MA 26: Focus: Towards quantitative magnetic measurements at ultimate spatial resolution with electrons

Organizer: B. Rellinghaus (IFW Dresden)

The decreasing size of functional magnetic materials, the concurrently growing significance of surfaces and interfaces, and novel nanoscale magnetic phenomena (such as skyrmions) cause a steadily increasing demand for ultra-high resolution quantitative magnetic characterization if possible, with atomic resolution. While spin-polarized STM already provides this resolution for the characterization of surfaces, techniques that probe volume magnetic properties are still lacking behind. Here, transmission electron microscopy (TEM) based methods such as electron holography or Lorentz microscopy meanwhile offer significantly improved resolutions even in three dimensions or at low temperatures. The use of inelastically scattered electrons was claimed to even allow for local and element-specific measurements of the magnetic dichroism with up to atomic resolution. The session highlights the current status-quo, potentials and limitations of TEM-based quantitative magnetic measurement techniques with a particular focus on ultimate resolution.

Time: Wednesday 9:30–12:30 Location: EB 202

Invited Talk MA 26.1 Wed 9:30 EB 202

Magnetic measurements at high resolution in an electron microscope: a review. — •Josef Zweck — University of Regensburg, 93040 Regensburg, Germany

This talk will introduce the various techniques which are today available in an electron microscope to yield highly resolved information of magnetic specimens.

While high resolution is usually associated with "high spatial resolution", this is nowadays only one aspect of (magnetic) electron microscopy, and certainly an important one. Beyond spatial resolution, and upon the advent of quantitative magnetic imaging, the second flavour of "high resolution", namely highly resolved measurements of local magnetic information, becomes more and more important.

Magnetic imaging in a TEM originated from the so-called Lorentz microscopy, which gave easy access to micromagnetic configurations on a local scale. It is tuneable in sensitivity, but suffers from being strongly non-linear. It is now complemented by other techniques such as electron holography, differential phase contrast (DPC) and the TIE reconstruction method which allow to exploit both meanings of "high resolution" at the same time.

The techniques will be presented, highlighting their specific advantages and disadvantages, examples of their use will be given.

Invited Talk MA 26.2 Wed 10:00 EB 202

Observation and Manipulation of Magnetic Skyrmions — •Shinichiro Seki — RIKEN Center for Emergent Matter Science (CEMS), Wako, Japan

Magnetic skyrmion is a topologically stable particle-like object, which appears as nanometer-scale vortex-like spin texture in a chiral-lattice magnet. In metallic materials (MnSi, FeGe, Fe1-xCoxSi etc), conduction electrons moving through skyrmion spin texture gain a nontrivial quantum Berry phase, which provides topological force to the underlying spin texture and enables the current-induced manipulation of magnetic skyrmion. Recently, we newly discovered that skyrmions appear also in an insulating chiral-lattice magnet Cu2OSeO3. We find that the skyrmions in insulator can magnetically induce electric polarization through the relativistic spin-orbit interaction, which implies possible manipulation of the skyrmion by external electric field without loss of Joule heating. Such electric controllability, as well as the particle nature and nanometric size, highlights skyrmion as a promising candidate of potential information carrior for next generation of magnetic storage device with high energy efficiency. In this talk, we discuss the imaging of skyrmions with Lorentz transmission electron microscopy (LTEM) technique and their dynamical response under various external stimuli.

15 min. break

Invited Talk MA 26.3 Wed 10:45 EB 202

Visualization Of Three Dimensional Magnetization Of Magnetic Nanostructures — •Charudatta Phatak — Argonne National Laboratory, Chicago, USA

Confinement of magnetic structures geometrically as well as energetically leads to novel and unexpected behavior. With advances in fabrication and lithography tools, magnetic structures can be made in complex, confined three-dimensional (3D) geometries at the nanoscale as well as patterned into a variety of interacting lattices. In order to control their behavior, it is necessary to understand the fundamental physics of such interactions along with the influence of physical shape of the nanostructures in 3D.

Lorentz transmission electron microscopy (LTEM) has been extensively used for characterizing magnetization and domains in magnetic structures as it offers a high spatial resolution along with direct visualization of the magnetization. LTEM combined with phase retrieval can be used to obtain quantitative information about the magnetization and interactions between nanostructures. In this work, we will present results using a dedicated Lorentz microscope equipped with a spherical aberration corrector which offers a highest spatial resolution of 0.5 nm while maintaining the sample in a field free region. In this work, we will present a brief introduction to the vector field tomography technique for 3D visualization of magnetization and demonstrate its application to various magnetic systems such as artificial spin ice lattices, shape memory alloys, and magnetic nanowires.

