MA 27: Skyrmions 2 (joint session MA/KFM)

Time: Thursday 9:30–12:45 Location: H37

MA 27.1 Thu 9:30 H37

Complementary investigations of magnetic textures in the antiskyrmion compound $Mn_{1.4}$PtSn with REXS and LTEM — M. Winter[1,2,3,4], M. Rahn[4], D. Wolf[3], S. Schneider[2], M. Valvidares[5], •C. Shekar[1], P. Vir[1], B. Achinuq[6], H. Popescu[7], N. Jaouen[7], G. Van der Laan[8], T. Hesjedal[6], B. Rellinghaus[2], and C. Felser[1] — [1]MPI CPfS, Dresden, Germany — [2]DCN, TU Dresden, Germany — [3]IFW Dresden, Germany — [4]IFMP, TU Dresden, Germany — [5]ALBA Synchrotron, Barcelona, Spain — [6]Clarendon Laboratory, University of Oxford, UK — [7]Synchrotron SOLEIL, Saint-Aubin, France — [8]Diamond Light Source, UK

The Heusler compound $Mn_{1.4}$PtSn is known to host multiple non trivial magnetic textures like antiskyrmions (aSks). It's phase diagram depends not only on temperature and sample shape, but also on strength and orientation of an external magnetic field as well as on the history of its application. In order to better understand the formation of aSks, we have conducted complementary experiments of resonant elastic x-ray scattering (REXS) and Lorentz transmission electron microscopy (LTEM) on an identical lamella of $Mn_{1.4}$PtSn. Our complementary approach allows for the first time to directly relate the REXS patterns to the underlying magnetic phase as determined from LTEM. Along this approach, LTEM has proven an ideal pre-characterization tool to navigate the high-dimensional parameter space and subsequently take advantage of the better control of magnetic field directions, temperature as well as of energy resolved measurements as provided by REXS. Part of this work is gratefully supported by DFG within SPP 2137.

MA 27.2 Thu 9:45 H37

Doping control of magnetic anisotropy for stable antiskyrmion formation in schreibersite (Fe,Ni)3P with S4 symmetry — Kosuke Karube[1], Licong Peng[1], •Jan Masell[1,2], Mamoun Hemmida[3], Hans-Albrecht Krug von Nidda[3], István Kézsmárki[3], Xiuzhen Yu[1], Yoshinori Tokura[1,4], and Yasujiro Taguchi[1] — [1]RIKEN CEMS, Wako, Japan — [2]Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — [3]University of Augsburg, Augsburg, Germany — [4]University of Tokyo, Tokyo, Japan

Recently, growing attention has also been paid to antiskyrmions emerging in non-centrosymmetric magnets with D2d or S4 symmetry. [1] In these magnets, complex interplay among anisotropic Dzyaloshinskii-Moriya interaction, uniaxial magnetic anisotropy, and magnetic dipolar interactions generates a variety of magnetic structures. We control the uniaxial magnetic anisotropy of schreibersite (Fe,Ni)3P with S4 symmetry by doping and investigate its impact on the stability of antiskyrmions. With magnetometry, supported by ferromagnetic resonance spectroscopy, Lorentz transmission electron microscopy, and micromagnetic simulations, we quantitatively analyze the stability of antiskyrmion as functions of uniaxial anisotropy and demagnetization energy, and demonstrate that subtle balance between them is necessary to stabilize antiskyrmions.

[1] K. Karube, L. C. Peng, J. Masell, X. Z. Yu, F. Kagawa, Y. Tokura, and Y. Taguchi, Nat. Mater. 20, 335-340 (2021) [2] The authors, Adv. Mater. 34 (11), 2108770 (2022)

MA 27.3 Thu 10:00 H37

Magnetic and Morphological Phases in the 2D van der Waals Magnet FexGeTe2 — •Kai Litzius[1], Max Birch[1,5], Lukas Powalla[2,3,5], Sebastian Wintz[1], Fabian Alten[1], Michael Miller[1], Markus Weigand[4], Klaus Kern[2,3], Marko Burghard[2], and Gisela Schütz[1] — [1]Max-Planck-Institute for Intelligent Systems, 70569 Stuttgart, Germany — [2]Max-Planck-Institute for Solid State Research, 70569 Stuttgart, Germany — [3]Institut de Physique, École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland — [4]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, 12489 Berlin, Germany — [5]These authors contributed equally to the work

