MA 11: Spin Transport and Orbitronics, Spin-Hall Effects I (joint session MA/TT)

Time: Tuesday 9:30–13:15 Location: H18

MA 11.1 Tue 9:30 H18

Topological orbital Hall effect caused by skyrmions and antiferromagnetic skyrmions — •Lennart Schimpf, Ingrid Mertig, and Börge Göbel — Institut für Physik, Martin-Luther-Universität Halle-Wittenberg

The topological Hall effect is a hallmark of topologically non-trivial magnetic textures such as magnetic skyrmions. It quantifies the transverse electric current once an electric field is applied and occurs as a consequence of the emergent magnetic field of the skyrmion. Likewise, an orbital magnetization is generated. Here we show that the charge currents are orbital polarized even though the conduction electrons couple to the skyrmion texture via their spin [1]. The topological Hall effect is accompanied by a topological orbital Hall effect even for s electrons without spin-orbit coupling. As we show, antiferromagnetic skyrmions and antiferromagnetic bimerons that have a compensated emergent field [2], exhibit a topological orbital Hall conductivity that is not accompanied by charge transport and can be orders of magnitude larger than the topological spin Hall conductivity.

[1] B. Göbel, L. Schimpf, I. Mertig, arXiv pre-print: 2410.00820
[2] B. Göbel, I. Mertig, O. Tretiakov, Physics Reports 895, 1 (2021)

MA 11.2 Tue 9:45 H18

Optimization of orbital torques in ferrimagnets and their relationship with Gilbert damping — •shilei ding, william legrand, hanchen wang, mingu kang, paul noel, and pietro gambardella — Department of Materials, ETH Zurich, 8093 Zurich, Switzerland

Application of an electric field can induce a non-equilibrium orbital angular momentum in conductive materials whose electronic bands have a k-dependent orbital character. This phenomenon can lead to the current-induced accumulation of orbital momenta in nonmagnetic layers, which can then diffuse into neighboring magnetic layers and interact with the local magnetization through spin-orbit coupling, giving rise to orbital torques. Conversely, the excitation of spin precession in a magnetic layer can give rise to an orbital current, resulting in orbital pumping and dissipation of angular momentum in the nonmagnetic layer. In the first part, I will present the efficacy of converting orbital to spin momenta in ferrimagnetic materials, specifically in the RE-TM ferrimagnet GdyCo100-y. This work underscores the mechanisms that facilitate orbital-to-spin conversion within a magnetic layer at the atomic level. In the second part, I will discuss how the Gilbert damping parameter correlates to spin and orbital torques in magnetic layers adjacent to Pt and CuOx layers, respectively. I will show that CoFe/CuOx bilayers exhibit a favorable combination of efficient orbital torque and minimal increase in Gilbert damping, which is promising for the implementation of orbital torque oscillators with reduced damping compared to spin torque oscillators.

MA 11.3 Tue 10:00 H18

Orbital magnetoresistance in insulating antiferromagnets — •Christin Schmitt[1], Sachin Krishnia[1], Edgar Galíndez Ruales[1], Takashi Kikkawa[2], Duc Tran[1], Timo Kuschel[1], Eiji Saitoh[2], Yuriy Mokrousov[1,3], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg-University Mainz, 55128 Mainz, Germany — [2]Department of Applied Physics, The University of Tokyo, Tokyo 113-8656, Japan — [3]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Insulating antiferromagnetic and ferrimagnetic materials are promising candidates for spintronic devices due to their intrinsic properties such as low damping [1]. Recently, orbital angular momentum (OAM) has emerged as a crucial concept in condensed-matter physics. Theoretical and experimental studies have highlighted that the orbital Hall effect (OHE) can enable orbital currents with efficiency orders of magnitude higher than that of spin Hall effects [2]. Here, we investigate magneto-resistance effects in magnetic systems [2,3]. We find that in TmIG the transverse magnetoresistance signal is increased significantly upon replacing Pt, a spin-current generator, by Cu*, a pure orbital-current generator. Further, we explore antiferromagnets with orbital magnetoresistance effects as pure orbital current is crucial for next generation pure orbitronics devices using abundant, cheap and environmentally friendly materials. [1] R. Lebrun, et al., Nature, 561, 222-225 (2018). [2] S. Ding, et al., Phys. Rev. Lett. 125, 177201 (2020). [3] S. Ding et al., Phys. Rev. Lett. 128, 067201 (2022).

MA 11.4 Tue 10:15 H18

Non-reciprocity in magnon mediated charge-spin-orbital current interconversion — •Sachin Krishnia[1], Omar Ledesma-Martin[1], Edgar Galindez-Ruales[1], Felix Fuhrmann[1], Duc Tran[1], Rahul Gupta[1], Marcel Gasser[1,2], Dongwook Go[1,2], Gerhard Jakob[1], Yuriy Mokrousov[1], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

In magnetic systems, angular momentum is carried by the spin and orbital degrees of freedom. Non-local devices can be used to study angular momentum transport. They consist of parallel heavy-metal nanowires placed on top of magnetic insulators like yttrium iron garnet (YIG), facilitating the transmission of information by magnons, generated by the accumulation of spin at the interface, created via the spin Hall effect (SHE) and detected via the inverse SHE (iSHE). It has been demonstrated that these processes have comparable efficiencies when the role of the detector and injector is reversed, which points to reciprocity of the processes. However, we show that by adding Ru as a source of direct and inverse orbital Hall effect (OHE), the system no longer exhibits this reciprocity. Specifically, the generation of magnons via the combination of SHE and OHE and detection via the iSHE is found to be about 35% more efficient than the inverse process for our system [1]. [1] O. Ledesma et al., arXiv:2411.07044 (2024).

