MA 7: Magnetic Textures: Statics and Imaging I

Time: Monday 15:00–19:15 Location: H37

Invited Talk MA 7.1 Mon 15:00 H37

The Surface Spin Flop in Synthetic Antiferromagnets with Perpendicular Magnetic Anisotropy — •Benny Böhm[1], Nikolai Kiselev[2], Darius Pohl[3], Lorenzo Fallarino[4], Leopold Koch[1], Bernd Rellinghaus[3], Kornelius Nielsch[5], and Olav Hellwig[1,4] — [1]Chemnitz University of Technology — [2]Forschungszentrum Jülich and JARA — [3]TU Dresden — [4]Helmholtz-Zentrum Dresden-Rossendorf — [5]IFW Dresden

The talk will provide an introduction to the basic mechanism of the surface spin flop, a transition predicted theoretically for layered antiferromagnets 50 years ago by Mills et. al.[1]. We will present the experimental confirmation that this transition exists also in the case of out-of-plane magnetic anisotropy in addition to the in-plane case studied already earlier [2]. While the in-plane case requires single crystal substrates to create a uniaxial in-plane anisotropy, our out-of-plane easy axis system based on a magnetic multilayer system provides such a uniaxial anisotropy naturally and can thus be easily prepared on amorphous surfaces. Furthermore, we reveal a pathway to stabilize the surface spin flop state, usually only obtained for high external fields of about 0.5 T, also at remanence. Overall, our results make the out-of-plane surface spin flop state accessible for further studies without the requirement of single crystal substrates or external fields, thus opening up the possibility of dynamic studies as well as an easy integration into more complex structures.

[1] D. L. Mills, Phys. Rev. Lett. 20, 1968, p. 18-21
[2] R. W. Wang et al., Phys. Rev. Lett. 72, 1994, p. 920-923

MA 7.2 Mon 15:30 H37

Magnetic exchange interaction at the Fe/Ir(111) interface — •Sergey Tsurkan and Khalil Zakeri Lori — Heisenberg Spin-dynamics Group, Physikalisches Institut, Karlsruhe Institute of Technology, Wolfgang-Gaede-Str. 1, D-76131 Karlsruhe, Germany

The magnetic ground state of the Fe monolayer on Ir(111) has been observed to be a spontaneous skyrmion lattice. The formation of such an exotic ground state is attributed to the interplay between the Heisenberg exchange, four spin and Dzyaloshinskii-Moriya interaction [1]. However, these fundamental magnetic interactions in this system have not been measured quantitatively. In order to quantify these interactions we performed spin-polarized high resolution electron energy-loss spectroscopy experiments on a trilayer structure consisting of Co/Co/Fe epitaxially grown on Ir(111). By probing the magnon dispersion relation across the surface Brillouin zone we quantified the interfacial exchange interaction at the Fe/Ir(111) interface. Our results indicate that the Heisenberg exchange interaction in the interface Fe layer is very weak and exhibits a rather complex pattern. Such a weak exchange interaction in the presence of the Dzyaloshinskii-Moriya interaction would allow for the formation of the skyrmionic ground state.

[1] S. Heinze, *et al.*, Nature Physics **7**, 713 (2011).

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MA 7.3 Mon 15:45 H37

Diversity of magnetic phases occuring in perpendicular synthetic antiferromagnets — •Leopold Koch[1], Fabian Samad[1], Benny Böhm[1], Sven Stienen[2], Pierre Pudwell[1], and Olav Hellwig[1,2] — [1]Technische Universität Chemnitz, Reichenhainer Straße 70, 09126 Chemnitz — [2]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden

Magnetic domain formation in synthetic antiferromagnets (SAF) consisting of layered thin films with perpendicular magnetic anisotropy and thin non-magnetic interlayers is determined by magnetic energies like interlayer exchange, interfacial anisotropy and demagnetization. The competitive character of the energies leads to a variety of stable magnetic configurations with characteristic domain patterns. We show that the energies depend on specific system parameters like films thicknesses or number of repeats and can therefore be easily controlled via the design of the multilayer. Furthermore, we show that also ex-situ manipulation like (focused) ion beam irradiation leads to a transition of the magnetic phases which provides a possibility to create lateral heterogeneous magnetic nanostructures.

Since the domain structures are highly reproducible and even compatible with amorphous substrates, the presented SAFs are suitable for a wide variety of applications.