Recently, observations of magnetic skyrmions in 2-dimensional (2D) itinerant ferromagnets opened many possibilities for technological implementation of 2D van der Waals structures in spintronics. However, the stability of the different magnetic states and morphological phases in FexGeTe2 remains an unresolved issue. In this work, we utilize real-space imaging to determine magnetic phase diagrams of exfoliated FexGeTe2 films. Our findings show besides complex, history-dependent magnetization states also that changes in the crystalline structure significantly alter the magnetic behavior. Ultimately, the choice of material and a proper nucleation mechanism result in the stabilization of a variety of (meta-) stable magnetic configurations, including skyrmions. These findings open novel perspectives for designing van der Waal heterostructure-based devices incorporating topological spin textures.

MA 27.4 Thu 10:15 H37

Antiskyrmions in B20-type FeGe — •Nikolai S. Kiselev[1], Fengshan Zheng[2,3], Luyan Yang[2], Vladyslav M. Kuchkin[1], Filipp N. Rybakov[4,5], Stefan Blügel[1], and Rafal E. Nikolai[2] — [1]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Le Brandst. 1 — [3]Spin-X Institute, School of Physics and Optoelectronics, State Key Laboratory of Luminescent Materials and Devices, Guangdong-Hong Kong-Macao Joint Laboratory of Optoelectronic and Magnetic Functional Materials, South China University of Technology, Guangzhou 511442, China — [4]Department of Physics and Astronomy, Uppsala University, SE-75120 Uppsala, Sweden — [5]Department of Physics, KTH-Royal Institute of Technology, SE-10691 Stockholm, Sweden

We report the highly reproducible observations of statically stable antiskyrmion [1] – skyrmion antiparticle in thin plates of B20-type FeGe chiral magnet where only skyrmions were observed earlier. Using Lorents TEM and electron holography, we showed that skyrmions and antiskyrmions could coexist in a wide range of fields and temperatures. These findings are entirely consistent with micromagnetic simulations and prior theoretical studies of two-dimensional systems [2]. The mechanism of antiskyrmion stability, nucleation, and annihilation with ordinary skyrmions is discussed in detail.

[1] F. Zheng et al., Nat. Phys. (2022) accepted.
[2] V. M. Kuchkin, N. S. Kiselev, Phys. Rev. B 101, 064408 (2020).

MA 27.5 Thu 10:30 H37

Asymmetric magnetization reversal in perpendicularly magnetized micro stripes induced by exchange-bias effect and Dzyaloshinskii-Moriya interaction — •Sapida Akhundzada[1], Piotr Kuświk[2], Christian Janzen[1], Arno Ehresmann[1], and Michael Vogel[1] — [1]Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Kassel, Germany — [2]Institute of Molecular Physics, Polish Academy of Sciences, Poznań, Poland

In a systematic study, the magnetization reversal in exchange-biased Ti/Au/Co/NiO/Au micro stripes with perpendicular magnetic anisotropy is characterized using high-resolution magneto-optical Kerr microscopy. Thereby, the remagnetization process is observed to be asymmetric with respect to the two branches of the hysteresis loop, being quantified as a higher nucleation density formed along one field branch with decreasing structure width. Additionally, a local asymmetry in the domain nucleation and domain wall movement within the stripe geometry is observed. The influence of the exchange bias effect and the Dzyaloshinskii-Moriya interaction is investigated by field-cooling and the application of additional in-plane magnetic fields during the magnetization reversal process. XMCD and XMLD experiments reveal the corresponding domain texture in the ferromagnetic and antiferromagnetic layers. These experiments show how the interplay between chiral Dzyaloshinskii-Moriya interaction and the unidirectional anisotropy modify the magnetic domain texture and the resulting magnetization reversal in microstructures.

