TT 25: Skyrmions I (joint session MA/TT)

Time: Tuesday 9:30–13:00 Location: POT 6

Invited Talk TT 25.1 Tue 9:30 POT 6

Emergent electromagnetic response of nanometer-sized spin textures — •Max Hirschberger — Department of Applied Physics, University of Tokyo, Bunkyo-ku 113-8656, Japan — RIKEN Center for Emergent Matter Science (CEMS), Wako 351-0198, Japan

A wide array of experimental techniques in condensed matter, including resonant elastic x-ray scattering and real-space imaging using Lorentz transmission electron microscopy, were incorporated to establish the presence of nanometer-sized skyrmion lattices in the new centrosymmetric materials Gd_2PdSi_3 and $Gd_3Ru_4Al_{12}$, with Heisenberg Gd^{3+} magnetic moments and competing interactions. When a conduction electron moves through a topological spin texture, it acquires a quantum mechanical phase (Berry phase) which can strongly modify the dynamical properties of the electron gas. The tiny topological spin textures (skyrmions) in Gd_2PdSi_3 and $Gd_3Ru_4Al_{12}$ are expected to give rise to a giant emergent magnetic field B_{em} of order 500 Tesla. We have recently found quantitative evidence for B_{em} using electrical Hall measurements and thermoelectric properties such as the topological Nernst effect. Ongoing work is focused on the tuning of magnetic interactions in these materials via chemical substitution; moreover, we are employing element-specific resonant x-ray scattering techniques to study the coupling between local moments and conduction electrons in this new class of skyrmion host.

TT 25.2 Tue 10:00 POT 6

Skyrmions in $SrRuO_3$ based heterostructures in tilted magnetic fields? — •Sven Esser[1], Sebastian Esser[1], Anton Jesche[1], Vladimir Roddatis[2], and Philipp Gegenwart[1] — [1]Experimentalphysik VI, Augsburg University, D-86159 Augsburg, Germany — [2]Interface Geochemistry, Helmholtz Centre Potsdam, 14473 Potsdam, Germany

Formation of Néel-type skyrmions at oxide interfaces is supported by Dzyaloshinskii-Moriya (DM) interaction through introducing a breaking of the inversion symmetry. Recently, artificial perovskite bilayers of the ferromagnetic metal $SrRuO_3$ (SRO) and spin-orbit semimetal $SrIrO_3$ (SIO) have been proposed to host two-dimensional Néel-type skyrmions [1].

Utilizing metal-organic aerosol deposition we have grown $[(SrIrO_3)_2/(SrRuO_3)_5]_k$ bilayers with $k = 1, 5, 10$ repetitions on cubic (001)-oriented $SrTiO_3$ substrate to investigate the interface induced changes of the electronic and magnetic properties. The fully epitaxially strained state of the thin films was verified by X-ray diffraction patterns in combination with reciprocal space mapping and TEM images. A contribution of the topological Hall effect to the Hall resistance can be observed for temperatures between 10K and 80K, which may hint at the formation of skyrmions.

Measurements of the angular-dependent Hall resistivity display additional contributions that are not observed in pure SRO thin films and thus most likely related to the SRO/SIO interface.

[1] J. Matsuno *et al.*, Science Adv. **2** (2016) e1600304.

TT 25.3 Tue 10:15 POT 6

Intrinsic stability of magnetic anti-skyrmions in tetragonal inverse Heuslers — •Rana Saha[1], Tianping Ma[1], Abhay K. Srivastava[1], Ankit Sharma[1], Jagannath Jena[1], Vivek Kumar[2], Praveen Vir[2], Claudia Felser[2], and Stuart Parkin[1] — [1]Max Planck Institute of Microstructure Physics, Halle, Germany — [2]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

One of the major topics in spintronics today is the study of chiral non-collinear spin textures of various topologies. Recently, a novel chiral spin texture, magnetic anti-skyrmion that has distinct topological features from that of Bloch and Néel skyrmions, was discovered in tetragonal inverse Heusler, $Mn_{1.4}Pt_{0.9}Pd_{0.1}Sn$ [1]. Anti-skyrmions have boundaries (the in-plane magnetization region between magnetization pointing up and pointing down) that have a complex structure consisting of successive left hand Bloch, left hand Néel, right hand Bloch, and right hand Néel wall segments. This complex structure is a result of an anisotropic Dzyaloshinskii-Moriya exchange interaction that is set by the symmetry of the underlying lattice. Interestingly, magnetic anti-skyrmions are stable over a wide range of temperature, magnetic field and thickness of the lamella in which they are formed [2]. In this presentation, I will discuss our recent in-situ Lorentz and magnetic force microscopic studies of nucleation, stabilization and size manipulation of anti-skyrmions in tetragonal inverse Heuslers.

