MA 9: Magnetic domain walls

Time: Monday 15:00–18:15 Location: EB 202

MA 9.1 Mon 15:00 EB 202

Emergence of antiferromagnetic domains out of domain walls — •Ehsan Hassanpour Yesaghi[1], Mads C. Weber[1], Amadé Bortis[1], Thomas Lottermoser[1], Yusuke Tokunaga[2], Yasujiro Taguchi[3], Yoshinori Tokura[3], and Manfred Fiebig[1] — [1]ETH Zurich, Switzerland — [2]Univ. of Tokyo, Japan — [3]RIKEN CEMS, Japan

Antiferromagnetic (AFM) materials are gaining increasing attention for their potential in technological applications such as spintronics. Strong coupling and faster dynamics as well as robustness against magnetic stray fields are their attractive properties. This robustness, however, makes it chronically difficult to influence AFM states. We propose to manipulate the AFM ordering through the controlled emergence of bulk domains at the phase transition. To demonstrate this, we investigate the weakly-ferromagnetic (wFM) to AFM phase transition in (Dy,Tb)FeO_3 which is driven by strongly coupled ordering of magnetic rare-earth and iron ions. The wFM ordering, which can be influenced by an external magnetic field, can persist as a metastable state in the AFM phase. By employing spatially-resolved magneto-optical methods, we demonstrate that AFM domains can emerge out of antiphase domain boundaries of the metastable wFM phase. Furthermore, we design domain-wall configurations that allow the nucleation of two oppositely oriented AFM domains separated by a wFM domain wall. We show with a simple model that symmetry of the domain wall in one phase is the key to seed the nucleation of the desired domain orientation of the other phase.

MA 9.2 Mon 15:15 EB 202

Experimental and numerical study of 360 degree domain wall annihilation — •Gurucharan V. Karnad[1], Eduardo Martinez[2], Michele Voto[2], Tomek Schulz[1], Berthold Ocker[3], Dafiné Ravelosona[4], and Mathias Kläui[1] — [1]Institut für Physik , Johannes Gutenberg-Universität Mainz, Mainz, Germany — [2]Departamento Fisica Applicada, Universidad de Salamanca, Salamanca, Spain — [3]Singulus Technology AG, Kahl am Main, Germany — [4]Centre for Nanoscience and Nanotechnology, University Paris-Saclay, Orsay, France

In the presence of interfacial Dzyaloshinkii-Moriya interaction (DMI) the domain walls (DWs) adopt a homochiral configuration. When two neighboring walls are in close proximity, they form winding pairs as they possess the same winding number. This leads to additional dipolar interaction which is directly related to the magnitude of the DMI. This is directly reflected in the terminal field which is required to annihilate the domain walls. We present an analytical model where we show that the contribution to dipolar repulsion by DMI can be modified under the application of external magnetic fields. This is further verified by micromagnetic simulations which propose an experimental set-up to observe this. This is experimentally realized and demonstrated in a system of Ta/Co20F60B20/MgO and Pt/Co/AlOx.

MA 9.3 Mon 15:30 EB 202

Effective description of domain walls as extended structures — •Davi Rohe Rodrigues[1,2,3], Karin Everschor-Sitte[2,4], Jairo Sinova[2], and Artem Abanov[1] — [1]Department of Physics & Astronomy, Texas A&M University, College Station, Texas 77843-4242, USA — [2]Institute of Physics, Johannes Gutenberg Universitat, 55128 Mainz, Germany — [3]Graduate School Materials Science in Mainz, Staudingerweg 9, 55128 Mainz, Germany — [4]Institute of Physics ASCR, v.v.i, Cukrovarnicka 10, 162 00 Prag 6, Czech Republic

Domain walls are often treated as one-dimensional objects whose dynamics is described by two soft modes, its position and azimuthal angle. In thin films, however, domain walls exhibit a richer structure including vortices and curvatures. We propose an effective description for domain walls as extended objects with local degrees of freedom. Our description includes tilted[1,2] domain walls, vortices[3], and more complex configurations. We analyze the transport of spin waves along the domain walls and the formation of cusps. Furthermore, considering Skyrmions as closed domain walls, we study the effects of deformations along their borders. Going beyond the often used circular approximation for skyrmions[4] we find for example that deformations in the skyrmion shape travel along its border. [1] Boulle, et al, PRL 111 (2013); [2] Muratov, et al, PRB 96, 134417 (2017); [3] Tretiakov, et al, PRL 100, 127204 (2008); [4] Rodrigues, et al, (manuscript in preparation).