MA 27.6 Thu 10:45 H37

Magnetic skyrmion braids — •Nikolai S. Kiselev[1], Fengshan Zheng[2], Filipp N. Rybakov[3], Dongsheng Song[2], András Kovács[2], Haifeng Du[4], Stefan Blügel[1], and Rafal E. Dunin-Borkowski[2] — [1]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons and Peter Grünberg Institute, Forschungszentrum Jülich, 52425 Jülich, Germany — [3]Department of Physics, KTH-Royal Institute of Technology, Stockholm, SE-10691 Sweden — [4]The Anhui Key Laboratory of Condensed Matter Physics at Extreme Conditions, High Magnetic Field Laboratory, Chinese Academy of Science (CAS), Hefei,

Anhui Province 230031, China

In cubic chiral magnets, the magnetization of skyrmions resembles a string-like or filamentary texture. Skyrmion strings are naturally expected to interwind and form complex three-dimensional superstructures by analogy to elastic strings. We found that skyrmion strings in cubic crystals of chiral magnets can form braids – statically stable configurations where skyrmion strings wind around one another [1]. This finding is confirmed by direct observations of skyrmion braids in B20-type FeGe using transmission electron microscopy. The theoretical analysis predicts that the discovered phenomenon is general for a wide family of chiral magnets and can be observed in thick plates and bulk crystals.

[1] F. Zheng, et al., Nature Commun. 12, 5316 (2021).

MA 27.7 Thu 11:00 H37

Tunable ellipticity of Bloch skyrmions in antiskyrmion-hosting materials — Sebastian Schneider[1,2], •Jan Masell[1,3], Fehmi S. Yasin[1], Licong Peng[1], Kosuke Karube[1], Yasujiro Taguchi[1], Darius Pohl[2], Bernd Rellinghaus[2], Yoshinori Tokura[1,4], and Xiuzhen Yu[1] — [1]RIKEN CEMS, Wako, Japan — [2]TU Dresden, Dresden, Germany — [3]Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — [4]University of Tokyo, Tokyo, Japan

Magnetic skyrmions are usually stabilized and studied in materials with isotropic Dzyaloshinskii-Moriya interaction (DMI). In materials with D2d or S4 symmetry, however, the sign of the DMI is exactly opposite in two orthogonal directions such that it favors antiskyrmions instead of skyrmions. [1,2] Yet, uniaxial anisotropy and dipolar interactions can also help stabilizing skyrmions in such materials which, as a consequence of the anisotropic DMI, are rendered elliptical. We quantify the elliptical distortion of skyrmions in an S4 symmetric material as function of magnetic field and temperature using LTEM holography. Our micromagnetic simulations and simple analytical modelling explain the experimentally observed behavior and provide a technique to quantitatively estimate the DMI.

[1] K. Karube, L. C. Peng, J. Masell, X. Z. Yu, F. Kagawa, Y. Tokura, and Y. Taguchi, Nat. Mater. 20, 335-340 (2021) [2] K. Karube, L. C. Peng, J. Masell, M. Hemmida, H.-A. Krug von Nidda, I. Kézsmárki, X. Z. Yu, Y. Tokura, and Y. Taguchi, Adv. Mater. 34 (11), 2108770 (2022) [3] In preparation.

MA 27.8 Thu 11:15 H37

Long-range non-collinearity and spin reorientation in the centrosymmetric hexagonal magnet NiMnGa — •Parul Devi[1], Sanjay Singh[2], Thomas Hermannsdörfer[1], and Joachim Wosnitza[1,3] — [1]Dresden High Magnetic Field Laboratory, HZDR, Germany — [2]Institut für Festkörper und Materialphysik, TU Dresden, Germany — [3]School of Materials Science and Technology, Indian Institute of Technology (BHU), Varanasi-221005, India

The recent discovery of biskyrmions and skyrmions in globally centrosymmetric crystals has raised questions about the role of the Dzyaloshinskii-Moriya interactions (DMI) in causing the topologically stable spin vortex textures, since DMI vanishes in such crystal structures. Here, we present a detailed crystal and magnetic structure investigation of the non-collinear hexagonal magnetic material NiMnGa exhibiting biskyrmions [1]. We show an investigation on the nature of the phase transitions, evidence of magnetoelastic coupling and anomalous thermal expansion in hexagonal, centrosymmetric NiMnGa using combined studies of magnetization and high-resolution synchrotron x-ray powder diffraction data. Magnetization data exhibits spin reorientation transition * 200 K. By means of powder neutron diffraction data, we investigate the change of the magnetic structure in NiMnGa. This study will help to understand the origin of biskyrmions in the absence of Dzyaloshinskii-Moriya interaction in magnetic materials.

