MA 41: Magnetic Textures: Statics and Imaging II

Time: Thursday 9:30–13:15 Location: H37

MA 41.1 Thu 9:30 H37

Tunig the chiral orbital magnetization of single magnetic skyrmions with atomic defects — •Imara Lima Fernandes and Samir Lounis — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany

Magnetic skyrmions are localized topologically protected non-collinear spin textures with particle-like properties. Recently, an optical experimental was proposed to access the topological nature of skyrmions by measuring the orbital magnetic moment generated by the non-collinearity of the spin magnetic moments [1]. Such a chiral orbital moment is independent of the strength of spin-orbit interaction and acquires a topological nature for large skyrmions [1,2]. Following our previous work [3], we explore from a full *ab initio* approach the effect of *3d* and *4d* transition metal defects interacting with realistic single magnetic skyrmions generated in PdFe bilayer deposited on Ir(111). We investigated the two main factors contributing to the chiral/topological orbital magnetization of skyrmions, namely the intertwining of the electronic structure properties with the three spin scalar chirality and possibly higher order chiralities.

[1] M. dos Santos Dias et al., Nat. Comm. **7**, 13613 (2016); [2] M. dos Santos Dias, S. Lounis, SPIE 10357, 103572A (2017); [3] I. Lima Fernandes et al., Nat. Comm. **9**, 4395 (2018).

– Funding from the ERC under the European Union's Horizon 2020 research and innovation programme (ERC-consolidator grant 681405 - DYNASORE).

MA 41.2 Thu 9:45 H37

Thermal stability of skyrmions in chiral magnets and frustrated magnets — Benjamin Heil, Achim Rosch, and •Jan Masell — Institut für Theoretische Physik, Universität zu Köln, Köln, Deutschland

Magnetic skyrmions are particle-like textures in the magnetization which are characterized by a topological winding number. Skyrmions have been observed on scales ranging from nano- to micrometers and from cryogenic temperatures up to room temperature. The combination of properties like small size, topological quantization, and efficient manipulation makes them interesting candidates for applications in future information technology devices.

The topological winding number implies that - in a continuous model for the magnetization - a skyrmion can not be erased smoothly. This property is often argued to provide them with an extraordinary stability against thermal fluctuations. We calculate the minimal energy barrier for the destruction/creation of two species of skyrmions which are stabilized by (i) Dzyaloshinskii-Moriya or (ii) frustrated exchange interactions. We show that the energy barriers remain finite even in the continuous limit and provide an expression for the saddle point configuration. In particular we show that, in the absence of frustration, the micromagnetic saddle point is independent of the external magnetic field.

MA 41.3 Thu 10:00 H37

Modulated Magnetic Structures in GaV_4S_8 and GaV_4Se_8 as Seen by Lorentz Transmission Electron Microscopy — •László Balogh[1], Markus Preissinger[2], Vladimir Tsurkan[2], István Kézsmárki[2], Sándor Bordács[1], Ádám Butykai[1], Franziska Harder[3], Felix Börrnert[3], Daniel Wolf[3], and Axel Lubk[3] — [1]Department of Physics, Budapest University of Technology and Economics — [2]Zentrum für Elektronsiche Korrelation und Magnetismus, Institut für Physik, Universität Augsburg — [3]Institute for Solid State Research, Leibniz-Institut für Festkörper- und Werkstoffforschung Dresden

Among bulk materials the lacunar spinel GaV_4S_8 was the first compound in which Néel-type skyrmions were observed. Although Lorentz transmission electron microscopy (L-TEM) is found to be an excellent probe to study the structure and dynamics of Bloch skyrmions, the L-TEM imaging of the Néel-type modulations in lacunar spinels has so far been elusive. Here, we present a L-TEM study of the magnetic textures in GaV_4S_8 and GaV_4Se_8. On thin platelet samples we found that a modulated magnetic order developes below 40 K, which is two times higher compared to bulk crystals. By probing both the local magnetic and crystal structures the coupling between the spin and lattice degrees of freedom was studied in these multiferroic compounds.