MA 9.4 Mon 15:45 EB 202

Dynamical depinning of chiral domain walls — •Simone Moretti[1,2], Michele Voto[2], and Eduardo Martinez[2] — [1]Department of Physics, University of Konstanz, 78457, Konstanz, Germany — [2]Department of Applied Physics, University of Salamanca, 37001, Salamanca, Spain

The domain wall depinning field represents the minimum magnetic field needed to move a domain wall, typically pinned by defects or patterned constrictions. From a technological point of view, it represents an important parameter since a small depinning field implies less energy required to move a domain wall and, therefore, an energetically cheaper (domain wall based) device. Conventionally, such field is considered independent on the Gilbert damping since it is assumed to be the field at which the Zeeman energy equals the pinning energy barrier (both damping independent). Consequently, a large or small depinning field is usually interpreted only in terms of the disorder strength of a certain sample. Here we analyse numerically the domain wall depinning field as a function of the Gilbert damping in a system with perpendicular magnetic anisotropy and Dzyaloshinskii-Moriya interaction. Contrary to expectations, we find that the depinning field depends also on the Gilbert damping and that it strongly decreases for small damping parameters. We explain this dependence with a simple one-dimensional model and we show that the reduction of the depinning field is related to the finite size of the pinning barriers and to the domain wall precessional dynamics, connected to the Dzyaloshinskii-Moriya interaction and the shape anisotropy.

MA 9.5 Mon 16:00 EB 202

A numerical study on ferrimagnetic domain wall motion in temperature gradients — •Andreas Donges[1], Unai Atxitia[2], Thomas Schönenberger[3], Severin Selzer[1], and Ulrich Nowak[1] — [1]Fachbereich Physik, Universität Konstanz, DE-78457 Konstanz, Germany — [2]Fachbereich Physik, Freie Universität Berlin, DE-14195 Berlin, Germany — [3]École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland

We investigate the domain wall (DW) dynamics of a typical rare earth-transition metal ferrimagnet in a constant temperature gradient using atomistic Langevin dynamics simulations based on the stochastic Landau-Lifshitz-Gilbert equation. Our results are compared to the ferro- and antiferromagnetic DW motion which have been studied more thoroughly so far [1,2]. Surprisingly, below the angular momentum compensation temperature T_{A}, we find a regime in which the DW is moving towards the colder region, i.e. against Schlickeiser's entropic torque [1] which suggests a drift into the hotter region. Recently, Moretti et al. [3] showed that such a reversed DW motion might be connected to spin wave reflections. Furthermore, our simulations suggest the existence of a torque compensation point $T_{\mathrm{T}} > T_{\mathrm{A}}$, at which the DW precession changes sign. This also implies that a DW propagating along such a temperature gradient can undergo two Walker breakdowns: one above and one below T_{T}.

[1] F. Schlickeiser, et al., *Phys.Rev.Lett.* **113**, 097201 (2014)
[2] S. Selzer, et al., *Phys.Rev.Lett.* **117**, 107201 (2016)
[3] S. Moretti, et al., *Phys.Rev.B* **95**, 064419 (2017)

15 minutes break

MA 9.6 Mon 16:30 EB 202

Properties of ferrotoroidic domains in artificial nanomagnetic crystals — •Jannis Lehmann[1], Claire Donnelly[1,2], Naëmi Leo[2], Peter Derlet[2], Laura Heyderman[1,2], and Manfred Fiebig[1] — [1]Department of Materials, ETH Zurich, Switzerland — [2]Paul Scherrer Institute, Villigen PSI, Switzerland

Periodic nanomagnetic arrays can be seen as model spin systems which allow a direct study of spontaneous order, magnetic frustration or other phenomena that emerge at the mesoscale. The possibility to design an artificial magnetic crystal and engineer the magnetic-dipole-based lattice potentials on demand opens the door to novel ferroic systems. Here we apply the concept of artificial crystals to examine ferrotoroidicity, an order that is based on magnetic moments forming a vortex at the level of a unit cell. This arrangement yields a toroidal moment as the associated order parameter. We introduce a two-dimensional nanomagnetic array that provides as-grown toroidal domains. By studying different systems with tailored magnetic-dipole strength via magnetic force microscopy we show how the dipole coupling determines the as-grown domain size and gives rise to an anisotropy in our domain walls. The magnetic configurations of a domain wall are of particular interest as they can be tuned to exhibit a ferro- or an antiferromagnetic-like ordering along the propagation direction of the wall. Our results demonstrate the control of domain size and domain-wall geometry in artificial magneto-toroidal crystals. This work provides an experimental approach for modelling and tailoring ferroic systems and for scrutinizing fundamental properties of ferrotoroidicity.