[1] Yu et al., Nat. Comm. 5, 3198 (2014).

MA 27.9 Thu 11:30 H37

Zero-field skyrmionic states and in-field edge-skyrmions induced by boundary tuning — •Jonas Spethmann, Elena Y. Vedmedenko, Roland Wiesendanger, André Kubetzka, and Kirsten von Bergmann — Universität Hamburg, Hamburg, Germany

When magnetic skyrmions are moved via currents, they do not strictly travel along the path of the current, instead their motion also gains a transverse component. This so-called skyrmion Hall effect can be detrimental in potential skyrmion devices because it drives skyrmions towards the edge of their hosting material where they face potential annihilation. To mitigate this problem it was proposed to create a potential well within the skyrmion hosting material and thereby guide the skyrmions along a desired pathway[1]. Here we have experimentally modified a skyrmion model system–an atomic Pd/Fe bilayer on Ir(111)[2]–by growing a self-assembled ferromagnetic Co/Fe bilayer adjacent to it. Employing spin-polarized scanning tunneling microscopy, we demonstrate that this ferromagnetic rim has an immediate effect on the spin spiral ground state of the Pd/Fe bilayer, stabilizes skyrmions and target states in zero field and prevents skyrmion annihilation at the film edge. Furthermore we show that in applied magnetic fields the Co/Fe gives rise to edge-skyrmions pinned to the Pd/Fe island rim. Finally we have performed spin dynamics simulations to investigate the role of different magnetic parameters in causing these edge effects.

[1] I. Purnama *et al., Scientific Reports* **5**, 10620 (2015).
[2] N. Romming *et al. Science* **341**, 636-639 (2013).

MA 27.10 Thu 11:45 H37

Real-space determination of the isolated magnetic skyrmion deformation under electric current flow — Fehmi S. Yasin[1], •Jan Masell[1,2], Kosuke Karube[1], Akiko Kikkawa[1], Yasujiro Taguchi[1], Yoshinori Tokura[1,3], and Xiuzhen Yu[1] — [1]RIKEN CEMS, Wako, Japan — [2]Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — [3]University of Tokyo, Tokyo, Japan

The effect of electric current on topological magnetic skyrmions, such as the current-induced deformation of isolated skyrmions, is of fundamental interest. The deformation has consequences ranging from perturbed dynamics to modified packing configurations. [1] We measure the current-driven real-space deformation of isolated, pinned skyrmions within CoZn at room temperature. We observe that the skyrmions are surprisingly soft, readily deforming during electric current application into an elliptical shape with a well-defined deformation axis. We find that this axis rotates towards the current direction, in agreement with our simply Thiele-based theoretical analysis. We quantify the average eccentricity and how the skyrmion size expands during current application. This first evaluation of in-situ electric current-induced skyrmion deformation paints a clearer picture of spin-polarized electron-skyrmion interactions and may prove essential when designing spintronic devices.

[1] J. Masell, D.R. Rodrigues, B.F. McKeever, and K. Everschor-Sitte, Phys. Rev. B 101, 214428 (2020). [2] Under review.