MA 7.4 Mon 16:00 H37

Boundary-Driven Twist States in Systems with Broken Spatial Inversion Symmetry — •Karin Everschor-Sitte — Institute of Physics, Johannes Gutenberg-University Mainz

In the quest for miniaturising magnetic devices, the effects of boundaries and surfaces become increasingly important. Bulk properties are modified or even dominated by the properties of the surface of the sample. We derive the general micromagnetic boundary condition for ferromagnetic systems with broken inversion symmetry. Based on these we predict novel boundary-induced twist states in ferromagnetic systems with Dzyaloshinskii-Moriya interaction.[1] We show that these new spin structures can even be purely boundary-induced. Furthermore, they can significantly influence the ferromagnetic bulk state as well as magnetic textures such as domain walls and skyrmions in thin films[2] which might lead to observable effects in transport measurements.

[1] Hals, Everschor-Sitte, PRL **119**, 127203 (2017)
[2] Mulkers et al., PRB **98**, 064429 (2018)

MA 7.5 Mon 16:15 H37

Metamagnetic texture in a polar antiferromagnet — •Dmitry A. Sokolov[1], Ulrich Rössler[2], Naoki Kikugawa[3], Robert Cubitt[4], Andrew P. Mackenzie[1], Toni Helm[1], and Kurt Kummer[5] — [1]MPI CPfS, Dresden, Germany — [2]IFW, Dresden, Germany — [3]National Institute for Materials Science, Tsukuba, Japan — [4]Institut Laue-Langevin, Grenoble, France — [5]ESRF, Grenoble, France

We report a new type of mixed state between antiferromagnetism and ferromagnetism, which can be created in certain acentric materials. In the Small-Angle Neutron Scattering (SANS) experiments we observe a field-driven spin-state in the layered antiferromagnet Ca3Ru2O7, which is modulated on a scale between 8 and 20 nm and has both antiferromagnetic and ferromagnetic parts [1]. We call this state a metamagnetic texture and explain its appearance by the chiral twisting effects of the asymmetric Dzyaloshinskii-Moriya (DM) exchange. The observation can be understood as an extraordinary coexistence, in one thermodynamic state, of spin-orders belonging to different symmetries.

[1] Metamagnetic texture in a polar antiferromagnet, D. A. Sokolov et al., arXiv:1810.06247.

MA 7.6 Mon 16:30 H37

Investigation of focused ion beam irradiation induced magnetic spin textures in synthetic antiferromagnets — •Fabian Samad[1,2], Leopold Koch[1], Sri Sai Phani Kanth Arekapudi[1], and Olav Hellwig[1,2] — [1]Institute of Physics, Chemnitz University of Technology, Germany — [2]Institute for Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Germany

We study synthetic antiferromagnets (AF) consisting of ferromagnetic (FM) multilayers that are antiferromagnetically-coupled via non-magnetic interlayers [1]. They possess various remarkable properties, such as very high domain wall velocities [2] and an absence of stray fields, making them interesting for possible future data storage applications. It was shown previously that the energy balance of those systems can be tuned by increasing the FM layer thickness, yielding a dipolar energy driven phase transition to a FM ground state [1].

In contrast, in our current work we use focused ion beam irradiation to locally change the energy balance between AF interlayer exchange and dipolar energy, using different ion beam energies and fluences. Therefore, we are able to create a rich variety of laterally coexisting magnetic phases and spin textures in different confinements. Detailed investigations of their interactions as well as their field reversal behavior are performed via in-field high-resolution magnetic force microscopy.

[1] Hellwig et al., J. Magn. Magn. Mater. 319, 13-55 (2007).
[2] Yang et al., Nat. Nanotechnol. 10, 221-226 (2015).

MA 7.7 Mon 16:45 H37

Magnetic bimerons as skyrmion analogues in in-plane mag-

nets — •Börge Göbel[1], Alexander Mook[2], Jürgen Henk[2], Ingrid Mertig[1,2], and Oleg A. Tretiakov[3,4] — [1]Max-Planck-Institut für Mikrostrukturphysik, D-06120 Halle (Saale), Germany — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, D-06099 Halle (Saale), Germany — [3]Institute for Materials Research and Center for Science and Innovation in Spintronics, Tohoku University, Sendai 980-8577, Japan — [4]School of Physics, The University of New South Wales, Sydney 2052, Australia