MA 9.7 Mon 16:45 EB 202

Monte-Carlo approach to ferrotoroidic domains in artificial crystals — •Amadé Bortis[1], Peter Derlet[2], Jannis Lehmann[1], Thomas Lottermoser[1], and Manfred Fiebig[1] — [1]Department of Materials, ETH Zürich, Switzerland — [2]Paul Scherrer Institute, Villigen PSI, Switzerland

Amongst the primary ferroic orders, ferrotoroidicity is least investigated and understood. Ferrotoroidic systems are defined by a chiral arrangement of magnetic moments which can be associated to a toroidic order parameter. Due to the scarcity of materials which show ferrotoroidicity on a microscopic scale, artificial crystals can be used to reproduce ferrotoroidic order on the mesoscale. These artificial nanomagnetic arrays consist of magnetic islands which are coupled through magnetic-dipole interactions. This implies that the interactions are well defined and tunable, allowing for geometric arrangements which show ferrotoroidic order. The magnetic islands can be modeled as classical Ising spins, which makes kinetic Monte-Carlo simulations (KMC) an efficient tool to investigate the formation of toroidic domains. Domain formation in these systems generally depends on the growth rate and the geometry which determines the strength of the dipolar interactions. We use KMC to understand the correlation of toroidic domains and domain walls as a function of the geometry. We find that the relative coupling strengths in between the islands determines the specific arrangement of the domain walls as well as the the average domain size. Our work provides new insights towards the understanding of ferrotoroidic domains and how they may be tuned.

MA 9.8 Mon 17:00 EB 202

Scanning Reflection X-ray Microscope (SRXM) - a new tool for magnetic domain imaging — •Andreas Schümmer[1], Hans-Christoph Mertins[1], Roman Adam[2], Claus Schneider[2], Larissa Juschkin[3], and Ulf Berges[4] — [1]University of Applied Sciences Münster, 48565 Steinfurt, Germany — [2]Forschungszentrum Jülich,52428 Jülich, Germany — [3]Rhein Westfälische Technische Hochschule Aachen, 52062 Aachen, Germany — [4]TU Dortmund, Zentrum für Synchrotronstrahlung, 44227 Dortmund, Germany

We present the first results of the newly developed scanning reflection x-ray microscope (SRXM) operating in the extreme ultraviolet (EUV) spectral range. Focus lies on the mechanical setup, efficient fabrication process of zone plate optics and first results in structural and element-selective imaging. The SRXM is dedicated for imaging of magnetic domains in buried layers exploiting magneto-optical reflection spectroscopy in T-MOKE, or for XMCD [1] under incidence angles from 20° to 60°. The advantage of working in the EUV region is the access to the 3p absorption edges of 3d transition metals. In addition, the intensity of reflected light is about two orders of magnitude higher than at the 2p edges. [1] M. Tesch, M. Gilbert, H-Ch. Mertins, D. Bürgler et al., Appl. Opt.52, 4294 (2013)

MA 9.9 Mon 17:15 EB 202

Magnetoelectric Force Microscopy on Antiferromagnetic 180° Domains in Cr_2O_3 — •Marcela Giraldo[1], Peggy Schoenherr[1], Martin Lilienblum[1], Morgan Trassin[1], Dennis Meier[2], and Manfred Fiebig[1] — [1]ETH Zurich, Switzerland. — [2]NTNU, Norway.

Scanning probe microscopy (SPM) techniques constitute the most widely-used characterization tool on the nanoscale. The diversity of operational modes makes them versatile tools with impact in a broad range of fields. SPM techniques proved particularly useful in the investigation of ferroic materials. Even though local ferroic properties have been studied by these techniques, the approach to antiferromagnetic order is almost non-existent. This is regrettable because antiferromagnets are getting increasing attention in recent years. Since antiferromagnets do not exhibit a net magnetization, it is not trivial to access or control them. Efforts aimed at understanding their properties at the domain level are key to their systematic manipulation. In my talk, I will discuss a benchmark experiment and the methodical aspects of a previously proposed SPM technique, termed magnetoelectric force microscopy, as a probe for the elusive type of 180° antiferromagnetic domains in a well known textbook material, Cr_2O_3. Direct comparison by second harmonic generation allows detecting its inherent advantages. I will finally draw your attention on further improvements of the technique which would increase its feasibility to cover most of the known bulk compounds and may even be sufficient to resolve antiferromagnetic domains in type-II multiferroics or magnetoelectric heterostructures.

