MA 52: Focus: Ultrafast spin currents for spin-orbitronics: from metals to topological insulators

Organized by Y. Mokrousov (FZ-Jülich) and M. Münzenberg (U. Greifswald)

Engineering relativistic spin-charge entanglement in complex multi-functional materials allows for novel ways of spin control. At the heart of newly discovered phenomena in the field of spinorbitronics is the relativistic spin-orbit interaction, which leads to a multitude of phenomena related to relativistic scattering, spin Hall effect and spin current generation, currently all of central interest in a spectrum of materials ranging from common metals to exotic topological insulators. The effect of spin-orbit torque (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 ferromagnets with electric field. While the SOT is a candidate for non-volatile random access and cache memories, the design of future relativistic spintronics devices relies on a deep microscopic understanding of coupled phenomenona taking place in prototypical experimental setups. Furthermore, to achieve ultrafast switching dynamics in these devices, the exploration and understanding of non-equilibrium spin-orbit physics at high frequencies is of utter importance. Spin-orbit effects at femtosecond time scale are believed to be very important for spin momentum redistribution in the presence of laser field-driven currents, and this issue is heavily debated at the moment. In this focus session we highlight the very recent developments related to the interplay of spin-orbit interaction and ultrafast currents in diverse materials.

Time: Friday 9:30–12:15 Location: H32

Invited Talk MA 52.1 Fri 9:30 H32

Experimental separation of various mechanisms leading to laser-pulse-induced magnetization precession in (Ga,Mn)As — •Petr Nemec — Charles University in Prague, Ke Karlovu 3, 121 16 Prague 2, Czech Republic

Ferromagnetic semiconductor (Ga,Mn)As is a favorable material for observing optical spin torques because the direct-gap GaAs host allows the generation of high density non-equilibrium photo-carriers and the carrier spins interact with ferromagnetic moments on Mn via strong exchange coupling [1]. In this contribution we show how various excitation mechanisms leading to laser-pulse-induced magnetization precession in (Ga,Mn)As can be experimentally separated. In particular, we demonstrate how the optical spin transfer torque, which is a non-relativistic phenomenon where angular momentum of spin polarized electrons photoinjected by circularly polarized laser pulse is transferred to the magnetization [2], and optical spin-orbit torque, which is a relativistic phenomenon originating from spin-orbit coupling of non-equilibrium photocarriers [3], can be separated from each other and from the thermal mechanism. We also illustrate how the laser-induced magnetization dynamics can be used for a determination of magnetic parameters of (Ga,Mn)As [4] and other materials.

[1] T. Jungwirth et al., Rev. Mod. Phys. 86, 855 (2014). [2] P. Nemec et al., Nature Physics 8, 411 (2012). [3] N. Tesarova et al., Nature Photonics 7, 492 (2013). [4] P. Nemec et al., Nature Communications 4:1422 (2013).

Invited Talk MA 52.2 Fri 10:00 H32

Ultrafast photocurrents and quantized conductance in 3D topological insulators — •Alexander Holleitner — Walter Schottky Institut and Physics Department, Technical University of Munich, Am Coulombwall 4a, 85748 Garching

We demonstrate that helicity-dependent photocurrents in 3D topological insulators can be controlled and read-out on a time-scale of a picosecond with near-unity fidelity even at room temperature [1,2]. Our experiments reveal the temporal interplay of such ultrafast spin currents with photo-induced thermoelectric currents of hot electrons in the optoelectronic circuits. Moreover, we verify millimeter-scale edge channels in bismuth chalcogenides with a quantized conductance of 1 e^2/h at zero magnetic field. In optoelectronic experiments [3], the quantum transport is found at the lateral edges of the 3D topological insulators and is explained by a one-dimensional quantum confinement of non-topological surface states with a strong Rashba spin-orbit coupling [4].

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[1] L. Prechtel et al. Nature Comm. 3, 646 (2012).
[2] C. Kastl et al. Nature Comm. 6, 6617 (2015).
[3] C. Kastl et al. 2D Materials 2, 024012 (2015).
[4] C. Kastl et al. (2016).