[1]Nayak *et al.*, Nature **548**, 561 (2017).
[2]Saha *et al.*, Nat. Commun. **10**, 5305 (2019).

TT 25.4 Tue 10:30 POT 6

Crystal Hall effect in an ultrathin film of $SrRuO_3$(SRO) grown on $SrTiO_3$(STO)[001]: A case of collinear antiferromagnetic insulator — •Kartik Samanta[1], Marjana Ležaić[1], Stefan Blügel[1], and Yuriy Mokrousov[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulation Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Institute of Physics, Johannes Gutenberg-University Mainz, 55128 Mainz, Germany

Motivated by the recently observed topological Hall effect in ultra-thin films of SRO grown on STO(001) substrate, we investigate the magnetic ground state and anomalous Hall response of the SRO ultra-thin films by virtue of spin density functional theory(DFT). Our findings reveal that in the monolayer limit of SRO film, large energy level splitting of Ru-t_{2g} states, stabilizes an anti-ferromagnetic insulating magnetic ground state. For the doped insulating state, our calculated electronic transport properties based on Berry curvature analysis show a large Hall response. From the systematic investigation of our results, we find that the large Hall effect is due to a combination of broken time-reversal and crystal symmetries caused by the arrangement of non-magnetic atoms (Sr and O) in the mono-layer of SRO thin film. We identify the emergent Hall effect as a clear manifestation of the so-called crystal Hall effect [1] occurring in compensated antiferromagnets.

We acknowledge funding from the Deutsche Forschungsgemeinschaft (DFG) through SPP 2137 "Skyrmionics" and the Jülich Supercomputing Center(project JIFF40).

[1] L. Šmejkal, *et al.*; arXiv:1901.00445 (2019)

TT 25.5 Tue 10:45 POT 6

Topological Hall effect in thin films of tetragonal inverse Heusler compounds — •Anastasios Markou[1], Peter Swekis[1], Jacob Gayles[1], Dominik Kriegner[1,2], and Claudia Felser[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden

Spin chirality in metallic materials with noncoplanar spin structure gives rise to a Berry phase induced topological Hall effect (THE). Topologically stable nontrivial spin structures, such as skyrmions and antiskyrmions exhibit THE. The THE is a transverse response to an applied current that can be used to distinguish magnetic textures for device applications, such as the racetrack memory. We focus on the Heusler compounds with D_{2d} symmetry [1,2], which recently found to host antiskyrmions [2]. We present the structural, magnetic, and transport properties in thin films of the tetragonal Mn_xPtSn (x=1.4-2.1) and Mn_2RhSn Heusler compounds. We find that the THE appears below spin reorientation temperature, and together with the anomalous Hall effect are strongly dependent on the composition and thickness of the films.

[1]O. Meshcheriakova *et al.*, Phys. Rev. Lett. **113**, 087203 (2014).
[2]A. K. Nayak *et al.*, Nature **548**, 561-566 (2017).

TT 25.6 Tue 11:00 POT 6

Skyrmions in Ta/CoFeB-wedge/MgO — •Christian Denker[1], Hauke Heyen[1], Sören Nielsen[2], Malte Römer-Stumm[2], Nina Meyer[1], Neha Jha[1], Kornel Richter[2], Enno Lage[2], Markus Münzenberg[1], and Jeffrey McCord[2] — [1]Institut für Physik, Universität Greifswald, Germany — [2]Nanoscale Magnetic Materials - Magnetic Domains, Institute for Materials Science, Universität Kiel, Germany

We investigate different generation approaches as well as pinning center distribution and strength for magnetic skyrmions in Ta/CoFeB-wedge/MgO trilayers. Skyrmions appear as a part of the out-of-plane hysteresis or using pulsed in-plane fields and zero-field stable skyrmions result from tilted in-plane remanent magnetic field application. Furthermore, we investigate energy landscapes for skyrmions by current-induced hopping motion in a stripe with regions of different defect types and densities, since skyrmion motion tracking allows us to access the pinning center distribution and strength.

