MA 31: Focus Session: Spin-Orbit Torque at Surfaces and Interfaces

Organizer: Y. Mokrousov (RWTH Aachen)

The phenomenon of the spin-orbit torque (SOT) is rapidly moving to the center of attention both in theoretical as well as applied spintronics. The principle of SOT relies on the spin-orbit interaction in combination with ferromagnetic magnetization and broken inversion symmetry, and it can be used to successfully switch the magnetization of a deposited collinear ferromagnetic layer with strong perpendicular anisotropy in an in-plane current geometry. Despite extensive experimental evidence of this effect, its origins are still intensively debated. In this session we want to focus on the foremost experimental achievements in the field of SOT, and on theoretical progress in understanding of the SOT and its description based on microscopic material theory.

Time: Wednesday 15:00–17:45 Location: BEY 118

Topical Talk MA 31.1 Wed 15:00 BEY 118
Magnetization switching and spin-orbit torques in AlOx/Co/Pt and MgO/CoFeB/Ta layers — •Pietro Gambardella — Department of Materials, ETH Zurich

Spin-orbit torques induced by spin Hall and Rashba-like effects in heavy metal/ferromagnetic bilayers allow for magnetization switching based on in-plane current injection. Using this geometry, we demonstrate deterministic magnetization reversal induced by sub-ns current pulses in 100 to 200 nm sized dots and discuss the switching efficiency as a function of pulse duration. Further, we present vector measurements of the longitudinal and transverse spin-orbit torques in AlOx/Co/Pt and MgO/CoFeB/Ta trilayers using harmonic analysis of the anomalous and planar Hall effects, providing evidence for strongly anisotropic field-like and spin transfer-like components that are compatible with the symmetry of the trilayers. The switching efficiency and relative magnitude of the longitudinal and transverse torques are analyzed in annealed MgO/CoFeB/Ta trilayers as a function of magnetization, magnetic anisotropy, and resistivity.

Topical Talk MA 31.2 Wed 15:30 BEY 118
Recent Theoretical Progress in Spin-orbit Torques — •Aurelien Manchon — Physical Science and Engineering Division, King Abdullah University of Science and Technology (KAUST), Thuwal 23955, Saudi Arabia

Utilizing spin-orbit coupling to enable the electrical manipulation of ferromagnets and magnetic textures has attracted a considerable amount of interest in the past few years. In a first part, I will introduce the most striking experimental achievements to date in bulk or interfacial inversion asymmetric systems. In a second part, I will present the most recent theoretical progress in the field, spanning from the role of intrinsic contributions to the spin-orbit torque to the impact of the newly predicted spin swapping effect. In a third part, I will introduce a new paradigm, coined spin-orbit caloritronics. Indeed, we recently demonstrated that even in the absence of magnetic texture, a magnon flow generates torques if magnons are subject to Dzyaloshinskii-Moriya interaction (DMI) just as an electron flow generates torques when submitted to Rashba interaction. We show that merging the spin-orbit torques with spin caloritronics is rendered possible by the emergence of DMI in magnetic materials and opens promising avenues in the development of chargeless information technology.

Topical Talk MA 31.3 Wed 16:00 BEY 118
Domain-wall depinning governed by the spin Hall effect — •Reinoud Lavrijsen, Bert Koopmans, Henk Swagten, Elena Mure, Jeroen Franken, and Pascal Haazen — Department of Applied Physics, Eindhoven University of Technology, Eindhoven, The Netherlands

Current induced domain wall motion (CIDWM) in perpendicular materials has caused much excitement over the last few year years due to the discovery of unexpected DW driving mechanisms. Recently, we have shown that the Spin Hall Effect (SHE) [1,2] provides a radically new mechanism for CIDWM in these systems [3]. Essential for this work was the ability to create and pin DWs at well-defined positions in a Pt/Co/Pt nanowire. By studying the depinning of these DW*s as function of applied field directions and current we were able to disentangle different contributions. This allows us to unambiguously identify the SHE as the driving mechanism.

In the first part of this talk we will discuss the SHE mechanism and introduce an DW depinning experiment that allows us to disentangle different contributions to CIDWM. In the second part of this talk we will discuss potential applications of the SHE for magnetization manipulation in gated heterostructures. Furthermore, we will discuss preliminary experiments where we study the effect of growth conditions on the SHE efficiency.

[1] I. M. Miron et al., Nature 476, 189 (2011) [2] L. Liu et al., Science 336, 555 (2012) [3] P.P.J. Haazen et al., Nature Materials, 12, 299-303 (2013

15 min. break

Topical Talk MA 31.4 Wed 16:45 BEY 118
The Spin Hall Effect and Spin Orbit Torques in Ferromagnetic/Normal Metal Nanostructures — •Robert Buhrman — Cornell University, Ithaca NY USA

In the spin Hall effect (SHE) the passage of a charge current through a non-ferromagnetic metal (NM) film generates a transverse spin current that when it impinges onto an adjacent ferromagnetic (FM) film will exert both a damping-like torque and a field-like torque on the FM, with the former arising from the absorption of the transverse component of the incident spin current and the latter due to spin rotation during the reflection of a portion of the incident spin current. Certain NMs (e.g. Pt, Ta, and W) have been found to exhibit a strong SHE and the damping-like torque that can be exerted in this manner on thin film magnetic materials has significant potential for spintronics in that it has been demonstrated to be capable of reversibly switching the magnetization direction of both in-plane and out-of-plane magnetized nanomagnets, to induce persistent microwave magnetic oscillations, and to facilitate the high-speed manipulation of domain walls in magnetic nanostrips. I will report some recent results from our SHE studies, including investigations into the fundamental role that the interfacial spin-mixing conductance plays in determining the effectiveness of the SHE for exerting strong anti-damping spin torques on the adjacent ferromagnet and experiments which demonstrate that both the damping-like torque and the field-like torque arise from the *bulk* SHE.

Topical Talk MA 31.5 Wed 17:15 BEY 118
Spin-orbit torques from first principles — •Frank Freimuth — Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Under application of electric currents, ferromagnetic (FM) layers asymmetrically sandwiched between nonmagnets (NM1, NM2) in NM1/FM/NM2 films are subject to spin-orbit torques (SOTs), which can serve to switch magnetization. Using density-functional theory calculations we study SOTs within the Kubo linear response formalism [1]. Comparing SOTs in NM1/FM films for different choices of NM1 (Pt, W, Ta, Ir, Ru, Au) we show that the sign of the spin Hall effect in these transition metals correlates with the even ("damping-like") component of SOT. Resolving torques and spin-fluxes on the atomic scale allows us to elucidate further the role of spin-currents in mediating the SOTs and to identify an additional spin-current independent component. Varying the thickness of Co and the choice of NM2 in NM2/Co/Pt(111) films we find a strong sensitivity of the odd ("field-like") component of SOT, while the even component is less sensitive. Estimating extrinsic contributions from a scalar disorder model [2] we argue that intrinsic effects prevail. We relate the intrinsic even SOT to the Dzyaloshinskii-Moriya interaction [3,4] and show that the intrinsic even SOT can be driven also by temperature gradients instead of electric currents.

[1] F. Freimuth et al., arXiv:1305.4873 [2] J. Weischenberg et al.,

PRL **107**, 106601 (2011) [3] F. Freimuth et al., arXiv:1308.5983 [4] F. Freimuth et al., arXiv:1307.8085