MA 41.4 Thu 10:15 H37

Ordering Temperature and Skyrmions in Thin Lamellas of $GaMo_4S_8$ — •Markus Preissinger[1], Vladimir Tsurkan[1], István Kézsmárki[1], László Balogh[3], Sándor Bordács[3], Hiroyuki Nakamuro[4], Franziska Harder[2], Felix Börrnert[2], and Axel Lubk[2] — [1]Zentrum für Elektronsiche Korrelation und Magnetismus, Institut für Physik, Universität Augsburg — [2]Institute for Solid State Research, Leibniz-Institut für Festkörper- und Werkstoffforschung Dresden — [3]Department of Physics, BME Faculty of Natural Science, Budapest University of Technology and Economics — [4]Department of Materials Science and Engineering, Kyoto University

Lacunar spinels are the first compounds found to host Néel-type skyrmions in their bulk forms. The Néel-type character of the skyrmions is a consequence of the polar rhombohedral distortion of their high-temperature cubic structure. Using Lorentz transmission electron microscopy, in thin lamellas of $GaMo_4S_8$ we found that the magnetic ordering temperature is 3 times higher compared to bulk crystals. Moreover, instead of Néel-type skyrmion lattices observed in bulk crystals with a typical periodicity of 10-20nm we found Bloch-type skyrmion crystals with lattice constants about 200nm. The change in the character of the skyrmions implies a chiral crystal structure realized in thin lamellas.

MA 41.5 Thu 10:30 H37

Zero-field magnetic skyrmions in RhCo films on Ir(111) — Marco Perini[1], André Kubetzka[1], Sebastian Meyer[2], Stephan von Malottki[2], Stefan Heinze[2], Roland Wiesendanger[1], and •Kirsten von Bergmann[1] — [1]Department of Physics, University of Hamburg, Germany — [2]Institut für Theoretische Physik und Astrophysik, University of Kiel, Germany

Magnetic skyrmions can be stablized in thin films by interface-induced Dzyaloshinskii-Moriya interactions that compete with exchange interactions. Such skyrmions can become lowest energy states in applied magnetic fields but are only metastable configurations in zero magnetic field.

We have studied the magnetic properties of a RhCo atomic bilayer on Ir(111) using spin-resolved scanning tunneling microscopy. Depending on the stacking of the Rh monolayer we observe a significant number of domain walls with unique rotational sense in the otherwise out-of-plane magnetized film. The path of these domain walls is typically not straight. We also observe small circular magnetic objects in the virgin state. They coexist in both oppositely magnetized ferromagnetic domains and resemble zero-field magnetic skyrmions with up- or down-pointing core. Ab-inito calculations in combination with spin dynamics simulations shed light on the origin of these unusual properties.

MA 41.6 Thu 10:45 H37

New findings in the magnetic phase diagram of GaV_4Se_8 — •Bertalan György Szigeti[1], Sándor Bordács[2], Ádám Butykai[2], Korbinian Geirhos[1], Jonathan Stuart White[3], Peter Lunkenheimer[1], Vladimir Tsurkan[1], Martino Poggio[4], and István Kézsmárki[1] — [1]Experimental Physics V, Center for Electronic Correlations and Magnetism, University of Augsburg, 86135, Ausgburg, Germany — [2]Department of Physics, Budapest University of Technology and Economics, 1111, Budapest, Hungary — [3]Laboratory for Neutron Scattering and Imaging, Paul Scherrer Institut, CH-5232, Villigen, Switzerland — [4]Department of Physics, University of Basel, 4056, Basel, Switzerland

GaV_4Se_8 is a member of the lacunar spinel family, which was found to host a robust Néel-type skyrmion lattice (SkL) on the full temperature range below the paramagnetic state down to zero kelvin and on a wide field range, even in oblique field directions[1]. This wide stability range is due to the polar, easy-plane anisotropic nature of GaV_4Se_8. In oblique magnetic fields we observed an additional modulated phase besides the cycloidal and the SkL states, using small-angle neutron scattering, magnetic torque, magnetization and magnetocurrent measurements. The formation of this novel modulated phase shows strong connection with the reorientation process of the modulation vectors.