MA 9.10 Mon 17:30 EB 202

Spin transfer torques in interacting quantum wires — •Hamidreza Kazemi[1], Nicholas Sedlmayr[2], Axel Pelster[1], Imke Schneider[1], and Sebastian Eggert[1] — [1]TU Kaiserslautern and Research Center OPTIMAS, Kaiserslautern, Deutschland — [2]TU Rzeszów, Rzeszów, Poland

The use of spin polarized currents for the manipulation of magnetic domain walls (DW) in ferromagnetic nanowires has been the subject of intensive research in recent years [1]. This is due to the promising application of such mechanisms e.g. in DW based magnetic devices. Our main goal is the inquiry into the full quantum effects of electron-electron correlation on the non-adiabatic spin transport in quasi one-dimensional nano-structures with magnetic DWs. It is known that the electrons confined to a one-dimensional wire behave fundamentally different from standard Fermi-liquid quasiparticle picture so that a characteristic change in the spin transfer torque is expected. In this respect, bosonization technique is used to go beyond mean-field theory in 1D nanowires with sharp DWs [2] in order to calculate the corresponding spin transfer torques.

[1] A. Brataas, A. D. Kent, and H. Ohno. Nat.Mater. **11**, 372.381 (2012).
[2] N., S. Sedlmayr, S. Eggert, and J. Sirker. Phys.Rev.B **84**, 024424 (2011).:

MA 9.11 Mon 17:45 EB 202

Wire edge dependent magnetic domain wall creep — •Liza Herrera Diez[1], Vincent Jeudy[2], Gianfranco Durin[3], Arianna Casiraghi[3], Juergen Langer[4], Berthold Ocker[4], and Dafiné Ravelosona[1] — [1]Centre de Nanosciences et de Nanotechnologies, CNRS, Univ. Paris-Sud, Université Paris-Saclay, C2N Orsay, 91405 Orsay cedex, France — [2]Laboratoire de Physique des Solides, CNRS, Univ. Paris-Sud, Université Paris-Saclay, 91405 Orsay Cedex, France — [3]Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce 91, 10135 Torino, Italy — [4]Singulus Technology AG, Hanauer Landstrasse 103, 63796 Kahl am Main, Germany

While edge pinning is known to play an important role in sub-μm wires, we demonstrate that strong deviations from the universal creep law can occur in 1 to 200μm wide wires. Edge pinning increasingly dominates the creep dynamics as the wire width decreases and it is also found to depend on aging and different fabrication processes. Magnetic imaging reveals that edge pinning deviations correlate with a marked bending of domain walls at low drive. This behaviour is described by a mixed-creep mechanism combining the creep law exponent $\mu = 1/4$ describing bulk pinning and an additional component accounting for edge pinning with an exponent of 0.38.

MA 9.12 Mon 18:00 EB 202

Exchange coupling torque in antiferromagnetically coupled Co/Gd bi-layer system — •Robin Bläsing[1,2], See-Hun Yang[3], Tianping Ma[1,2], Chirag Garg[1,2,3], and Stuart S. P. Parkin[1,2,3] — [1]Max Planck Institute for Microstructure Physics, Halle , Germany — [2]Institute of Physics, Martin Luther University Halle-Wittenberg, Halle, Germany — [3]IBM Research Almaden, San Jose, USA

In antiferromagnetic and ferrimagnetic thin films the efficiency of current-induced domain wall motion (CIDWM) by spin Hall currents from a heavy metal underlayer like Pt can be dramatically raised compared to ferromagnetic systems. As soon as the total angular momentums of the magnetic sublattices are equal, the torque due to the Dzyaloshinskii Moriya interaction (DMI) tends to zero and the more efficient exchange coupling torque becomes the dominant driving force. We carried out CIDWM experiments in antiferromagnetically coupled Co/Gd systems at base temperatures between 125 K and 250 K. The change of the magnetization of Gd due to the change of temperature within this range allows to compensate the total magnetic angular momentum of the Gd and Co sublayers at a compensation temperature $T_\tau \approx 219$ K which is slightly higher than the magnetic moment compensation temperature at $T_\mathrm{M} = 210$ K. Our data suggests the existence of DMI in Co arising at the Co/Gd interface which effective field is opposite to that of the DMI at the Pt/Co interface. Based on findings of our 1D model, we develop a novel method to measure heating effects in a two-material based magnetic bi-layer system and prove an efficiency boost due the exchange coupling torque at T_τ