany

High penetration depths and short wavelengths of X-rays render X-ray microscopy (XRM) a unique tool in a variety of fields, ranging from materials science to medicine for investigating inorganic and biological matter. The success of XRM was historically built on high-resolution diffractive optics. However, limitations in nanofabrication of high aspect ratio diffractive lenses became a crucial bottleneck. Over the last decade, our group has been developing novel X-ray optics by combining atomic layer deposition and focused ion beam micro-machining techniques to attack this bottleneck from several angles. Resolving 20 to 15 nm features was possible using FZPs fabricated via novel ion-beam-lithography and atomic-layer-deposition methods, respectively. Pushing resolutions of these optics below 20 nm while improving efficiencies is a major goal for us. Here, we will discuss fabrication routes that can help achieve this goal. In addition, we present the nanofabrication processes for point focusing kinoform lenses and kinoforms of higher topological charges, shaping of the intensity profile as well as the phase-front of soft X-rays in order to create beams that carry orbital angular momenta. The challenges and solutions in characterization of these complex X-ray phases will also be discussed.

Invited Talk MA 2.2 Mon 10:00 H 1012

Time-resolved imaging of nanoscale spin textures and spin waves — •Jörg Raabe, Simone Finizio, and Sebastian Wintz — Paul Scherrer Institut, Villigen, Schweiz

The direct imaging of nanoscale spin textures and their dynamics represents a key demand in magnetism research. Scanning transmission x-ray microscopy (STXM) using soft x-rays [e.g. 1] provides unique means for high-resolution, element-selective magnetic imaging, by exploiting diffractive lenses and the x-ray magnetic circular dichroism (XMCD) effect [2]. In particular, time-resolved STXM offers an ultimate combination of spatial and stroboscopic temporal resolution, down to $\Delta r \sim 10$nm, $\Delta t \sim 10$ps. In this contribution, we will present three examples of state of the art dynamic STXM imaging. In the first example, magnetoelastic coupling is used to control the intrinsic anisotropy of a vortex spin texture. This control results in drastic changes of the vortex core gyration frequency and orbit which were directly imaged in the experiment [3]. In the second part, we will show dynamic imaging of a remnant topological bubble at room temperature in a low-pinning iron-nickel alloy with weak perpendicular magnetic anisotropy. Finally, we will present how such topological spin textures can be exploited as natural antennas for the coherent excitation of nanoscale spin waves, which have also been directly observed [4].

[1] J. Raabe et al. Rev. Sci. Instrum. 79, 113704 (2008).
[2] G. Schütz et al. Phys Rev. Lett. 58, 737 (1987).
[3] S. Finizio et al. Phys. Rev. B 96, 054438 (2017).
[4] S. Wintz et al. Nat. Nanotechnol. 11, 948 (2016).

Invited Talk MA 2.3 Mon 10:30 H 1012

Direct observation of magnetic droplet solitons — •Martina Ahlberg[1], Sunjae Chung[1,2,3], Q. Tuan Le[1,2], Ahmad A. Awad[1], Markus Weigand[4], Iuliia Bykova[4], Roman Khymyn[1], Mykola Dvornik[1], Hamid Mazraati[2], Afshin Houshang[1], Sheng Jiang[2], T. N. Anh Nguyen[1,2,5], Eberhard Goering[4], Gisela Schütz[4], Joachim Gräfe[4], and Johan Åkerman[1,2] — [1]University of Gothenburg, Gothenburg, Sweden — [2]KTH Royal Institute of Technology, Kista, Sweden — [3]University Uppsala, Uppsala, Sweden — [4]Max Planck Institute for Intelligent Systems, Stuttgart, Germany — [5]Vietnam Academy of Science and Technology, Hanoi, Vietnam

The magnetic droplet is a localized excitation found in uniaxial ferromagnets where a polarized current provides sufficient spin transfer torque to counteract the inherent damping. This dissipative soliton was first detected in nanocontact spin torque oscillators (NC-STO). The droplet is created underneath the contact and is predicted to have a reversed core where the spins precess at angles almost antiparallel to the initial state. However, the first images of a droplet revealed much smaller precession angles.

In this work we use all-perpendicular NC-STOs and image the spin wave excitation by X-ray microscopy. We observe a fully reversed droplet core, in accordance with theory, while the droplet diameter is twice as big as the expected value. Micromagnetic simulations show that the origin of the enlargement is current-in-plane Zhang-Li torque adding an outward pressure on the droplet perimeter. We also image the evolution of the magnetic state as a function of current and field.

15 minutes break

Invited Talk MA 2.4 Mon 11:15 H 1012

Studying nanomagnets by XMCD PEEM — •Florian Kronast — Helmholtz-Zentrum Berlin für Materialien und Energie

At the nanoscale magnetic materials exhibit novel physical, chemical, electrical, and optical properties that are relevant to a wide variety of applications. Investigations of static and dynamic properties of such low-dimensional structures require spectro-microscopy tools capable of appropriate lateral and temporal resolution, such as the synchrotron based photoemission electron microscope (PEEM) operated at Hemholtz-Zentrum Berlin. The combination of element-specific magnetic contrast with temporal and lateral resolution offers a unique toolbox for magnetic nanoscale science. This paper will present a review on recent activities ranging from the investigation of magnetic nanostructures found in meteorites to the microscopic mechanism behind all-optical magnetic switching and its scalability to the nanometer level.

