MA 12: Superconductivity – Topological Defects in Superconductors and Magnets (joint session TT/MA)

Time: Monday 15:00–17:45 Location: HFT-FT 101

MA 12.1 Mon 15:00 HFT-FT 101

Topological domain walls in helimagnets — •Laura Köhler[1], Peggy Schönherr[2], Jan Müller[3], Naoya Kanazawa[4], Yoshinori Tokura[4,5], Achim Rosch[3], Dennis Meier[6], and Markus Garst[1] — [1]Institut für Theoretische Physik, TU Dresden, Dresden, Germany — [2]Department of Materials, ETH Zürich, Zürich, Switzerland — [3]Institut für Theoretische Physik, Universität zu Köln, Köln, Germany — [4]Department of Applied Physics, University of Tokyo, Tokyo, Japan — [5]RIKEN Center for Emergent Matter Science (CEMS), Wako, Japan — [6]Department of Materials Science and Engineering, NTNU, Trondheim, Norway

The Dzyaloshinskii-Moriya interaction in chiral magnets stabilizes a magnetic helix with a wavelength set by the spin-orbit coupling. We study domain walls of helimagnetic order both theoretically and experimentally using micromagnetic simulations and magnetic force microscopy studies on surfaces of FeGe. We find that such domain walls are distinctly different from those in ferromagnets and rather similar to grain boundaries of liquid crystals. Three types of domain walls are realized depending on the relative domain orientation: a curvature wall, a zig-zag disclination wall and a dislocation wall. Disclinations are vortex defects in the helix axis orientation, and they can be combined to form dislocations. We discuss the topological skyrmion charge associated with these dislocations which can be finite. This leads to an emergent electrodynamics and thus a coupling to spin currents as well as to a contribution to the topological Hall effect.

[1] P. Schönherr et al. arXiv1704.06288 (2017).

MA 12.2 Mon 15:15 HFT-FT 101

Nanoscale imaging of magnetic topological defects in helimagnetic FeGe — •Peggy Schönherr[1], Jan Müller[2], Laura Köhler[3], Achim Rosch[2], Naoya Kanazawa[4], Yoshi Tokura[4,5], Manfred Fiebig[1], Markus Garst[3], and Dennis Meier[6] — [1]ETH Zürich, Switzerland — [2]Universität zu Köln, Germany — [3]Technische Universität Dresden, Germany — [4]University of Tokyo, Japan — [5]Riken, Japan — [6]NTNU Trondheim, Norway

Complex spin textures, like helical spin spirals with a fixed wavelength, can occur due to chiral magnetic interactions. Chiral magnets are a striking nanoscopic analog to liquid crystals, possessing lamellar phases and ordered topological defects. Defects are of great importance as they strongly influence order and mobility of the spin system. Here, we present magnetic force microscopy measurements in combination with micromagnetic simulations, discussing the dynamics and interactions of 1D and 2D objects with non-trivial topology in the helimagnetic phase of FeGe. We show that the local magnetization dynamics are strongly influenced by depinning and subsequent motion of edge dislocations (1D). Their motion is part of a slow relaxation process, having profound impact on the formation of the helical ground state. Other 1D objects that play an important role for the micromagnetism are so-called π disclinations, which can form chains and build domain walls that are distinctly different from classical antiferro- and ferromagnetic domain walls. Thus, our microscopy data reveal a new multitude of magnetic nano-objects with non-trivial topology going beyond the previously discussed skyrmions.

