MA 25: Magnetic Imaging and Sensors II

Time: Wednesday 9:30–13:00 Location: EB 301

MA 25.1 Wed 9:30 EB 301

Imaging propagating spin waves using NV centers — •Carolina Lüthi[1], Lukas Colombo[1], and Christian Back[1,2] — [1]Physics Department, Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Spin waves, also known as magnons, are collective excitations of the magnetic moments in a material. The study of spin waves is essential for understanding the magnetic properties of materials, as well as their potential applications in spintronic devices.

A promising novel platform for investigating spin waves is the nitrogen vacancy (NV) center in diamond, a defect in the diamond lattice consisting of a substitutional nitrogen atom and a missing carbon atom. It exhibits remarkable properties, such as the ability to detect magnetic fields with high sensitivity and spatial resolution, even below opaque materials, making it an ideal candidate for detecting spin waves.

In this talk, we present how NV centers can be employed to measure spin waves by detecting the magnetic stray field fluctuations arising from the oscillations of spins in a magnetic material. As an example material we use the ferrimagnetic insulator yttrium iron garnet, which is of great importance due to its extreme low intrinsic Gilbert damping. By comparing spin wave measurements using NV centers to spin wave imaging done through the well-established time-resolved magneto-optical Kerr effect, we discuss the advantages and limitations of utilizing NV centers as spin wave sensors.

MA 25.2 Wed 9:45 EB 301

Development of an Ultra High Vacuum and Low Temperature Scanning NV Magnetometer — •Sandip Maity[1], Dinesh Pinto[1,2], Ricardo Javier peña Román[1], Klaus Kern[1,2], and Aparajita Singha[1] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Institut de Physique, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

The nanoscale spatial resolution and ambient condition measurement capabilities of nitrogen vacancy (NV) sensors have enabled us to perform magnetic imaging through scanning probe microscopy (SPM) across a wide range of temperature and pressure. I will be discussing the development of a scanning probe magnetometer, capable of imaging magnetic nanostructures with a high spatial resolution under ultra-high vacuum and low temperature (10^{-10} mbar and 4 K) conditions, enabled with an external vector magnetic field (1 T in z and 0.25 T in both x and y direction). Here, NV centers are integrated within diamond tips to perform Atomic Force Microscopy (AFM). We have used NV tips with a home built tip holder equipped with an AFM amplifier and microwave excitations on the tip (not on the sample), allowing us to have a magnetic image of any region of a sample without restriction. Optically Detected Magnetic Resonance (ODMR) using Zeeman splitting can locally quantify the stray magnetic field from a sample. Additionally, the integrated facilities involving UHV and low temperature capabilities will allow us to investigate the stability of the NV probes and the effects of surface modifications at UHV condition, in a highly controlled manner.

MA 25.3 Wed 10:00 EB 301

SOPHIE: A New Soft X-ray Ptychographic Microspectroscopy Endstation — •Tim A. Butcher, Nicholas W. Phillips, Lars Heller, Mirko Holler, Carlos A. F. Vaz, Armin Kleibert, Simone Finizio, and Jörg Raabe — Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

The SOPHIE (SOft X-ray Ptychography Highly Integrated Endstation) endstation, newly developed at the Swiss Light Source (SLS), is designed for microspectroscopy in the soft X-ray range at synchrotrons. This energy range allows elemental and magnetic sensitivity for measurements involving 3d transition metals, which is key for studies in nanomagnetism. Soft X-ray ptychography is able to deliver a spatial resolution in the order of 5 nm, which can be extended to three dimensional imaging in a laminographic geometry. Currently, SOPHIE is located at the SoftiMAX beamline of MAX IV and will be returned to the SIM beamline after the upgrade to SLS 2.0. The first imaging results and the general capabilities of the endstation will be presented during this talk. This includes the successful imaging of non-collinear magnetic order such as the spin cycloid in bismuth ferrite.

MA 25.4 Wed 10:15 EB 301

Third-order magnetooptic Kerr effect in magnetic thin films — Maik Gaerner[1], Robin Silber[2], Jaroslav Hamrle[3], and •Timo Kuschel[1] — [1]Bielefeld University, Germany — [2]Technical University of Ostrava, Czechia — [3]Charles University, Prague, Czechia

The magnetooptic Kerr effect (MOKE) describes the change of polarization when linear polarized light is reflected from a magnetized sample. This enables to study the reversal processes of the magnetization **M**, image magnetic domain patterns or investigate the dynamics of **M** on short time scales. Here, the linear MOKE (LinMOKE) being proportional to **M** is regularly utilized for investigations of ferromagnetic samples while the quadratic MOKE (QMOKE) being proportional to $\mathbf{M}^2$ [1] is the tool to study antiferromagnetic properties and sense the structural order in Heusler compounds [2].

