MA 24: Spin Transport and Orbitronics, Spin-Hall Effects

Time: Wednesday 15:00–18:00 Location: H37

MA 24.1 Wed 15:00 H37

Interplay between ferroelectricity and orbital angular momentum in a two-dimensional SnTe monolayer — •Dimos Chatzichrysafis[1,2], Dongwook Go[1,3], and Stefan Blügel[1] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Physics Department, RWTH-Aachen University, 52062 Aachen, German — [3]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany

Recent work on Orbitronics has shown that the orbital angular momentum (OAM) plays an important role in transport phenomena. A question that has arisen concerns the exploration of physical mechanisms that can serve as a control knob for the OAM. For that, ferroelectrics comprise the perfect playground. In this talk, we theoretically investigate the interplay between the electrical polarization in 2D SnTe monolayer, the OAM, and its transport effects. Using a tight-binding model we analyze the influence of the ferroelectric polarization on the electronic structure and the OAM texture. Based on this, we show that electric responses of the OAM and its current can be modulated by a ferroelectric order parameter. We believe that our work provides a novel route to controlling the OAM in 2D materials

MA 24.2 Wed 15:15 H37

Spin and orbital transport in rare earth dichalcogenides: The case of EuS2 — •Mahmoud Zeer[1,2], Dongwook Go[1,3], Johanna P Carbone[1,2], Tom G Saunderson[3], Matthias Redies[1,2], Mathias Kläui[3], Jamal Ghabboun[4], Wulfhekel Wulf[3], Stefan Stefan Blügel[1,2], and Yuriy Mokrousov[1,3] — [1]Peter Grünberg Institute and Institute for Advanced Simulation,Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Department of Physics, RWTH Aachen University, 52056 Aachen, Germany — [3]Institute of Physics, Johannes Gutenberg-University Mainz, 55099 Mainz, Germany — [4]Department of Physics, Bethlehem University, Bethlehem, Palestine

With first principles the electronic, magnetic and transport properties of rare-earth dichalcogenides taking a monolayer of the H-phase EuS_2 as a representative. We predict that the H-phase of the EuS_2 monolayer exhibits a half-metallic behaviour upon doping with a very high magnetic moment. We find the EuS_2 is very sensitive to the value of Coulomb repulsion U. We further predict that the non-trivial electronic structure of EuS_2 directly results in a pronounced anomalous Hall effect with non-trivial band topology. Moreover, while we find that the spin Hall effect closely follows the anomalous Hall effect in the system, the orbital complexity of the system results in a very large orbital Hall effect, whose properties depend very sensitively on the strength of correlations. Our findings thus promote rare earth based dichalcogenides as a promising platform for topological spintronics and orbitronics. Work funded by (MMBF-01DH16027, Zeer et al., arXiv:2201.11017

MA 24.3 Wed 15:30 H37

Differences between magnetotransport properties of doped alloys and doped crystals via ab-initio calculations — •Ondrej Sipr[1,2], Sergey Mankovsky[3], and Hubert Ebert[3] — [1]Institute of Physics, Czech Academy of Sciences, Praha — [2]New Technologies Research Centre, University of West Bohemia, Plzeň — [3]Ludwig-Maximilians-Universität München

The description of magnetotransport has so far focused on how doping influences clean crystals. However, interest is turning also to substitutional alloys as hosts. Our aim is to investigate to what extent the approaches that proved to be useful for doped crystals can be applied to doped alloys. Calculations are performed for permalloy $Fe_{19}Ni_{81}$ doped with V, Co, Pt, and Au impurities, relying on the Kubo-Bastin equation implemented using the KKR-Green function method.

The dependence of the anomalous Hall and spin Hall conductivities σ_{xy} and σ^z_{xy} on the dopant concentration is nonmonotonic and strongly influenced by the temperature. The fact that the host is disordered and not crystalline has profound influence on how σ_{xy} and σ^z_{xy} depend on the dopant concentration. In particular, σ_{xy} and σ^z_{xy} are not proportional to σ_{xx} for low dopant concentrations. Consequently, the dependence of the anomalous Hall effect and spin Hall effect on the dopant concentration cannot be ascribed unambigously to skew scattering, side-jump scattering, or intrinsic contributions in the same way as it can be done when investigating the effect of doping for a crystalline host, i.e., the standard scaling laws do not apply.