[1] Bordács, S., et al., Sci. Rep. 7.1, 7584 (2017)

MA 41.7 Thu 11:00 H37

Observation of Skyrmion nucleation and manipulation by Ultrafast laser pulse — •Mohamad-Assaad Mawass[1], Nina Novakovic[1], Alexander Steigert[1], Oleksii Volkov[2], Denys Makarov[2], and Florian Kronast[1] — [1]Helmholtz-Zentrum Berlin für Materialen und Energie, Berlin, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf e.V., Dresden, Germany

Skyrmions are topologically protected magnetic entities, particle-like magnetization structures. They are considered as potential candidates for spintronic devices e.g. racetrack memories. While the controlled formation and motion of skyrmions is a key issue for the functionality of such devices, the conventional approach to generate and stabilize skyrmions in thin magnetic materials mostly leads to multiple and randomly distributed skyrmions (skyrmions cluster) without control on the formation or annihilation of individual entities. Here we provide a direct experimental visualization of ultrafast nucleation of individual Skyrmions by local laser heating at room temperature (RT) using a tunable fs-Laser beam in ultrathin ferromagnetic system employing X-ray Photoemission Electron Microscope (XPEEM). Furthermore, using the advantage of the all-optical helicity-dependent switching (AO-HDS) in which a circularly polarized femtosecond laser pulse switches the magnetization of a ferromagnetic thin film as function of laser helicity, we show for the first time writing and erasing one single Skyrmionic bubble domain controlled by the laser chirality at a specific laser condition at RT.

15 min. break

MA 41.8 Thu 11:30 H37

Skyrmion meets magnetic tunnel junction: an efficient way for electrical skyrmion detection investigated by ab initio theory — •Jonas F. Schäfer, Philipp Risius, Michael Czerner, and Christian Heiliger — Institut für Theoretische Physik, JLU Giessen

Building devices based on skyrmions requires a sufficiently sensitive detection method. The most straightforward way would be a device based on tunnel magnetoresistance, where a second magnetic electrode has to be used. However this approach is not practical since the magnetic counter electrode is most likely going to interfere with the skyrmion. This issue can be overcome by nonmagnetic counter-electrodes, which detect skyrmions from their non-collinear magnetization. Up to now, skyrmion induced non-collinear effects on transport were only investigated for STM tips based on the Tersoff and Hamann model, reaching about 20% for specific energies. In our work we examine the effects of skyrmions on electronic transport in Cu/Fe/MgO/Cu, Cu/Fe/MgO/V and V/Fe/MgO/Cu tunnel junctions, incorporating the influence of the barrier and the non-magnetic reference electrode material. Using our KKR based NEGF code, we show that non-collinear effects on transport strongly depend on the material of the leads, beyond energy dependent variations in the density of states. While for the copper electrodes only a variation in conductivity of a few percent can be reached, for vanadium the effect reaches up to 125% and is large over a wide energy range. The calculated large effect for vanadium is quite surprising and motivates further investigation.

MA 41.9 Thu 11:45 H37

High-resolution tunneling electron charge and spin transport theory of various skyrmions — •Krisztián Palotás — Wigner Research Center for Physics, Hungarian Academy of Sciences, Budapest, Hungary — Budapest University of Technology and Economics, Budapest, Hungary — University of Szeged, Szeged, Hungary

Based on a combined charge and vector spin transport theory [1] capable of imaging noncollinear magnetic textures on surfaces with spin-polarized scanning tunneling microscopy (SP-STM) [2], the high-resolution tunneling electron charge and coupled spin transport properties [3] of a variety of Néel- and Bloch-type skyrmions are investigated [4]. The chosen axially symmetric skyrmions belong to the same topology class, having a vorticity value of 1. It is demonstrated that the SP-STM images can be used to determine the helicity of the skyrmions. Moreover, the modified spin polarization vectors of the conduction electrons due to the local chirality of the complex spin texture are incorporated into the tunneling model. It is found that this effect modifies the apparent size of the skyrmions. These results contribute to the proper identification of topological surface magnetic objects imaged by SP-STM, and deliver important spin transfer torque vector parameters for current-induced spin dynamics.