We recently explored the third-order MOKE, so-called cubic MOKE (CMOKE), being proportional to $\mathbf{M}^3$, which depends on the degree of structural domain twinning [3]. The individual MOKE contributions can experimentally be separated by the eight-directional method, i.e. by applying an external magnetic field in various in-plane sample directions for different orientations of the crystal structure. Within this talk, we will introduce the CMOKE and discuss its dependency on twinning properties, materials and crystal orientations. In addition, we will point out potential future applications of CMOKE.

[1] R. Silber et al., Phys. Rev. B 100, 064403 (2019)
[2] R. Silber et al., Appl. Phys. Lett. 116, 262401 (2020)
[3] M. Gaerner et al., arXiv: 2205.08298

MA 25.5 Wed 10:30 EB 301

Introduction to magnetization measurements with high hydrostatic pressure — •Börge Mehlhorn[1], Markus Hücker[2], Laura Teresa Corredor Bohórquez[1], Anja Wolter[1], and Bernd Büchner[1,3] — [1]Leibniz IFW Dresden, D-01069 Dresden, Germany — [2]Weizmann Institute of Science, IL-7610001 Rehovot, Israel — [3]Institute for Solid State and Materials Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, D-01062 Dresden, Germany

Hydrostatic pressure has become an important addition to the variables that can be controlled in the characterization of novel materials. It allows the lattice parameters of a solid material to be altered without doping or exchanging atoms, potentially leading to the tuning of its physical properties. For many characterization methods technical developments like diamond anvil cells have led to the discovery of new properties in many materials, for example high-pressure superconducting states. Those advances are however not easily transferred to bulk magnetization measurements. Not only is the choice of materials for the fabrication of a pressure device limited, its geometry is also greatly constrained. Sample space, resolvable moment and maximum pressure have to be balanced to fit the specific research goals. This talk gives an introduction to the study of magnetization of a sample that is simultaneously exposed to high magnetic field, low temperature and high pressure. An experiment design tuned to resolve very low magnetic moments of the quasi-2D Heisenberg antiferromagnet La_2CuO_4 are presented as an example.

MA 25.6 Wed 10:45 EB 301

Devices for Correcting Phase Aberration in Longitudinal MIEZE at RESEDA — •Luke Jatho[1], Denis Mettus[1], Lukas Beddrich[2], Johanna K. Jochum[2], and Christian Pfleiderer[1,2] — [1]Physik Department, Technische Universität München, Garching, Germany — [2]Heinz Maier-Leibnitz Zentrum (MLZ), Technische Universität München, Garching, Germany

The RESEDA instrument, situated at the FRM II facility, operates as a resonant spin-echo spectrometer utilizing the MIEZE (Modulated Intensity with Zero Effort) technique in a longitudinal geometry. While RESEDA offers access to a broad range of energy scales, its optimal resolution for momentum-transfer vectors is primarily concentrated at small scattering angles. Recent advancements have demonstrated the extension of the accessible scattering angle range through the incorporation of Magnetic Wollaston Prisms (MWPs) [1]. However, MWPs are not suited for longitudinal MIEZE. Consequently, there is a pressing need to develop a similar device capable of providing spatial-intensity modulation capabilities within the L-MIEZE geometry. In this contribution, we explore various magnetic coil configurations designed to generate the required field gradient and present the results of numerical simulations. [1] F. Li, J. Appl. Cryst. (2022). 55, 90-97

MA 25.7 Wed 11:00 EB 301

Portable devices for adding Spatial-Intensity-Modulation-mode capabilities to polarized neutron beams — •Denis Mettus[1], Jonathan Leiner[2], Johanna Jochum[3], Lukas Beddrich[3], and Christian Pfleiderer[1] — [1]Physik-Department, Technische Universität München, D-85748 Garching, Germany — [2]Oak Ridge National Laboratory, Oak Ridge, TN 37830, United States — [3]Heinz Maier-Leibnitz Zentrum (MLZ), Technische Universität München, Garching, Germany

The Modulated IntEnsity with Zero Effort (MIEZE) resonant spin-echo technique implemented at the RESEDA instrument at the FRM II has its optimum resolution at small scattering angles, i.e. SANS geometries. To extend the application of MIEZE to larger scattering angles, the incorporation of magnetic Wollaston prisms (MWPs) has been suggested which would allow correction of the neutron time of flight differences restoring the signal contrast [1]. In addition to that, MWPs promises to be useful in such applications as measuring diffraction peaks with enhanced resolution at Larmor diffraction instruments, improving the resolution of small angle neutron scattering instruments, or in the context of intra-particle mode-entangled neutron beams for potential use in probing many-body quantum entanglement in materials. In the following contribution, we present the progress of the MWPs construction for use at FRM II, and describe the details of their operation and the various possibilities they offer.