MA 24.4 Wed 15:45 H37

Atomic scale control of spin current transmission at interfaces — •Mohamed Amine Wahada[1], Ersoy Sasioglu[2], Wolfgang Hoppe[3], Xilin Zhou[1], Hakan Denis[1], Reza Rouzegar[4], Tobias Kampfrath[4], Ingrid Mertig[2], Stuart Parkin[1], and Georg Woltersdorf[3] — [1]Max Planck Institute of Microstructure Physics, Weinberg 2, 06120 Halle(Saale) — [2]Institute of Physics, Martin Luther University Halle-Wittenberg, Von-Seckendorff-Platz 1, 06120 Halle, Germany — [3]Institute of Physics, Martin Luther University Halle-Wittenberg, von Danckelmann Platz 3, 06120 Halle, Germany — [4]Department of Physics, Freie Universität Berlin, Arnimalee 14, 14195 Berlin, Germany

Ferromagnet (FM)/heavy metal (HM) bilayers are a fundamental building block in the field of spintronics. Exciting such bilayers with a femtosecond laser pulse can trigger ultrafast spin current (SC) from the FM to the HM layer. In the HM layer, the spin Hall effect converts the SC pulse into a charge current pulse, enabling efficient spintronic THz emitters. Equally as important as the SC generation process is the efficiency of the SC transmission across the FM/HM interface. We show experimentally that the SC transmission is partially suppressed when Ta is interfaced directly with 3d FM materials while this effect is absent when Pt is used as a HM. Based on theoretical calculations, we show that this is due to 3d-5d hybridization effects causing a significant moment reduction at the interface. This effect is expected for all 5d elements with less than half-filled 5d shell. Furthermore, we show that this effect can be eliminated by atomic scale oxide interlayers.

MA 24.5 Wed 16:00 H37

Spin Dynamics in Magnetic Nanojunctions — •Rudolf Smorka[1], Martin Žonda[2], and Michael Thoss[1,3] — [1]Institute of Physics, Albert-Ludwigs-Universität Freiburg — [2]Department of Condensed Matter Physics, Faculty of Mathematics and Physics, Charles University Prague — [3]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg

Recent experimental advances of atomic and nanoscale magnetism motivate the study of spin dynamics on ultrafast time scales. In this contribution, we use a quantum-classical hybrid approach to study current-driven magnetization dynamics in systems consisting of tight-binding electrons and localized classical spins. Using this approach, we show that both the electronic structure of the central system and the self-consistent feedback of spin and electron dynamics play a significant role in the dynamical properties of magnetic nano-junctions driven by a dc voltage. Specifically, relaxation dynamics can be enhanced by tuning the dc voltage in resonance with electronic levels of the central system. We analyze this characteristic in nano-junctions containing a single classical Kondo impurity. Furthermore, we investigate current-induced spin-transfer torques in a ferromagnetic spin valve far away from equilibrium and show that electronic levels in the bias window lead to an enhancement of the spin-transfer torques.

MA 24.6 Wed 16:15 H37

Spin and orbital Edelstein effects in a bilayer system with Rashba interaction — •Sergio Leiva[1], Ingrid Mertig[1], and Annika Johansson[2] — [1]Martin Luther University Halle-Wittenberg, Institute of Physics, 06099 Halle, Germany — [2]Max Planck Institute of Microstructure Physics, Halle, Germany

The spin Edelstein effect has proved to be a promising phenomenon to generate spin polarization from a charge current in systems without inversion symmetry. In recent years, current-induced orbital magnetization, also called the orbital Edelstein effect, has also been predicted for various systems with broken inversion symmetry [1-7].

In the present work, we calculate the current-induced spin and orbital magnetization for a bilayer system with Rashba interaction, using Boltzmann transport theory with a constant relaxation time. We compare the magnitudes of the spin and orbital Edelstein effects and find that their dependencies on model parameters such as effective mass, spin-orbit coupling, or energy, differ qualitatively, and they can even exhibit opposite signs.

[1] T. Koretsune *et al.*, Phys. Rev. B, **86**, 125207 (2012).

[2] T. Yoda *et al.*, Sci. Rep., **5**, 12024 (2015).
[3] D. Go *et al.*, Sci. Rep. **7**, 46742 (2017)
[4] T. Yoda *et al.*, Nano Lett., **18**, 916 (2018).
[5] L. Salemi *et al.*, Nat. Commun. **10**, 5381 (2019)
[6] D. Hara *et al.*, Phys. Rev. B, **102**, 184404 (2020).
[7] A. Johansson *et al.*, Phys. Rev. Research, **3**, 013275 (2021).

