MA 24: Focus Session: Chiral domain walls in ultrathin films

Organizer: Stefan Blügel (Forschungszentrum Jülich)

During the past years we witnessed a breakthrough in the observation and application of chiral domain walls to spintronics. In chiral domain walls the magnetization rotates from one domain to the next with a preferred handedness. They are a result of the Dzyaloshinskii-Moriya interaction originating from spin-orbit interaction in combination with the lack of inversion symmetry of the atomic structure e.g. due to the presence of interfaces. The presence of Néel-type chiral domain walls in thin perpendicularly magnetized ferromagnetic films has been pointed out by theory and they were observed first by spin-polarized scanning tunneling microscopy (SP-STM). Recent low-energy electron microscopy (LEEM) experiments show that the formation of this novel type of wall may be a rather general phenomenon in thin films with structure-asymmetry and that the chirality of the domain wall can be engineered using different materials combinations and stackings. It was demonstrated that the Dzyaloshinskii-Moriya interaction stabilizes the domain wall during motion and the current-induced wall motion is very efficient for this type of wall. The origin of the torque the current exerts on the magnetization when driving the domain wall motion, i.e. the degree of spin-transfer torque (STT) and spin-orbit torque (SOT) is currently a matter of debate. Chiral domain walls provide unprecedented opportunities for the development of spintronic devices and in the focus session we try to illuminate different aspects including their observation, the dynamics and applications.

Time: Wednesday 9:30–12:15 Location: BEY 118

Topical Talk MA 24.1 Wed 9:30 BEY 118

On the rediscovery of the Dzyaloshinskii-Moriya interaction—A review — •Matthias Bode — Physikalisches Institut, Experimentelle PhysikUniversität Würzburg II, , Am Hubland, D-97074 Würzburg, Germany

Even though it had already been theoretically predicted in 1960 [1,2] that the spin-orbit–driven Dzyaloshinskii–Moriya interaction (DMI) may lead to chiral spin structures in magnetic systems with broken inversion symmetry, this term was largely ignored for decades. This is particularly astonishing as experimental progress allowed the preparation of increasingly subtle magnetic structures which feature surfaces and interfaces or even—as in the case of magnetic nanostructures—exclusively consist of surfaces and interfaces. Obviously, in all these sample geometries inversion symmetry is broken and a sufficiently strong spin-orbit coupling should lead to chiral magnetism [3]. In this talk I will review why the importance of the DMI interaction in thin film and nano magnetism was overlooked for so long, and how scientific persistence [4] eventually led to irrefutable evidence that it not only exists [5] but in some (if not many) cases strongly influences [6,7] or even dominates magnetic order.

[1] I.E. Dzialoshinskii, Sov. Phys. JETP **5**, 1259 (1957).
[2] T. Moriya, Phys. Rev. **120**, 91 (1960).
[3] A. Bogdanov and A. Hubert, J. Magn. Magn. Mat. **138**, 255 (1994).
[4] A. Bogdanov and U. Rößler, Phys. Rev. Lett. **87**, 037203 (2001).
[5] M. Bode *et al.*, Nature **447**, 190 (2007).
[6] M. Heide *et al.*, Phys. Rev. B **78**, 140403 (2008).
[7] S. Meckler *et al.*, Phys. Rev. Lett. **103**, 157201 (2009).

Topical Talk MA 24.2 Wed 10:00 BEY 118

Chiral Magnetic Domain Wall Structure in Epitaxial Multilayers — •Yizheng Wu[1], Gong Chen[2,1], Jie Zhu[1], Alpha T. N'Diaye[2], Tianping Ma[1], HeeYoung Kwon[3], Changyeon Won[3], and Andreas. K. Schmid[2] — [1]Physics Department,Fudan University, Shanghai, China — [2]NCEM, LBNL, Berkeley, California, USA — [3]Department of Physics, Kyung Hee University, Seoul , Korea

In ultrathin film, the inversion symmetry broken at interface will induce Dzyaloshinskii-Moriya interaction (DMI). In this talk, we will show that the DMI at interface will induce the chiral Néel type domain wall in perpendicularly magnetized films. The spin structure in magnetic domain wall was identified in real-space at room temperature by spin-polarized low energy electron microscopy (SPLEEM). The chiral Néel-type domain wall was identified in the magnetic stripe domain phase in Fe/Ni/Cu(001), and the chirality can switch from the right-hand cycloid in Fe/Ni/Cu(001) to the left-hand cycloid in Ni/Fe/Cu(001), which indicates that the chirality is caused by the DMI mainly located at the Fe/Ni interface [1]. The chiral domain wall structure can also be observed in [Co/Ni]n multilayer grown on Pt(111) and Ir(111)[2]. by inserting an Ir layer between the Co/Ni stack and the Pt substrate and varying the thickness of the Ir layer, we prove that domain wall chirality together with the sign and strength of the DMI can be tuned through the interface engineering, which may enable more possibility for designing of new spintronics devices.