References: [1] K. Palotás et al., Phys. Rev. B 94, 064434 (2016). [2] K. Palotás et al., Phys. Rev. B 96, 024410 (2017). [3] K. Palotás et al., Phys. Rev. B 97, 174402 (2018). [4] K. Palotás, Phys. Rev. B 98, 094409 (2018).

MA 41.10 Thu 12:00 H37

Skyrmions in 2D chiral magnets stabilized by tilted magnetic field — •Vladyslav Kuchkin[1], Filipp Rybakov[2], Stefan Blügel[1], and Nikolai Kiselev[1] — [1]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Department of Physics, KTH-Royal Institute of Technology, SE-10691 Stockholm, Sweden

Chiral magnets are known to host a variety of different nontrivial localized magnetization configurations possessing particle-like properties, which can be effectively manipulated by various external stimuli. The corresponding model Hamiltonian contains contributions of Heisenberg exchange, Dzyaloshinskii-Moriya interaction and Zeeman energy. In the current work, we consider 2D chiral magnets in the presence of tilted magnetic fields. Using the micromagnetic approximation allows reducing the problem to the system of partial differential equations, which can be analyzed with accurate analytical methods. This approach allowed us to study the long-range interaction between the skyrmions of different types and their stability as a function of the angle and strength of the tilted magnetic field. The combination of the analytical approach with numerical simulations allowed us to obtain the phase diagrams, the coexisting regions of magnetic skyrmions with different topological charges, as well as to describe the interaction potential between them. The presented results are important for both fundamental research as well as practical applications of magnetic skyrmions.

MA 41.11 Thu 12:15 H37

Small Skyrmions at room temperature: Realistic skyrmion lifetimes from the atomistic model — •Markus Hoffmann[1], Gideon P. Müller[1,2], and Stefan Blügel[1] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Science Institute of the University of Iceland, VR-III, 107 Reykjavík, Iceland

Chiral magnetic skyrmions are of great scientific interest but also of potential relevance in information technology, data storage, processing, and neuromorphic computing. To compete with existing technology, those skyrmions have to fulfill stringent requirements: Long lifetimes at room temperature at sizes smaller than 10 nm. Therefore, a significant effort of the magnetism community lies on the analysis of the stability of such small skyrmions. So far [1,2], mainly the micromagnetic model was employed. Here, we go beyond the micromagnetic limit, using the atomistic Heisenberg-type spin-lattice Hamiltonian. We show that the range and the frustration of magnetic interactions as well as structural aspects provide a bright outlook for lifetime dependence on the materials properties. For this, we perform LLG, GNEB and HTST calculations within our Spirit code [3].

We acknowledge funding from the DARPA TEE program through grant MIPR (#HR0011831554) from DOI.

[1] F. Büttner *et al.*, Sci. Rep. **8**, 4464 (2018)
[2] A. Bernand-Mantel *et al.*, SciPost Phys. **4**, 27 (2018)
[3] Spirit spin simulation framework, spirit-code.github.io

MA 41.12 Thu 12:30 H37

Co/Pt/W and Co/Pt/Ir multilayers as host materials for potential Skyrmion devices — •Valentin Ahrens, Simon Mendisch, Martina Kiechle, Ádám Papp, and Markus Becherer — Technische Universität München(TUM), Chair of Nanoelectronics, Arcisstr. 21, 80333 Munich, Germany