A magnetic bimeron [1] is a pair of two merons and can be understood as the in-plane magnetized version of a skyrmion. Here [2] we theoretically predict the existence of single magnetic bimerons as well as bimeron crystals, and compare the emergent electrodynamics of bimerons with their skyrmion analogues. We show that bimeron crystals can be stabilized in frustrated magnets and analyze what crystal structure can stabilize bimerons or bimeron crystals via the Dzyaloshinskii-Moriya interaction. We point out that bimeron crystals, in contrast to skyrmion crystals, allow for the detection of a pure topological Hall effect. By means of micromagnetic simulations, we show that bimerons can be used as bits of information in in-plane magnetized racetrack devices, where they allow for current-driven motion for torque orientations that leave skyrmions in out-of-plane magnets stationary.

[1] Y. Kharkov, et al., Phys. Rev. Lett. 119, 207201 (2017)
[2] B. Göbel, et al., arXiv: 1811.07068 (2018)

15 min. break

MA 7.8 Mon 17:15 H37

THz and SANS study of magnons in BiFeO3 — •Dániel Gergely Farkas[1], Dávid Szaller[1,2], István Kézsmárki[1,3], Laur Peedu[4], Johan Viirok[4], Urmas Nagel[4], Toomas Rõõm[4], and Sándor Bordács[1] — [1]Department of Physics, BUTE, Hungary — [2]Institute of Solid State Physics, TU Wien, Austria — [3]Experimental Physics V., UA, Augsburg, Germany — [4]NICPB, Tallinn, Estonia

Multiferroic materials with coexisting and strongly coupled magnetic and ferroelectric orders have attracted much interest due to the novel phenomena they possess, such as magnetoelectric effect [1] and directional dichroism [2]. Among these compounds BiFeO3 has received special attention as it is one of the few known room-temperature multiferroics [3]. Previously we showed by using THz spectroscopy that in contrast to the theoretical models the (111) plane of BiFeO3 is almost isotropic and the magnetic field dependence of the excitation frequencies have hysteresis. With small angle neutron scattering (SANS) measurements we determined the low temperature behavior of the magnetic domains in external magnetic fields [4], which helped in the interpretation of the THz data. The improved picture of the magnetic domains supports all THz results including the isotropic (111) plane, selection rules and hysteresis of the mode frequencies. References: [1] M. Tokunaga, et al., Nat. Commun. 6, 5878 (2015). [2] I. Kézsmárki, et al., Phys. Rev. Lett. 106, 057403 (2011). [3] J. Moreau, et al., J. Phys. Chem. Solids 32, 1315 (1971). [4] S. Bordács, et al., Phys. Rev. Lett. 120, 147203 (2018).

MA 7.9 Mon 17:30 H37

LTEM and DPC measurements on room temperature magnetic skyrmions in Pt/Co/W multilayers — •S. Pöllath[3], T. Lin[1], H. Liu[2], Y. Zhang[4], B. Ji[1], N. Lei[1], J. J. Yun[5], L. Xi[5], D. Z. Yang[5], Z. Xing[1], Z. L. Wang[1], L. Sun[2], Y. Z. Wu[2], L. F. Yin[2], W. B. Wang[2], J. Shen[2], J. Zweck[3], C. H. Back[6], Y. G. Zhang[1], and Q. S. Zhao[1] — [1]Beihang University, Beijing 100191, China — [2]Fudan University, Shanghai 200433, China — [3]Universität Regensburg, Regensburg 93040, Germany — [4]Chinese Academy of Sciences, Beijing 100190, China — [5]School of Physical Science and Technology, Lanzhou University, Lanzhou 730000, China — [6]Technische Universität München, Garching 85748, Germany

In this work, measurements on Pt/Co/W multilayer systems using Transmission Electron Microscopy (TEM) in Lorentz (LTEM) and Differential Phase Contrast (DPC) mode are reported. In LTEM, the contrast mechanism of the Neel-type skyrmions is analyzed and used to estimate the skyrmion size with LTEM image contrast simulations. Phase diagrams are recorded showing the wide range of the skyrmion phase pocket in temperature. History dependent phase diagrams reveal that the thermodynamical existence of the observed skyrmions is rather allowed by the topological remnants of the stripe domains, than by a real thermodynamic phase. Further it is shown how DPC can be used to measure the skyrmion size in-focus.