Invited Talk MA 2.5 Mon 11:45 H 1012

A time-resolved view on magnetic domains and spin textures by x-ray holography — •Stefan Eisebitt — Max Born Institute, Berlin, Germany

Fourier transform X-ray holography is a high resolution imaging technique when performed with soft x-rays.[1] As it is based on interference of an object beam with a reference beam, it requires coherent illumination and is thus particularly well suited for use at 3rd generation and diffraction limited storage rings and free electron lasers. When combined with magnetic contrast via x-ray magnetic circular dichroism, it has been very successfully used for the study of magnetism on the nanometer length scale. I will briefly review the specific capabilities of this imaging approach, where a single hologram can be used to encode images of several samples simultaneously, of a sample seen at differ-

ent x-ray wavelengths, of a sample seen at different times or including 3D information.[2] Results of the first time resolved experiments at synchrotron sources and free electron lasers down to femtosecond temporal resolution will be presented, including work on skyrmions and magnetic data storage [3,4,5] and ultrafast light-induced manipulation of magnetization.[6] [1] S. Eisebitt et al., Nature 432, 885 (2004). [2] B. Pfau and S. Eisebitt, X-ray holography, in: ISBN 978-3-319-14395-8 (2016). [3] B. Pfau et al.:, Appl. Phys. Lett. 99 062502 (2011) & Appl. Phys. Lett. 105 132407 (2014) [4] F. Büttner et al., Nature Physics 11, 225 (2015). [5] F. Büttner et al., Nature Nanotechnology 12, 1040 (2017) [6] von Korff Schmising et al., Phys. Rev. Lett. 112 217203 (2014).

MA 2.6 Mon 12:15 H 1012

Room temperature ferromagnetism in EuO revealed by XMCD — •Patrick Lömker[1], Marek Wilhelm[1], Ronja Heinen[1], Mai Hussein[1], Andrei Gloskovskii[2], Wolfgang Drube[2], Peter Bencok[3], Paul Steadman[3], and Martina Müller[1,4] — [1]PGI-6, FZ Jülich GmbH, Jülich, DE — [2]Photon Science, DESY, Hamburg, DE — [3]DIAMOND Light Source, Oxford, GB — [4]Fakultät Physik, TU Dortmund, Dortmund, DE

The Heisenberg model system EuO is both a 4f ferromagnet and an electric insulator. This rare combination exhibits both fundamentally and technologically exciting properties, however limited to $T < 70$ K. We study interface effects between EuO and the 5d metal Pt and the itinerant 3d ferromagnet Co, enhancing T_C up to room-temperature.

While electron doping is typically utilized to enhance the T_C of EuO, we employ a hole-doped EuO/Pt interface instead. Pt virtual substrates are prepared on $SrTiO_3(001)$, the Pt surface state is observed by LEED. EuO is deposited using the adsorption-limited growth mode. We observe an enhanced T_C with HAX-MCD and check our results with VSM. Our findings agree with a recent DFT study of a Pt/EuO/Pt system, which predicts a 2D hole gas at the EuO/Pt interface and a strong hybridization of the Eu 4f and O 2p bands.

Furthermore, we study the Co/EuO interface with XMCD. The EuO films are grown by a novel redox method on $SrTiO_3(001)$. EuO ferromagnetism at room temperature is observed and we determine the coupling strength and -length revealing a strong magnetic proximity effect between the 3d/4f ferromagnets.

MA 2.7 Mon 12:30 H 1012

Element-specific characterization of Co:FePt nanocomposite magnet films — •Fabrice Wilhelm[1], Veronique Dupuis[2], Damien Le Roy[2], Nora Dempsey[3], and Andrei Rogalev[1] — [1]European Synchrotron Radiation Facility, Grenoble, France — [2]Institut Lumière Matière, Villeurbanne, France — [3]Institut Néel, Grenoble, France

Nanocomposite magnets consisting of a fine mixture of a hard magnetic phase and a high saturation magnetization phase are promising systems to overpass performances of the best permanent magnets. To achieve this aim, it is necessary to confine the soft magnetic phase in grains of typically less than 10nm [1]. Here we report on thorough study of Co:FePt nanocomposite where Co nanoclusters with size of 6 nm constitute the soft magnetic phase which is embedded in L10-FePt matrix. Standard structural (e.g. XRD, SEM, TEM) and magnetic (SQUID magnetometry, MFM) characterizations were complemented with X-ray natural linear dichroism (XLD) and X-ray magnetic circular dichoism (XMCD) spectroscopies at the K-edges of Fe and Co. XLD measurements confirmed that Co is embedded in FePt matrix. XMCD measurements in turn show that Co and Fe atoms are ferromagnetically coupled and that the Co:FePt nanocomposite behaves like a single magnetic phase.

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[1]Skomski R. and Coey J. M. D. Giant energy product in nanostructured two-phase magnets. Phys. Rev. B 48, 15812 (1993).