MA 24.7 Wed 16:30 H37

Dynamic and static detection of current-induced spin-orbit magnetic fields — •Lin Chen[1], Matthias Kronseder[2], Dieter Schuh[2], Dominique Bougeard[2], Jaroslav Fabian[2], Dieter Weiss[2], and Christian Back[1] — [1]Department of Physics, Technical University of Munich, Garching bei Munich, Germany — [2]Institute of Experimental and Applied Physics, University of Regensburg, Regensburg

Quantifying current-induced effective spin-orbit magnetic-fields (SOFs) accurately is a central task for spin-orbitronics. Several methods, e.g., spin-transfer torque ferromagnetic resonance or second harmonic Hall measurements, have been frequently used in the past 10 years. However, most methods show weaknesses, and are not ideal to determine SOFs. Here, we will show two new approaches in this regard. Firstly, we show that it is possible to quantify the SOFs through an analysis of the shape of standing spin-wave patterns, which are probed by time-solved magneto-Kerr microscopy in a laterally confined Fe/GaAs system. This method, which is conceptually different from previous approaches based on lineshape analysis, is phase independent and self-calibrated1. Secondly, we show that one can simultaneously quantify the SOFs and the unidirectional magnetoresistance (UMR) by measuring the second harmonic longitudinal resistance in Co/Pt bilayers2. From these measurements, we can: I) establish a connection between SOFs and UMR, and II) discuss the origin of SOFs. References:1.L. Chen et. al., Phys. Rev. B. 104, 014425 (2021).2.L. Chen et. al., Phys. Rev. B 105, L020406 (2022).

MA 24.8 Wed 16:45 H37

Hidden current-induced spin and orbital torques in bulk Fe_3GeTe_2 from first-principles — •Tom G. Saunderson[1,2], Dongwook Go[1,2], Stefan Blügel[2], Mathias Kläui[1,3], and Yuriy Mokrousov[1,2] — [1]Institute of Physics, JGU, 55099 Mainz, Germany — [2]PGI and IAS, Forschungszentrum Jülich, Germany — [3]Centre for Quantum Spintronics, NTNU, 7491 Trondheim, Norway

Within the field of spintronics, the two dimensional (2D) van der Waals (vdW) material Fe_3GeTe_2 has been in the spotlight in the last few years for exciting characteristics such as nodal line semimetallicity [1], highly efficient spin-orbit torque switching [2] and skyrmion formation [3]. In a recent collaboration [4] we found that spin-orbit torques were observed within the bulk, yet the clean crystal's bilayer system is centrosymmetric. Whilst this leads to overall vanishing spin-orbit torques, strong 'hidden' current-induced torques are harvested by each of the two-dimensional FGT layers separately. We demonstrate, from first principles [5], that an interplay of spin and orbital degrees of freedom has a profound impact on spin-orbit torques in this prototype material. We uncover a drastic difference in the behavior of the conventional spin flux torque and so-called orbital torque as the magnetization is varied resulting in a non-trivial evolution of switching properties. Our findings promote the design of non-equilibrium orbital properties as the guiding mechanism for crafting the properties of spin-orbit torques in layered vdW materials. [1] Nat. Mater. 794, 17 (2018) [2] Nano Lett. 4400, 19 (2019) [3] Nano Lett. 868, 20 (2020) [4] arXiv:2107.09420 [5] arXiv:2204.13052

MA 24.9 Wed 17:00 H37

Modeling spin transport through thin antiferromagnetic insulators — •Niklas Rohling[1] and Roberto E. Troncoso[2,3] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz — [2]Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim — [3]Department of Mechanical and Industrial Engineering, NTNU

Experiments have shown spin transport enhancement by a thin antiferromagnetic insulator between a metal and a ferromagnetic insulator [1]. While previous theoretical work [2] was able to reproduce some of the features of those experiments, the interface is typically described by a single parameter only. We consider a model of a thin layer NiO oriented in (111) direction, sandwiched between a metal and a ferromagnetic insulator. We take into account nearest and next-nearest neighbor exchange coupling at the interfaces as well as different magnetic order. We compute the spin current through this system using Fermi's Golden Rule [3]. We find a sensitive dependence on the magnetic configuration as well as on the interface parameters.

[1] Wang et al., Phys. Rev. Lett. 113, 097202 (2014), Phys. Rev. B 91, 220410(R) (2015); Lin et al. Phys. Rev. Lett. 116, 186601 (2016).