[1] Fankang Li, J. Appl. Cryst. 55, 90-97 (2022).

15 min. break

MA 25.8 Wed 11:30 EB 301

Planar Hall effect sensors enabling improved Magnetic Particle Tracking — •Jan Schmidtpeter, Yevhen Zabila, Denys Makarov, and Thomas Wondrak — Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Dresden Germany

Magnetic Particle Tracking is able to track the position and orientation of magnetic particles in opaque media by measuring the magnetic field outside the vessel. This technique was already applied in granular flows with a magnet of 8 mm^3 volume [1]. The extension of this technique to flotation, which is used in ore processing and recycling, requires magnetic particles in sub-mm range, which float with the foam. The vessel diameter of 100 mm demands for sensors with a resolution in the order of nT. Thin-film sensors reduce the distance from the sensor to the magnet. We will present in detail a newly developed measurement system with an array of 12 tailored planar Hall magnetoresistive sensors with a measurement range from 300 μT down to 10 nT and demonstrate the reliable detection of the position of a cubic magnet with edge length of 0.4 mm. The sensors consist of single layer permalloy in a 5 ring Wheatstone bridge configuration. Furthermore, we will show preliminary results of an sensor array on a flexible substrate [2], which can be easily and accurately placed around a complex shaped vessel.

[1] Buist, et al. AIChE Journal 60.9 (2014): 3133-3142.
[2] Granell, et al. npj Flexible Electronics 3.1 (2019): 3.

MA 25.9 Wed 11:45 EB 301

Green transferring of GMR sensors onto arbitrary substrates with loss-free performance and mechanical robustness for interactive electronics — •Olha Bezsmertna[1], Rui Xu[1], Eduardo Sergio Oliveros-Mata[1], Clemens Voigt[2], Sindy Mosch[2], Mykola Vinnichenko[2], and Denys Makarov[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf e.V., 01328 Dresden, Germany — [2]Fraunhofer Institute for Ceramic Technologies and Systems IKTS, 01277 Dresden, Germany

Recent progress in branch of flexible electronics led to the expansion of its applications in artificial intelligence, the Internet of Things (IoTs), wearable electronics, etc. Flexible magnetic field sensors enable new generation of devices based on touchless interaction [1, 2]. However, integration of highly-sensitive magnetic sensors into non-planar surfaces still remains challenging. Although transfer printing method has been adopted to diversify the applicable substrates, the selection freedom is still limited. We propose a green transfer printing method, capitalizing on the following features: 1) our technique only relies on biocompatible water and does not resort to any additional treatments; 2) sensors can be transferred onto arbitrary substrates without performance degradation; 3) the transferred sensors have robust mechanical stability. Thanks to the above advantages, the magnetic sensors demonstrate promising potentials in on-skin electronics as human-machine interfaces, smart agriculture and household IoTs applications.

[1] Xu, R. et al. Nat. Comm., 13(1), 6587 (2022); [2] Cañón Bermúdez, G. S. et al. Adv. Funct. Mat., 31(39), 2007788 (2021).

MA 25.10 Wed 12:00 EB 301

Eco-sustainable Printed Magnetoresistive Sensors — •Lin Guo, Rui Xu, Eduardo Sergio Oliveros Mata, Xuan Peng, Proloy Taran Das, Xilai Bao, Ihor Veremchuk, Larysa Baraban, and Denys Makarov — Helmholtz-Zentrum Dresden-Rossendorf e.V.,01328 Dresden, Germany

As an important member of printed electronics, printed magnetic sensors have revealed potential in industrial production, consumer electronics, etc, relying on large scale, low cost and high production fabrication[1]. However, the escalated demand and short lifespan for electronics contribute significantly to the accumulation of electronic waste, meanwhile magnetic sensors usually contain hazardous elements. Therefore, there is a growing demand for eco-sustainable printed magnetoresistive sensors. Firstly, we introduced self-healing property to printed magnetoresistance sensors to extend their lifetime[2]. Going a step further, here we designed biocompatible and biodegradable printed magnetic sensors to address the e-waste issues using non-toxic iron particles bonded with edible starch. Benefiting from a completely eco-friendly printing process and food-grade materials, these sensors can be applied not only on conventional substrates but also on surfaces like plants, human skin, and nails, furthermore they demonstrate washability and degradability in aqueous environments. By virtue of these advantages, we demonstrated their application as customized speedometers, IoTs, and human-machine interfaces.