MA 12.3 Mon 15:30 HFT-FT 101

Mechanisms of nucleation of chiral bobbers in helical magnets — Fengshan Zheng[1,2], •Filipp N. Rybakov[3], Aleksandr B. Borisov[4], Dongsheng Song[5], Shasha Wang[6,7], Zi-An Li[8], Haifeng Du[6,7], Nikolai S. Kiselev[2], Jan Caron[1,2], András Kovács[1,2], Mingliang Tian[6,7], Yuheng Zhang[6,7], Stefan Blügel[2], and Rafal E. Dunin-Borkowski[1,2] — [1]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Forschungszentrum Jülich, Germany — [2]Peter Grünberg Institut, Forschungszentrum Jülich, Germany — [3]Department of Physics, KTH-Royal Institute of Technology, Stockholm, Sweden — [4]M.N. Miheev Institute of Metal Physics, Ekaterinburg, Russia — [5]National Center for Electron Microscopy in Beijing, Tsinghua University, China — [6]High Magnetic Field Laboratory, Hefei, China — [7]Collaborative Innovation Center of Advanced Microstructures, Nanjing University, China — [8]Institute of Physics, Beijing, China

Magnetic chiral bobbers are stable particlelike states that represent a skyrmion texture combined with Bloch point [1]. Recently they were discovered experimentally in B20-type FeGe compound [2]. Here we present the detailed description on different mechanisms of nucleation of chiral bobbers which were revealed theoretically and then confirmed in experiments with FeGe specimens. The discussed mechanisms represent general phenomena and can be applied to a variety of other chiral magnetic compounds.

[1] F.N. Rybakov et al. PRL **115**, 117201 (2015).
[2] F. Zheng et al. arXiv:1706.04654 (2017).

MA 12.4 Mon 15:45 HFT-FT 101

Skyrmion optical creation/annihilation in a chiral magnet — •Gabriele Berruto[1], Ivan Madan[1], Yoshie Murooka[1], Giovanni Maria Vanacore[1], Enrico Pomarico[1], Damien McGrouther[2], Yoshihiko Togawa[2], Heinrik Rønnow[1], and Fabrizio Carbone[1] — [1]Institute of Physics, EPFL, Lausanne, Switzerland — [2]SUPA, University of Glasgow, United Kingdom

We show that single light pulses of different duration and color can create and annihilate skyrmions for a broad range of parameters in the magnetic phase diagram of a 50 nm-thick slab of FeGe, a prototypical chiral magnet. Using a combination of camera-rate and ns pump-probe cryo-Lorentz Transmission Electron Microscopy, we directly resolve the spatio-temporal evolution of the magnetization ensuing (fs and ns) optical excitation. When we excite optically the skyrmion lattice, its structural parameters are not modified, only the magnetization being affected: it transiently decreases, and recovers to the initial value over long (μs) time scales, reflecting the important role of the cooling rate of the system. Contrary to previously reported cases in different systems, in our experiment the skyrmions are not created via a transient demagnetized (paramagnetic) state. The laser pulses transiently heat the system, driving it into a region of the phase diagram where the appearance of skyrmions is strongly favored, but still staying far below the Curie temperature. The system then supercools down to base temperature, and skyrmions remain frozen into their (meta)stable state. The skyrmion topological charge is injected from geometric edges, defects, and magnetic boundaries.

MA 12.5 Mon 16:00 HFT-FT 101

Coupling of magnetic flux quanta to tunable domain structures in superconductor/ferromagnet bilayers with varying Dzyaloshinskii-Moriya interaction — •Palermo Xavier[1], Samokhvalov Alexei[3], Collin Sophie[1], Bouzehouane Karim[1], Santamaria Jacobo[1], Sander Anke[1], Reyren Nicolas[1], Cros Vincent[1], Buzdin Alexander[2], and Villegas Javier E.[1] — [1]Unité Mixte de Physique CNRS-Thales, Palaiseau, France — [2]Laboratoire Ondes et Matière d'Aquitaine (LOMA), Talence, France — [3]N.Novgorod, Russia

We study magneto-transport in hybrids combining superconducting films with magnetic multilayers in which varying the stacking sequence (e.g. Co/Pt vs. Ir/Co/Pt) allows tailoring the interfacial Dzyaloshinskii-Moriya interaction, and the characteristics of the magnetic domain structure. The magnetoresistance in the superconducting state shows a strong hysteresis, which is observed during the magnetization reversal and closely follows the reversal details. This behavior is in stark contrast with that expected for a plain superconducting film, and is strongly dependent on the size and morphology of the domain structure (presence of wormlike or skyrmion structures). The results can be understood in terms of mutual interaction between flux quanta and the local magnetization, which modifies vortex nucleation and mobility, and possibly the magnetic structure in the ferromagnets.