[1] G. Chen, et al., Phys. Rev. Lett. 110, 177204 (2013) [2] G. Chen, et al., Nature Communication, 4,2671(2013)

15 min. break

Topical Talk MA 24.3 Wed 10:45 BEY 118

'Dzyaloshinskii domain walls' in ultrathin magnetic films — •André Thiaville[1], Stanislas Rohart[1], Emilie Jué[2], Olivier Boulle[2], Vincent Cros[3], Albert Fert[3], Stefania Pizzini[4], and Jan Vogel[4] — [1]Lab. Phys. Solides, CNRS, Univ. Paris-Sud, 91405 Orsay, France — [2]SPINTEC, INAC, CEA-CNRS-UJF-INPG, 38054 Grenoble, France — [3]UMP CNRS-Thales & Univ. Paris-Sud, 91767 Palaiseau, France — [4]Institut Néel, CNRS-UJF, 38042 Grenoble, France

In ultrathin magnetic films with perpendicular anisotropy and vertical structural inversion asymmetry, we have recently proposed [1] that the domain walls are chiral Néel walls with a peculiar dynamics. This results from a Dzyaloshinskii-Moriya interaction (DMI) of the interfacial type, predicted by A. Fert long ago and observed on monolayers by SP-STM [2]. Several recent experimental observations of the dynamics of domain walls in such samples, under fields and current, are in agreement with this picture, with the effect of current incorporated by the spin Hall effect in an adjacent layer [3].

After recalling the main characteristics of these Dzyaloshinskii domain walls, I will describe additional features that occur at large values of the DMI (but still in the region where an isolated domain is stable), namely the tilt of such walls in nanostrip-shaped samples. This affects the statics and dynamics of these walls [4].

[1] A. Thiaville et al., EPL 100, 57002 (2012) [2] P. Ferriani et al., PRL 101, 027201 (2008) [3] S. Emori, et al., Nature Mater. 12, 611 (2013) [4] O. Boulle et al., PRL 111, 217203 (2013)

Topical Talk MA 24.4 Wed 11:15 BEY 118

Current-driven dynamics of chiral ferromagentic domain walls — •Geoffrey Beach — MIT Dept. of Mater. Sci. and Eng., Cambridge, MA, USA

In most ferromagnets the magnetization rotates from one domain to the next with no preferred handedness. However, broken inversion symmetry can lift the chiral degeneracy, leading to topologically rich spin textures such as spin-spirals and skyrmions via the Dzyaloshinskii-Moriya interaction (DMI) [1-3]. Here we show that in ultrathin metallic ferromagnets sandwiched between a heavy metal and an oxide, the DMI stabilizes chiral domain walls (DWs) whose spin texture enables extremely efficient current-driven motion [4-6]. We show that spin torque from the spin Hall effect drives DWs in opposite directions in Pt/CoFe/MgO and Ta/CoFe/MgO, which can be explained only if the DWs assume a Néel configuration with left-handed chirality. We directly confirm the DW chirality and rigidity by examining current-driven DW dynamics with magnetic fields applied perpendicular and parallel to the spin spiral [4,6]. This work identifies the origin of efficient current-driven domain wall motion in heavy metal/ferromagnet bilayers, and highlights a new path towards interfacial design of spintronic devices. In collaboration with S. Emori, U. Bauer, and E. Martinez.

[1] M. Bode, et al., Nature 447, 190 (2007). [2] S. Heinze, et al., Nature Physics 7, 713 (2011). [3] A. Thiaville, et al., Europhys. Lett. 100, 57002 (2012). [4] S. Emori, et al., Nature Mater. 12, 611 (2013). [5] E. Martinez, et al., APL 103, 072406 (2013). [6] S. Emori, et al., arXiv:1308.1432 (2013).

Topical Talk MA 24.5 Wed 11:45 BEY 118

Phenomenology of current-induced spin-orbit torques — •Kjetil M. D. Hals — The Niels Bohr International Academy, Niels Bohr Institute, 2100 Copenhagen, Denmark

Recent developments have shown that currents can cause magnetization torques via relativistic, intrinsic spin-orbit coupling, often referred to as spin-orbit torques (SOTs). A detailed understanding of the SOTs requires improved theoretical models that exceed the present phenomenological framework used to model current-induced magnetization dynamics. In this talk, I present a novel phenomenology of current-induced torques that is valid for any strength of intrinsic spin-orbit coupling [1]. In Pt|Co|AlOx, I demonstrate that the domain walls move in response to a novel relativistic dissipative torque that is dependent on the domain wall structure and that can be controlled via the Dzyaloshinskii-Moriya interaction. Unlike the non-relativistic spin-transfer torque, the new torque can, together with the spin-Hall effect in the Pt-layer, move domain walls by means of electric currents parallel to the walls.

[1] K. M. D. Hals and A. Brataas, Phys. Rev. B 88, 085423 (2013).