15 min. break.

TT 25.7 Tue 11:30 POT 6

Impact of light and heavy single atomic defects on single magnetic skyrmions — •Imara Lima Fernandes and Samir Lounis — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany

Incorporating magnetic skyrmions as future bits of information technology is challenged by the unavoidable defects inherent to any device. Recently, the universality of the skyrmion-defect interaction profiles for the $3d$ and $4d$ elements was established [1], which is mainly dictated by the defect-induced changes in the magnetic exchange interactions. Those defects can be used to enhance the skyrmions detection using all-electrical means via the spin-mixing magnetoresistance (XMR) [2,3]. In the current study based on a full *ab initio* approach, we explore impurities from various parts of the periodic table, which enable different mechanisms determining the skyrmion-defect interactions. We address systematically the case of vacancies, *sp* and $5d$ elements in order to find correlations between their chemical nature and the energetics as well as the electronic properties of skyrmions generated in Pd/Fe/Ir(111) surface.
– Funding provided by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (ERC-consolidator grant 681405 - DYNASORE).
[1] I. Lima Fernandes *et al.*, Nature Commun. **9**, 4395 (2018).
[2] I. Lima Fernandes *et al.*, arXiv:1906.08838, (2019)
[3] D. M. Crum *et al.*, Nature Commun. **6**, 8541 (2015)

TT 25.8 Tue 11:45 POT 6

Beyond Skyrmions Utilizing alternative magnetic quasiparticles for spintronics devices — •Börge Göbel[1,2], Oleg Tretiakov[3], Stuart S. P. Parkin[2], and Ingrid Mertig[1] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany — [2]Max-Planck-Institut für Mikrostrukturphysik, Halle (Saale), Germany — [3]School of Physics, The University of New South Wales, Sydney, Australia

Skyrmions are considered as the bits in future spintronic devices like the racetrack storage. One issue, which is hindering the realization of this application, is the so-called skyrmion Hall effect: A skyrmion does not move parallel to an applied spin-polarized current. Instead, the skyrmion is pushed towards the edge of the sample where it annihilates. In this talk, I will give an overview about observed or proposed alternative magnetic quasiparticles. The stabilization, as well as the emergent electrodynamic effects will be discussed for the antiskyrmion, the antiferromagnetic skyrmion, the skyrmionium, and the bimeron. These magnetic objects are either attractive from a fundamental point of view, or are advantageous application-wise.
[1] B. Göbel, A. Mook, J. Henk, I. Mertig. PRB 96, 060406(R) (2017) [2] B. Göbel, A. Schäffer, J. Berakdar, I. Mertig, S. Parkin. Sci. Rep. 9, 12119 (2019) [3] B. Göbel, A. Mook, J. Henk, I. Mertig, O. Tretiakov. PRB 99, 060407(R) (2019) [4] B. Göbel, J. Henk, I. Mertig. Sci. Rep. 9, 9521 (2019)

TT 25.9 Tue 12:00 POT 6

Observation of anti-skyrmions in $Mn_2Rh_{0.95}Ir_{0.05}Sn$ Heusler compound — •Jagannath Jena[1], Rolf Stinshoff[2], Rana Saha[1], Abhay K. Srivastava[1], Tianping Ma[1], Hakan Deniz[1], Peter Werner[1], Claudia Felser[2], and Stuart S. P. Parkin[1] — [1]Max Planck Institute of Microstructure Physics, Weinberg 2, 06120 Halle, Germany — [2]Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Str. 40, 01187 Dresden, Germany

Magnetic anti-skyrmions are topologically protected nanoscopic chiral spin textures. They are composed of alternating boundary of Bloch and Néel domain walls. Recently anti-skyrmions have been discovered in a ferromagnetic tetragonal inverse Heusler compound $Mn_{1.4}Pt_{0.9}Pd_{0.1}Sn$ [1]. Here we report the observation of anti-skyrmions in a ferrimagnetic Heusler compound $Mn_2Rh_{0.95}Ir_{0.05}Sn$ using Lorentz transmission electron microscopy. This compound has a lower magnetic moment which orders at 270 K. Our results may pave the way to search for antiskyrmions in a ferrimagnetic material with a very low magnetic moment for future spintronic applications. [1]Nayak *et al.*, Nature **548**, 561 (2017).