MA 7.10 Mon 17:45 H37

Multi-k spin textures in the complex magnetic phase diagram of rare-earth copper compounds — •Wolfgang Simeth[1], Marein Rahn[2], Andreas Bauer[1], Robert Georgii[3], Matthias Gutmann[7], Vladimir Hutanu[3], Pascal Manuel[7], Martin Meven[3], Sebastian Mühlbauer[3], Kirill Nemkovski[4], Bachir Ouladdiaf[6], Karel Prokes[5], Tobias Schrader[3,4], and Christian Pfleiderer[1] — [1]Technische Universität München — [2]Los Alamos National Laboratory — [3]Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II) — [4]Forschungszentrum Jülich — [5]Helmholtz-Zentrum Berlin — [6]Institut Laue-Langevin — [7]ISIS neutron and muon source

The rare-earth intermetallics RCu (R = Ho, Tm, Er) condense in the centrosymmetric CsCl-structure. As a consequence of several competing interactions (itinerant, indirect exchange, quadrupolar interactions as well as crystal electric fields), a rich magnetic phase diagram with a multitude of phase pockets unfolds. In these phases, the localized 4f magnetic moments exhibit complex arrangements as magnetic ground states. For a proper determination of these structures, several neutron techniques were combined. Both as a function of temperature and field the compounds undergo phase transitions between several antiferromagnetic multi-k states. The textures we identified are highly non-collinear and exhibit modulations with a large wavelength in the range of nanometres.

MA 7.11 Mon 18:00 H37

Chiral Magnetic Skyrmions with Arbitrary Topological Charge — Filipp N. Rybakov[1] and •Nikolai N. Kiselev[2] — [1]Department of Physics, KTH-Royal Institute of Technology, SE-10691 Stockholm, Sweden — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, D-52425 Jülich, Germany

In many work related to study of magnetic skyrmions one can find the statement that in a conventional model of a chiral magnet the coexistence of stable skyrmion solutions with Q=*1 and Q= 1 is impossible. In this presentation we show that in fact a conventional model of chiral ferro- and antiferromagnets possesses an infinite number of skyrmion solutions with different value and sign of topological charge [1]. We provide a detailed description of the diverse morphology of new skyrmions and the corresponding energy dependencies of skyrmions with respect to their topological charge. Because the considered model is general it is expected that predicted phenomenon may occur in various compaunds including atomic layers, e.g., PdFe/Ir(111), rhombohedral GaV_4S_8 semiconductor, B20-type alloys as $Mn_{1-x}Fe_xGe$, $Mn_{1-x}Fe_xSi$, $Fe_{1-x}Co_xSi$, Cu_2OSeO_3, acentric tetragonal Heusler compounds.

[1] F. N. Rybakov, N. S. Kiselev, Chiral Magnetic Skyrmions with Arbitrary Topological Charge, arXiv:1806.00782

MA 7.12 Mon 18:15 H37

Entropic stabilization of magnetic skyrmions in ultrathin films — •Stephan von Malottki[1], Pavel F. Bessarab[2], Soumyajyoti Haldar[1], Anna Delin[3], and Stefan Heinze[1] — [1]Institute of Theoretical Physics and Astrophysics, University of Kiel — [2]School of Engineering and Natural Sciences - Science Institute, University of Iceland — [3]Department of Applied Physics, School of Engineering Sciences, KTH, Kista

We show that thermal stability of magnetic skyrmions can be strongly affected by entropic effects [1]. The lifetimes of isolated skyrmions in atomic Pd/Fe bilayers on Ir(111) and on Rh(111) are calculated in the framework of harmonic transition state theory based on an atomistic spin model parametrized from density functional theory. Depending on the system the attempt frequency for skyrmion collapse can change by up to nine orders of magnitude with the strength of the applied magnetic field. We demonstrate that this effect is due to a drastic change of entropy with skyrmion radius which opens a novel route towards stabilizing sub-10 nm skyrmions at room temperature.