MA 27.11 Thu 12:00 H37

Magnetocrystalline anisotropy in cubic chiral magnets — •Vivek Kumar[1], Andreas Bauer[1], Schorsch Michael Sauther[1], Michelle Hollricher[1], Markus Garst[2], Marc Andreas Wilde[1], and Christian Pfleiderer[1] — [1]Physik-Department, Technische Universität München, D-85748 Garching, Germany — [2]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, D-76131 Karlsruhe, Germany

Magnetocrystalline anisotropy plays an important role in the stabilization, orientation and manipulation of exotic spin textures like skyrmions in cubic chiral magnets [1-3]. Here, we report the determination of the fourth and sixth order anisotropy constants of MnSi as a function of temperature and field using the cantilever torque magnetometry option in a physical property measurement system. Torque curves were recorded by rotating the single-crystalline spherical sample in the field polarized state. This allows us to extract anisotropy constants by fitting the experimental data to the theoretical expressions of torques belonging to the symmetry class ($P2_13$). In addition, we discuss technical issues in measurement related to sample shape and geometry. The present technique is used to obtain the anisotropy constants of other cubic chiral magnets including Cu_2OSeO_3, $Mn_{1-x}Fe_xSi$ and $Fe_{1-x}Co_xSi$ series.

[1] Chacon *et al.*, Nat. Phys. **14**, 936 (2018).
[2] Bauer *et al.*, Phys. Rev. B **95**, 024429 (2017).
[3] Adams *et al.*, Phys. Rev. Lett. **121**, 187205 (2018).

MA 27.12 Thu 12:15 H37

Change of electronic Chern number induced by phase shifts in multiple-Q textures — •Pascal Prass[1], Fabian R. Lux[1], Duco van Straten[2], and Yuriy Mokrousov[1,3] — [1]Institute of Physics, Johannes Gutenberg University Mainz, Germany — [2]Institute of Mathematics, Johannes Gutenberg University Mainz, Germany — [3]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Germany

A multiple-Q spin texture is given by the superposition of multiple spin spirals and gives rise to a periodic array of topological spin structures, such as skyrmions. Using the emergent magnetic field formalism [1] the topological Hall current in the texture is proportional to the real-space winding number of its spin vector field. In recent articles [2,3], it was illustrated how tuning the relative phase shifts of the spin waves as well as the textures' net magnetization leads to topological phase transitions in the spin texture, i.e. integer jumps of its winding number. Combining these ideas implies the existence of significant discontinuous jumps in the topological Hall current and its associated Chern numbers in the underlying electronic spectrum. In this work, we directly investigate the spin textures' electronic band topology to determine the relationship between its real-space winding number and quasi-momentum space Chern numbers. Understanding the electronic behaviour during these transitions will have far-reaching implications for developing tunable topological Hall devices. [1] T. Schulz et al. Nat. Phys. 8, 301-304 (2012). [2] K. Shimizu et al. arXiv:2201.03290 (2022). [3] S. Hayami et al. Nat. Commun. 12, 6927 (2021).

MA 27.13 Thu 12:30 H37

Audio Recognition with Skyrmion Mixture Reservoirs — •Robin Msiska[1], Jake Love[1], Jonathan Leliaert[2], Jeroen Mulkers[2], George Bourianoff[3], and Karin Everschor-Sitte[1] — [1]University of Duisburg-Essen, Duisburg, Germany — [2]Ghent University, Ghent, Belgium — [3]Senior Principle Engineer, Intel Corp. (Retired)

Physical reservoir computing is an information processing scheme that enables energy efficient temporal pattern recognition to be performed directly in physical matter [1]. Previously, random topological magnetic textures have been shown to have the characteristics necessary for efficient reservoir computing [2] and allowed for simple pattern recognition with two input channels [3].

We propose a skyrmion mixture reservoir computing model with multi-dimensional inputs. Through micro-magnetic simulations, we show that our implementation can solve audio classification tasks at the nanosecond timescale to a high degree of accuracy. Due to the quality of the results shown and the low power properties of magnetic texture reservoirs, we argue that skyrmion magnetic textures are a competitive substrate for reservoir computing.

Funding from the Emergent AI Centre (Carl-Zeiss-Stiftung), DFG (320163632), FWO-Vlaanderen and computer resources by VSC (Flemish Supercomputer Center) are gratefully acknowledged.

[1] G. Tanaka et al., Neural Networks 115, 100 (2019). [2] D. Prychynenko et al., Physical Review Applied 9, 014034 (2018) [3] D. Pinna et al., Phys. Rev. Applied 14, 054020 (2020)