TT 25.10 Tue 12:15 POT 6

B20-type MnSi films on Si (111) grown by flash lamp annealing — •Zichao Li[1,2], Yufang Xie[1,2], Viktor Begeza[1,2], Ye Yuan[1,3], Lars Rebohle[1], Manfred Helm[1,2], Kornelius Nielsch[2,4], Slawomir Prucnal[1], and Shengqiang Zhou[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstrasse 400, D-01328 Dresden, Germany — [2]Technische Universität Dresden, D-01062 Dresden, Germany — [3]Songshan Lake Materials Laboratory, Dongguan, Guangdong 523808, People's Republic of China — [4]Institute for Metallic Materials, IFW-Dresden, Dresden, 01069, Germany

B20-type MnSi is one of the noncentrosymmetric materials hosting magnetic skyrmions, which are promising information carriers in spintronic devices. In this work, we report the preparation of (111)-textured MnSi films on Si substrates. The preparation method only includes the deposition of Mn layers at room temperature and a following process by flash lamp at milli-second. By controlling the thickness of Mn layers and flash energy, we can obtain pure MnSi or mixtures of MnSi and MnSi1.7. Surprisingly, all prepared films show Curie temperatures around 41 K, which is much higher than for bulk MnSi or films reported previously. Magnetic skyrmions are stabilized at the whole temperature range below 41 K and under a much wider magnetic-field range. We speculate that the increased Curie temperature is due to the strain in the MnSi films arising from the MnSi1.7 phase or from the substrate. Our work calls a re-examination of the structural and magnetic properties of B20 MnSi films.

TT 25.11 Tue 12:30 POT 6

Universality of energy barriers of large magnetic skyrmions — •Jan Masell — Center for Emergent Matter Science RIKEN, Wako, Saitama, Japan

Magnetic skyrmions can only decay via singular spin configurations. We analyze the corresponding energy barriers of skyrmions for two distinct stabilization mechanisms, i.e., Dzyaloshinskii-Moriya interaction (DMI) and competing interactions [1]. Based on our numerically calculated collapse paths on an atomic lattice, we derive analytic expressions for the saddle-point textures and energy barriers of large skyrmions. The sign of the spin stiffness and the sign of fourth-order derivative terms in the classical field theory determines the nature of the saddle point and thus the height of the energy barrier. In the most common case for DMI-stabilized skyrmions (positive stiffness and negative fourth-order term) the saddle-point energy approaches a universal upper limit described by an effective continuum theory. For skyrmions stabilized by frustrating interactions, the stiffness is negative and the energy barrier arises mainly from the core of a singular vortex configuration.
[1] B. Heil, A. Rosch, and J. Masell, Phys. Rev. B 100, 134424 (2019)

TT 25.12 Tue 12:45 POT 6

The Chimera skyrmion collapse mechanism in harmonic transition state theory — •Stephan von Malottki[1], Pavel F. Bessarab[2,3], and Stefan Heinze[1] — [1]Institute of Theoretical Physics and Astrophysics, University of Kiel — [2]University of Iceland, Reykjavík, Iceland — [3]ITMO University, St. Petersburg, Russia

Recent studies reveal a new skyrmion annihilation mechanism via the Chimera skyrmion state [1-3]. We study the skyrmion lifetimes for this collapse mechanism in the ultrathin film system Pd/Fe/Ir(111) by a combination of nudged elastic band method calculations and harmonic transition state theory, based on an atomistic spin model parametrised from density functional theory [4]. The skyrmion lifetime has the form of an Arrhenius law and requires the energy barriers and prefactors of all relevant collapse mechanisms [5,6]. We address the crossover from the radial symmetric skyrmion collapse to the Chimera mechanism as well as the challenge of identifying and treating new Goldstone modes correctly.
[1] Meyer *et al.*, Nat. Commun. **10**, 3823 (2019)
[2] Heil *et al.*, Phys. Rev. B **100**, 134424 (2019)
[3] Desplat *et al.*, Phys. Rev. B **99**, 174409 (2019)
[4] von Malottki *et al.*, Sci. Rep. **7**, 12299 (2017)
[5] Bessarab *et al.*, Sci. Rep. **8**, 3433 (2018)
[6] von Malottki *et al.*, Phys. Rev. B **99**, 060409(R) (2019)