15 min. break

Invited Talk MA 52.3 Fri 10:45 H32

Real-time time-dependent DFT for spin dynamics in magnets — •Stefano Sanvito, Maria Stamenova, and Jacopo Simoni — School of Physics and CRANN, Trinity College, Dublin 2, Ireland

Ultra-fast laser-driven spin dynamics is rapidly becoming a tool to manipulate the magnetic interaction at the femtosecond timescale. In this limit both the magnetic exchange and the anisotropy become time-dependent and the modelling of the spin-dynamics must be carried out at the electronic level. Here we show how real time time-dependent density functional theory can be used to understand the first femtoseconds of the laser-induced spin dynamics of magnetic transition metals. In particular we will present the case of both finite magnetic clusters and bulk transition metals. We will show how the demagnetisation immediately following the laser excitation is uniquely driven by the strength of the spin-orbit interaction, and how it relates to oscillations of the charge density between the core and the interstitial regions. Furthermore, we will demonstrate how such rapid demagnetisation is affected by the laser intensity and polarisation, and how it scales with the size of the system under investigation.

Invited Talk MA 52.4 Fri 11:15 H32

Spin transport and spin-orbit interaction at terahertz frequencies: spectroscopy and applications — •Tom Seifert — Fritz-Haber-Institute, Berlin, Germany

On the route toward spin-based electronics (spintronics), spin-orbit interaction (SOI) is envisioned to play a major role since it permits spin-to-charge conversion and vice versa via the spin Hall effect (SHE). To study the dynamics of the SHE and related effects, terahertz (THz) time-domain spectroscopy is a promising tool because THz photon energies (4 meV at 1 THz) are comparable with the energy scale of SOI (1-100 meV). At the same time, future spintronic devices should eventually operate at such elevated frequencies.
Here, we use two complementary approaches to address the interplay of SOI, electron and spin transport at THz frequencies. First, we employ broadband THz time-domain ellipsometry [*A. Rubano et al., APL (2012)*] to measure the anomalous Hall effect in various magnetic metals from 1 to 40 THz. Second, we use femtosecond laser pulses (800 nm, 10 fs, 2 nJ) to induce ultrafast spin currents in magnetic heterostructures which, through the inverse SHE, lead to emission of THz radiation [*T. Kampfrath et al., NatNano (2013)*]. Detection of the latter allows us to measure the spin current and the spin Hall angle in a contactless manner. Finally, optimization of these structures results in new, efficient, scalable and ultrabroadband emitters of THz electromagnetic pulses [*T. Seifert et al., http://arxiv.org/abs/1510.03729 (2015)*].

Invited Talk MA 52.5 Fri 11:45 H32

Driving currents by magnetization dynamics in systems with broken inversion symmetry — •Frank Freimuth — Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

By breaking the inversion symmetry in crystals, one switches on the correlation between axial and polar vectors, which otherwise would be forbidden by symmetry. In magnetic crystals one can thereby generate torques on the magnetization by applying electrical or heat currents, the so-called spin-orbit torques. Conversely, magnetization dynamics induces currents, which is the inverse spin-orbit torque effect. At small frequencies, i.e., under typical FMR conditions, the inverse spin-orbit torque can be understood in terms of spin pumping combined with the spin-Hall effect and the Rashba or Dresselhaus spin-orbit fields. However, when magnetic solids are excited by femtosecond laser pulses, additional effects set in, such as the generation of ultradiffusive spin-currents and ultrafast demagnetization, which lead to new mechanisms for generating electrical currents in inversion asymmetric magnets. Using the Kubo linear response formalism we systematically identify mechanisms behind the generation of electrical currents in the range from FMR up to optical frequencies, discovering also several new effects. In particular, we find that not only precession of magnetization, but also demagnetization, drive currents. Based on DFT calculations we investigate these effects in Co/Pt and Mn/W bilayers as well as in the half-Heusler compound PtMnSb and elucidate the role that spin-currents play.