[1] von Malottki *et al.*, arXiv:1811.12067

MA 7.13 Mon 18:30 H37

Electrically controllable magnetic switching and soliton motion in insulating magnetic garnets with perpendicular magnetic anisotropy — •Andrew Ross[1,2], Shilei Ding[1,2,3], Sven Becker[1], Yuichiro Kurokawa[1,4], Shruti Gupta[2], Jinbo Yang[3], Romain Lebrun[1], Gerhard Jakob[1,2], and Mathias Kläui[1,2,5] — [1]Johannes Gutenberg University, Mainz, Germany — [2]Staudinger Weg 7 — [3]Peking University, China — [4]Kyushu University, Japan

— [5]QuSpin, Center for Quantum Spintronics, Norwegian University of Science and Technology, Norway

Insulating rare earth iron garnets (RIG), with low Gilbert damping, low pinning, and magnetic and angular momentum compensation points, show great promise for the field of spintronics[1]. Here we grow high quality TmIG ($Tm_3Fe_5O_{12}$)films by pulsed laser deposition. Over a range of thicknesses, perpendicular magnetic anisotropy is observed, tailored by lattice strain between film and substrate. Utilizing the (inverse) spin Hall effect in a neighboring heavy metal layer, electrical detection and control of the magnetic state is successfully achieved for low current densities. We investigate the switching of TmIG films as a function of in-plane and out of plane magnetic fields, highlighting a thickness dependence to the efficiency of the interfacial spin orbit torques in such an insulating system. [1] C. O. Avci et al, Nature Materials, 16 (2017)

MA 7.14 Mon 18:45 H37

Robust modulated magnetic phases in lacunar spinel $GaMo_4S_8$ — •Ádám Butykai[1], Dávid Szaller[2], László Balogh[1], László Ferenc Kiss[3], Lisa DeBeer-Schmitt[4], Hiroyuki Nakamura[5], Sándor Bordács[1], and István Kézsmárki[1,6] — [1]Department of Physics, Budapest University of Technology and Economics — [2]Institute of Solid State Physics, Vienna University of Technology — [3]Department of Experimental Solid State Physics, Wigner-MTA Research Centre for Physics — [4]Oak Ridge National Laboratory — [5]Department of Materials Science and Engineering, Kyoto University — [6]Center for Electronic Correlations and Magnetism, University of Augsburg

Two members of the lacunar spinel crystal family, GaV_4S_8 and GaV_4Se_8, featuring a polar symmetry, have been reported to host Néel-type skyrmions [1,2]. Here, we present a provisional magnetic phase diagram for the 4d cluster magnet $GaMo_4S_8$, based on the combination of magnetization and small-angle neutron scattering experiments. $GaMo_4S_8$ is isostructural with the two other lacunar spinels, but exhibits a markedly stronger spin-orbit interaction. As a result, the periodicity of the magnetic modulations is found to be two times smaller, ∼ 10 nm, whereas the modulated magnetic phases extend from the Curie-temperature down to the lowest temperatures and show an extreme robustness against external fields up to 1.5-2 T.

[1] I. Kézsmárki *et al.*, Nat. Mat., **14**, 1116, (2015). [2] S. Bordács *et al.*, Sci. Rep., **7**, 7584, (2017).

MA 7.15 Mon 19:00 H37

Magnetic force microscopy investigation of spin textures in the ferromagnetic semimetal Fe_3Sn_2 — •Markus Altthaler[1], Dennis Meier[2], Mohammed Kassem[3], Vladimir Tsurkan[1], Stephan Krohns[1], and István Kézsmárki[1] — [1]Experimentalphysik V, EKM, Universität Augsburg, 86135 Augsburg — [2]Department of Materials Science and Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway — [3]Department of Physics, Assiut University, Assiut 71516, Egypt

Recently, Fe_3Sn_2 has been reported to exhibit a giant anomalous Hall effect [1] as well as a topological electronic structure [2] and to host magnetic skyrmions [3]. Z. Hou et al. [3] suggested that both uniaxial magnetic anisotropy and frustration due to the Kagome lattice play a significant role in the formation of skyrmions at room temperature in this compound. Our goal was to specify in more details the driving force of skyrmion formation, namely whether exchange frustration or uniaxial anisotropy competing with long-range dipolar interactions stabilize the skyrmions. In contrast to former observations of magnetic spirals and skyrmions in sub-micron thin lamellas, on the surface of bulk crystals we did not find such modulated structures, instead a dendrite pattern with fascinating magnetic field evolution was observed. The fact that the stability of skyrmions is restricted to thin lamellas implies that the uniaxial anisotropy competing with dipolar interactions is the main drive of skyrmion formation in Fe_3Sn_2.

[1] L. Ye et al., Nature **555** (2018), 638; [2] J.-X. Yin et al., Nature **562** (2018), 91; [3] Z. Hou et al., Adv. Mater. (2017), 1701144