[2] Khymyn et al., Phys. Rev. B 93, 224421 (2016); Rezende et al., Phys. Rev. B 93, 054412 (2016).

[3] Bender et al., Phys. Rev. Lett. 108, 246601 (2012).

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MA 24.10 Wed 17:15 H37

Unified theory of itinerant transport in magnetic platforms based on the slave-boson formalism — •Ricardo Zarzuela[1] and Jairo Sinova[1,2] — [1]Institut für Physik, Johannes Gutenberg Universität Mainz, D-55099 Mainz, Germany — [2]Institute of Physics Academy of Sciences of the Czech Republic, Cukrovarnická 10, 162 00 Praha 6, Czech Republic

The slave-boson formalism, rooted in the idea that electron hopping in the lattice is accompanied by a backflow of spin excitations, has been widely used in the field of strongly correlated systems to describe metal-insulator transitions and high-Tc superconductivity, to name a few. It is also well suited to explore transport phenomena in spintronic platforms, since the spin exchange with the magnetic background can be easily incorporated into the representation of the electron operators. We show that the slave-boson approach to the Hubbard model for conduction electrons (near half filling) yields an effective low-energy long-wavelength theory for the itinerant transport in magnetic conductors. In particular, an emergent coupling between the magnetization current and the itinerant spin current is responsible for the spin-transfer physics as well as the topological Hall effect observed in magnetic systems. Our slave-boson approach does not require the adiabatic dynamics of the itinerant carriers, so our findings hold for any itinerant spin polarization. We also show that topological defects (e.g., magnetic vortices and magnetic disclinations) mediate both spin-transfer and topological Hall responses in the magnetic medium, which have not been observed experimentally yet.

MA 24.11 Wed 17:30 H37

Non-Collinear Spin Current for Switching of Chiral Magnetic Textures — •Dongwook Go[1,2], Moritz Sallermann[1,3], Fabian R. Lux[2], Stefan Blügel[1], Olena Gomonay[2], and Yuriy Mokrousov[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany — [3]Science Institute and Faculty of Physical Sciences, University of Iceland, VR-III, 107 Reykjavík, Iceland

We propose a concept of non-collinear spin current, whose spin polarization varies in space even in non-magnetic crystals. While it is commonly assumed that the spin polarization of the spin Hall current is uniform, asymmetric local crystal potential generally allows the spin polarization to be non-collinear in space. Based on microscopic considerations we demonstrate that such non-collinear spin Hall currents can be observed for example in layered Kagome Mn_3X (X = Ge, Sn) compounds. Moreover, by referring to atomistic spin dynamics simulations we show that non-collinear spin currents can be used to switch the chiral spin texture of Mn_3X in a deterministic way even in the absence of an external magnetic field. Our theoretical prediction can be readily tested in experiments, which will open a novel route toward electric control of complex spin structures in non-collinear antiferromagnets. Reference: Go *et al.* arXiv:2201.11476

MA 24.12 Wed 17:45 H37

Theory of charge and spin pumping in atomic-scale spiral magnets — Daichi Kurebayashi[1,2], Yizhou Liu[1], •Jan Masell[1,3], and Naoto Nagaosa[1,4] — [1]RIKEN CEMS, Wako, Japan — [2]University of New South Wales, Sydney, Australia — [3]Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — [4]University of Tokyo, Tokyo, Japan

An Archimedean screw is a classical pump that exploits the equivalence of rotation and translation in helices. Similarly, a spin spiral texture can pump charge and spin by rotating at a frequency. We study these pumping phenomena within a microscopic quantum model by both perturbation theory and numerical simulations. Inside the spiral region, the spin polarization and charge current are linear in the frequency whereas the spin current scales with its square. We find that the charge current is related to the mixed momentum-phason Berry phase which can be viewed as a novel approximate realization of a Thouless pump. It is nearly quantized in spirals with short pitch but decays with 1/lambda for longer pitches unlike true Thouless pumps or Archimedean screws. Moreover, we study the onset of non-adiabaticity, the impact of attached non-magnetic or magnetic contacts, the real-time evolution of the transport observables, and the efects of disorders which, surprisingly, might enhance the spin current but suppress the charge current.[1]

[1] D. Kurebayashi, Y. Liu, J. Masell, and N. Nagaosa, https://doi.org/10.48550/arXiv.2201.05446