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MA 12.6 Mon 16:15 HFT-FT 101

Interactions between superconductor-ferromagnet thin films — •Annika Stellhorn[1], Anirban Sarkar[1], Emmanuel Kentzinger[1], Sonja Schröder[1], Grigol Abuladze[1], Markus Waschk[1], Patrick Schöffmann[2], Zhendong Fu[2], Vitaliy Pipich[2], and Thomas Brückel[1,2] — [1]Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science (JCNS-2) and Peter Grünberg Institut (PGI-4), JARA-FIT, 52425 Jülich GERMANY —

[2]Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science at MLZ, Lichtenbergstr. 1, 85748 Garching Germany

Interactions at superconductor-ferromagnet (S/F) interfaces have been studied on a prototype Nb (S)/ FePd (F) system. Our goal is to understand the proximity effects of FePd with different strength of perpendicular magnetic anisotropy (PMA) and magnetic domain texture on the superconducting Nb layer. Proximity effects at S/F interfaces with an inhomogeneous magnetic field texture result in various effects, like domain-wall superconductivity and long-ranged triplet cooper pairs in the F-layer, making them good candidates for superconducting spintronics. Epitaxial heterostructures of Nb/FePd are prepared on MgO (001) substrate using Molecular Beam Epitaxy. Magnetic Force Microscopy images of FePd grown by shuttered growth reveal a striped domain structure. Macroscopic magnetization measurements show weak PMA. However, co-deposition of FePd at varying temperatures results in different strength of PMA. Grazing-Incidence-Small-Angle-Neutron-Scattering reveals the depth profile of the magnetization in the heterostructure.

15 min. break.

MA 12.7 Mon 16:45 HFT-FT 101

Giant non-local vortex motion in WC nanowires grown by Ga+ focused ion beam deposition — •Rosa Córdoba[1,2], José María De Teresa[1,2,3], Ricardo Ibarra[2,3], Isabel Guillamón[4], Hermann Suderow[4], Sebastián Vieira[4], and Javier Sesé[2,3] — [1]Instituto de Ciencia de Materiales de Aragón (ICMA), CSIC-UZ, Spain — [2]Departamento de Física de la Materia Condensada, Universidad de Zaragoza, Spain — [3]Laboratorio de Microscopías Avanzadas, Instituto de Nanociencia de Aragón, UZ — [4]Departamento de Física de la Materia Condensada, Universidad Autónoma de Madrid, Spain

In this contribution, we propose an unconventional route to transfer vortices as single particles through long distances (in the micrometers range), within WC nanowires (50 nm in width), taking profit of current-induced non-local vortex motion [1]. By reducing the lateral dimensions of wires near superconducting coherence length of the material, we measured a giant non-local electrical signal which is 40 times higher than those reported for wider wires of other superconductors. Comparing the non-local electrical signal in WC wires of different dimensions, we found that the signal for 50 nm-wide WC nanowires is nearly two orders of magnitude higher than for the 200 nm-wide WC ones. The measured giant non-local signal in the former strongly confirms that the vortex line is more rigid than the vortex lattice in wider wires due to its quasi-1D character and its confinement potential that prevents the transversal vortex displacements.

[1] R. Córdoba et al. manuscript submitted to Applied Physics Letters.

MA 12.8 Mon 17:00 HFT-FT 101

Unusual critical state and vortex commensurability in cuprate superconductors with regular topological defects — •Wolfgang Lang[1], Georg Zechner[1], Kristijan L. Mletschnig[1], Florian Jausner[1], Meirzhan Dosmailov[2], Marius A. Bodea[2], and Johannes D. Pedarnig[2] — [1]University of Vienna, Faculty of Physics, Wien, Austria — [2]Johannes-Kepler-University Linz, Institute of Applied Physics, Linz, Austria