Perpendicular magnetized, room temperature sputtered, Co/Pt/Ir and Co/Pt/W multilayers are investigated as a potential host for skyrmions. Basic investigations on the magnetic properties (H_c, K_{eff} and IEC), of single and bilayer stacks were performedin order to promote a better understanding of those multilayer systems. These properties are assessed by means of magneto-optical Kerr effect(MOKE) measurements and K_{eff} is fitted from anomalous hall effect (AHE) measurements. Furthermore the hysteretic behaviour of nanostructured films is investigated using a laser-MOKE. By means of FIB irradiation (Ga^+), the anisotropy of the nanostructures is locally decreased to form artificial nucleation centers. This allows to explicitly tune the interlayer exchange coupling (IEC) from FM to AF by means of Ga^+ radiation. This tunability is highly sensitive to the Ga^+ ion dose. Different multilayer stacks are evaluated according to their ability to host skyrmions. To reach certain domain states the samples are

demagnetized by a linearly decreasing oscillatory magnetic field. By application of field pulses of different length t_{pulse} and strength B_{pulse} the domains are transformed into skyrmions. The skyrmion behaviour in 3D magnetic fields is investigated by means of MOKE and magnetic force microscopy (MFM) imaging.

MA 41.13 Thu 12:45 H37

Nucleation process of the low-temperature skyrmion phase in Cu_2OSeO_3. — •Denis Mettus, Marco Halder, Alfonso Chacon, Andreas Bauer, and Christian Pfleiderer — Physik Department, Technische Universität München, Garching, Germany

Magnetic materials can host topologically non-trivial spin textures called skyrmions, which are an object of interest in recent years. For bulk chiral magnets with cubic lattice symmetry, it was believed that a skyrmion phase exists near the helimagnetic to paramagnetic transition, which is stabilized by thermal fluctuations.

Recently, a second skyrmion phase in Cu_2OSeO_3 has been identified at low temperatures (LTS), accompanied by a tilted conical phase. The new skyrmion phase is thermodynamically disconnected from the well-known high-temperature phase (HTS) and has a different stabilization mechanism given by cubic magnetocrystalline anisotropy terms.

We report a study of the nucleation process of the LTS. We present first order reversal magnetization data revealing that the nucleation of the LTS occurs by virtue of the tilted conical phase. We consider in addition the effects of magnetic field cycling on the magnetization and ac susceptibility for single crystal Cu_2OSeO_3 sample. The analysis of the susceptibility data allows us to identify the changes in the different phases concentrations with the varying parameters of a magnetic field cycling, which helps to understand the process of the phase nucleation.

MA 41.14 Thu 13:00 H37

Nanoscale magnetic structure dependence on plate thickness in $Mn_{1,4}PtSn$ single crystals — •Belen Zuniga[1,2], Peter Milde[1], Praveen Vir[2], Markus König[2], Lukas Eng[1], Claudia Felser[2], and Andy Mackenzie[2] — [1]Institute of Applied Physics, TU Dresden, Dresden, Germany. — [2]Max-Planck-Institute for Chemical Physics of Solids, Dresden, Germany.

Materials with D_{2d} crystal symmetry may theoretically host a variety of different magnetic textures such as spirals or antiskyrmions [1,2]. $Mn_{1,4}PtSn$ is an acentric tetragonal Heusler compound that possesses such a D_{2d} symmetry and furthermore, a helical ground state and an antiskyrmion lattice under the application of a small magnetic field at room temperature [3].

Here we show that the *ab*-plane of bulk $Mn_{1,4}PtSn$ exhibits ferromagnetic order, with high anisotropy and self-organization of the magnetic domains, hosting magnetic structures over a broad range of sizes, ranging from $\sim 10\ \mu m$ down to $\sim 100\ nm$. Moreover, when preparing ultra-thin single-crystalline $Mn_{1,4}PtSn$ samples, we find a critical sample thickness of $4.5\ \mu m$ below which the fractal-like magnetic domain patterns abruptly change into magnetic lamellar structures with sub-micrometer periodicity. When applying a magnetic field, a regular lattice of bubble-like domains is induced into these crystalline thin-plate $Mn_{1,4}PtSn$ samples.

References: [1] A.N. Bogdanov and D.A. Yablonskii, Sov. Phys. JETP 68 (1989) 101. [2] W. Koshibae and N. Nagaosa, Nat. Commun. 7 (2016) 10542. [3] A.K. Nayak et al., Nature 548 (2017) 561.