Invited Talk MA 26.4 Wed 11:15 EB 202

Utilizing chirality to explore local magnetic moments — •Peter Schattschneider — Institute of Solid State Physics, Vienna University of Technology, Vienna, Austria

Energy loss magnetic chiral dichroism (EMCD) is a rather new approach to study element specific magnetic moments with highest spatial resolution. EMCD is detected as an asymmetry in the transition probability to states with positive or negative magnetic quantum numbers (chiral transitions). The technique is similar to its well established relative, X-ray magnetic circular dichroism (XMCD) where the asymmetry appears in the fine structure of ionisation edges of magnetic materials. The observation that chiral electronic transitions break certain mirror symmetries in energy spectroscopic diffraction (ESD) led to the prediction that this breaking pertains in energy filtered high resolution imaging, thus opening the road to mapping spins of individual atomic columns under high resolution conditions in a conventional TEM. This was experimentally demonstrated on magnetite. An important advantage over XMCD is the site specificity, enabling the study of ferri- and antiferromagnets.

One of the intriguing consequences of EMCD is that the outgoing probe electrons have topological charge. Such electrons carry quantized orbital angular momentum, similar to the recently discovered vortex electrons. Vice versa, vortex electrons are a promising probe for atomic resolution spin mapping.

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Invited Talk MA 26.5 Wed 11:45 EB 202

Linking magnetic properties to nanoscale spectral and spatial features — •Thomas Thersleff[1], Jan Rusz[2], Shunsuke Muto[3], and Klaus Leifer[1] — [1]Department of Engineering Sciences, Uppsala University, Box 534, 75121 Uppsala, Sweden — [2]Department of Physics and Astronomy, Uppsala University, Box 516, 75120 Uppsala, Sweden — [3]Division of Energy Science, EcoTopia Science Institute, Nagoya University, Chikusa-ku, 464-8603 Nagoya, Japan

The fundamental questions posed by the field of nanomagnetism demand characterization techniques that are both quantitative and capable of resolving nanoscale features. Electron Magnetic Circular Dichroism (EMCD) in the Transmission Electron Microscope (TEM) is a relatively young technique that promises to meet both of these criteria, and it has already demonstrated quantitative results with a spatial resolution superior to what can be achieved with x-rays. An additional advantage of EMCD is that the scattering geometry in the TEM permits the acquisition of an EMCD signal in parallel to a multitude of additional properties, such as composition, valence, strain, and crystallographic structure. In this talk, we describe an EMCD experimental design that enables these disparate property domains to be directly linked to magnetic behavior on the nanoscale. This allows us to quantitatively map the orbital to spin magnetic moment ratio (m_L/m_S) in real space and correlate it to nanoscale features such as interfaces and the presence of oxide. We also present our progress into the spectral segregation of overlapping EMCD signals from similar materials using blind-source separation techniques.

MA 26.6 Wed 12:15 EB 202

EMCD measurements on ferromagnetic nanoparticles using electron vortex probes — •Darius Pohl[1], Sebastian Schneider[1,2], Jan Rusz[3], Peter Tiemeijer[4], and Bernd Rellinghaus[1] — [1]IFW Dresden, P.O. Box 270116, D-01171 Dresden, Germany — [2]TU Dresden, Institute for Solid State Physics, D-01062 Dresden, Germany — [3]Uppsala University, Department of Physics and Astronomy, SE-752 37 Uppsala, Sweden — [4]FEI Company, PO Box 8066, 5600 KA Eindhoven, The Netherlands

Recently discovered electron vortex beams, which carry a discrete orbital angular momentum (OAM) L, are predicted to reveal dichroic signals. Since electron beams can be easily focused down to subnanometer diameters, this novel technique provides the possibility to quantitatively determine local magnetic properties with unrivalled lateral resolution. As the spiralling wave front of the electron vortex beam has an azimutally growing phase shift of up to 2π and a phase singularity in its axial center, specially designed apertures are needed to generate such non-planar electron waves. We report on the preparation and successful implementation of spiral and dislocation apertures into the condenser lens system of an aberration-corrected FEI Titan[3] 80-300 transmission electron microscope (TEM). This setup allows to perform scanning TEM (STEM) with vortex beams carrying user-selected OAM. First experiments and simulations on the interaction of vortex beams with ferromagnetic FePt nanoparticles reveal both the potential and present limitations of this technique.