[1]D. Makarov et al, ChemPhysChem 2013, 14, 1771. [2]R. Xu, et al, Nature Communications 2022, 13, 6587.

MA 25.11 Wed 12:15 EB 301

Magnetic field mapping with a GMR sensor array: "An IR-camera analogy" — •Laila Bondzio[1], Torben Tappe[1], Holger Sachs[2], Bernd Rebhorn[2], and Andreas Hütten[1] — [1]Bielefeld University, Bielefeld, Germany — [2]Messtechnik Sachs GmbH, Schorndorf, Germany

Giant Magnetic Resistance multilayer systems of Py/Cu-bilayers exhibit nearly triangular shaped GMR curves with a high sensitivity, which is desirable for sensor applications. With a grid of multiple sensor elements a two dimensional magnetic landscapes can be mapped as changes in a magnetic field with an output image similar to an IR-camera. The challenging aspect for such an application is the necessity to cover a relatively large area of few centimeters with sensor elements. To organize and contact this large number of sensor elements the structures can be sputtered directly onto contacts on a circuit board. Using an optimized buffer system ontop of a not ideal substrate improves the GMR effect and provides a foundation for a CPP (current perpendicular to plane) configuration.

MA 25.12 Wed 12:30 EB 301

Sensing of magnetic excitations in 2D-materials with NV spins — •Hossein Mohammadzadeh, Dominik Maile, and Joachim Ankerhold — Institute for complex quantum systems (ICQ), University of Ulm, Ulm, Germany

Magnetism in two-dimensional (2D) van der Waals (vdW) materials has recently emerged as one of the most promising areas in condensed matter research, with a significant potential for applications ranging from topological magnonics to low-power spintronics, quantum computing, and optical communications [1]. In this talk, we theoretically investigate the possibility of sensing magnetic excitations in such materials with nitrogen-vacancy (NV) center in diamond. The NV center in diamond is an excellent platform for noninvasively detecting nano-scale signatures and magnetic domain walls [2]. We present a description of the low-energy magnetic excitations within a Kitaev-Heisenberg model for a honeycomb lattice. Coupling these excitations to the single NV-electronic spin paves the way to use magnetic noise spectroscopy to probe magnons in such a system. Utilizing Fermi*s golden rule and quantum linear response theory, we show how the spin relaxation time of the NV alters in the magnetic field induced by magnons in both bulk and topologically protected edge states. The relaxation time of the NV changes by different NV-sample distances and in various strengths of spin-spin interactions inside the material. [1] Qing Hua Wang et al., ACS Nano, 16, 5, 6960-7079 (2022)

[2] Jörg Wrachtrup et al. Nat Commun 12, 1989 (2021)

MA 25.13 Wed 12:45 EB 301

Directly mapping of magnetization dynamics in chiral three-dimensional magnetic nano double helices — •Imelda Pamela Morales Fernandez[1], Sandra Ruiz Gomez[1], Claudia Fernandez Gonzalez[1], Elina Zhakina[1], Markus König[1], Aurelio Hierro Rodriguez[2], Simone Finizio[3], Sebastian Wintz[4], Claas Abert[5], Dieter Suess[5], Amalio Fernandez-Pacheco[6], and Claire Donnelly[1] — [1]MPI CPFS, Dresden, Germany — [2]Universidad de Oviedo, Spain — [3]PSI, Switzerland — [4]HZB BESSY II, Germany — [5]University of Vienna, Austria — [6]TUWien, Austria

The expansion of nanomagnetism into the third dimension provides exciting opportunities beyond the physics of planar systems. Here, we experimentally explore the magnetic properties of three-dimensional double-helix (DH) nanostructures, which can host an exotic magnetic configuration featuring pairs of highly coupled domain walls(CDWs). Here we consider the magnetization dynamics on the nanosecond time-scale within the 3D-DH nanostructure. Specifically, we harness three-dimensional nanofabrication techniques to manufacture cobalt nano-double-helices onto striplines and subject them to high-frequency magnetic field excitations. Utilizing time-resolved scanning transmission X-ray microscopy, we map the magnetization dynamics on the three-dimensional nanostructure in real space, revealing localized enhanced dynamics in the positions of CDWs within the DH conduit, that depend on the geometry of the nanostructure and the excitation. These initial findings provide exciting insight into the physics and opportunities for the future of 3D magnetization dynamics.