The interaction of vortices with artificial defects in a superconductor is a vibrant topic in experimental and theoretical research, but also important for its prospects of technical applications. The advantage of a higher operation temperature in $YBa_2Cu_3O_{7-\delta}$ (YBCO) is opposed by the demand for advanced nanopatterning methods. To this end, YBCO thin films are irradiated with He^+ ions by shadow projection through a Si stencil mask to create a square array of columnar defect regions of 180 nm diameter and 300 nm lattice constant. Peaks of the critical current as a function of the applied magnetic field reveal the commensurate trapping of vortices in domains near the edges of the sample. Upon ramping an external magnetic field, an unconventional critical state emerges that is characterized by a pronounced hysteresis and different positions of the critical current peaks in virgin and field-saturated down-sweep curves, respectively. Interestingly, the distances of the various peaks in a sweep remain constant and correspond exactly to the matching field. The observations are interpreted as a nonuniform, terrace-like critical state, in which individual domains are occupied by a fixed number of vortices per pinning site.

MA 12.9 Mon 17:15 HFT-FT 101

Vortex motion and change inside the superconducting phase of the ferromagnetic superconductor UCoGe — •Beilun Wu[1], Dai Aoki[2,3], and Jean-Pascal Brison[2] — [1]Universidad Autonoma de Madrid, Spain — [2]CEA/University of Grenoble Alps, France — [3]Tohoku University, Japan

Ferromagnetic superconductors can show equal spin pairing superconductivity, in form, for example, of a p-wave pair wave function. Among the different candidates, the U-based single crystalline systems stand out because of the real coexistence between the superconducting and ferromagnetic order, and their numerous interesting properties, such as the unusual upper critical field and the field-induced re-entrant superconductivity. Recent measurements show that superconductive pairing is remarkably sensitive to the external magnetic field. However, it is unknown if the magnetic field induces strong difference in the pairing interaction in different parts of the phase diagram. Here we address this issue by a combined study of thermal and electrical transport in UCoGe, under magnetic field up to 15T. We observe that the resistive transition width considerably sharpens in the high field region. In addition, it lies at a lower temperature than the bulk transition observed in the thermal conductance. This shows strongly enhanced vortex mobility in this high field region, in which a freezing transition from a vortex liquid to a glass-like or solid lattice might occur. Meanwhile a sudden change in thermal conductivity is observed inside the superconducting phase. Altogether these results suggest a field-induced change in the superconducting phase. *supported by ERC Pnicteyes

MA 12.10 Mon 17:30 HFT-FT 101

Domain formation in the type-II/1 superconductor niobium — •Alexander Backs[1,2], Tommy Reimann[1,2], Michael Schulz[1,2], Vitaliy Pipich[1,3], Sebastian Mühlbauer[1], and Peter Böni[2] — [1]Heinz Maier-Leibnitz Zentrum, Garching, Germany — [2]Physik-Department E21, Technische Universität München, Garching, Germany — [3]Jülich Center for Neutron Research, Jülich, Germany

In type-II/1 superconductors, an attractive interaction between single magnetic vortices leads to the formation of a magnetic domain structure, denoted intermediate mixed state (IMS). The IMS is made up of flux free domains and regions containing a vortex lattice (VL) [1].

We have studied the nucleation and morphology of the IMS in the type-II/1 s-wave superconductor niobium [1] [2] with a combination of small and ultra small angle neutron scattering and neutron grating interferometry to gain information about the VL, the IMS domains and their spatial distribution, respectively. In the case of strong pinning, the magnetic structure changes from a homogeneous VL into clustered domains upon field cooling. This phase separation sets in below the freezing transition of the VL, thereby demonstrating how vortex pinning can be overcome on a local scale while macroscopically retaining it. The IMS scattering function shows strong similarities to the model of spinodal decomposition where the usual time dependence is implicit in the cooling process.

[1] E. H. Brandt and M. P. Das, Journal of Superconductivity and Novel Magnetism 24, 57 (2011)
[2] T. Reimann et al., Nat. Commun.6, 8813 (2015)
[3] T. Reimann et al., Phys. Rev. B 96, 144506 (2017)