MA 11.5 Tue 10:30 H18

Detection of dynamic x-ray magnetic linear dichroism in NiO — •Timo Kuschel[1], Johannes Demir[1], Olga Kuschel[2], Joachim Wollschläger[2], and Christoph Klewe[3] — [1]Bielefeld University, Germany — [2]Osnabrück University, Germany — [3]Advanced Light Source (ALS), Berkeley, USA

Spin transport through thin antiferromagnetic layers such as NiO has been studied by ferromagnetic resonance (FMR) spin pumping [1], spin Seebeck effect [2], non-local magnon spin transport [3] and x-ray detected FMR (XFMR) [4]. In all these experiments, the spin current has been identified in an adjacent Pt layer [1-3] or FeCo film [4] via inverse spin Hall effect or dynamic x-ray magnetic *circular* dichroism, respectively, after having the NiO layer already passed.

In this contribution, we study Fe_3O_4/NiO/Pt [5] by XFMR and present the identification of dynamic x-ray magnetic *linear* dichroism (XMLD) [6] at the Ni L edges directly in the NiO layer for FMR spin pumping in the adjacent Fe_3O_4 layer. We will analyze the XFMR response depending on the NiO thickness. Further, we will discuss coupling phenomena at the NiO-Fe_3O_4 interface vs. spin transport through the NiO layer as the origin of the dynamic XMLD response.

[1] H. L. Wang et al., Phys. Rev. Lett. 113, 097202 (2014)
[2] W. Lin et al., Phys. Rev. Lett. 116, 186601 (2016)
[3] G. R. Hoogeboom et al., Phys. Rev. B 103, 144406 (2021)
[4] M. Dabrowski et al., Phys. Rev. Lett. 124, 217201 (2020)
[5] L. Baldrati et al., Phys. Rev. B 98, 014409 (2018)
[6] C. Klewe et al., New J. Phys. 24, 013030 (2022)

MA 11.6 Tue 10:45 H18

Manipulating the sign of the interlayer exchange coupling — •Nathan Walker — The Open University, Milton Keynes, UK

We demonstrate, using computer simulations and a non-equilibrium Greens function approach, that the sign of the out-of-equilibrium interlayer exchange coupling (ooeIEC) changes in the presence of an external bias. The system consists of a double barrier connected to an exchange coupled ferromagnetic tri-layer. We find a strongly nonlinear dependence of the spin current on voltage which results in the exchange coupled tri-layer switching between parallel and antiparallel configurations. Our results are in excellent agreement with earlier theoretical calculations, which predict an approximately 2π topological phase change of the (equilibrium) IEC. We believe that this could act as an energy efficient mechanism for magnetic switching which does not rely on spin-transfer torque (STT). There are potential applications to magnetoresistive random-access memory (MRAM), one of the principal contenders for a universal memory.

MA 11.7 Tue 11:00 H18

Harnessing Orbital Hall Effect in Spin-Orbit Torque MRAM
— •J. Omar Ledesma Martin[1,2], Rahul Gupta[1], Chloé Bouard[2], Fabian Kammerbauer[1], Iryna Kononenko[1], Sylvain Martin[2], Gerhard Jakob[1,3], Marc Drouard[2], and Mathias Kläui[1,3] — [1]1 Institute of Physics, Johannes Gutenberg University Mainz, 55099, Mainz, Germany — [2]Staudingerweg 7 — [3]Department of Physics, Center for Quantum Spintronics, Norwegian University of Science and Technology, 7491, Trondheim, Norway

There is considerable potential in the Orbital Hall Effect (OHE) and the Spin Hall Effect (SHE) as electrical means for controlling the magnetization of spintronic devices. Here Ru stands out exhibiting an orbital Hall conductivity four times greater than the spin Hall conductivity of Pt. [1] This work assesses the efficiency of four distinct stacks in devices with perpendicular Magnetic Tunnel Junctions (MTJ). Following the formula Ta/OHE/Pt/[Co/Ni]x3/Co/MgO/CoFeB/Ta/Ru, where the OHE materials are Ru, Nb, and Cr. Additionally, a sample with Pt instead of OHE serves as a reference. The results demonstrate an improvement for the Ru samples, exhibiting higher damping-like torque and significantly lower switching current density compared to both the other samples and the Pt reference. These findings, including first-principle calculations, underscore the potential of Ru as an OHE material for enhancing the performance and power consumption of spintronic devices.

[1] R. Gupta et al., arXiv:2404.02821 (2024). Nature Comm. In press (2024)

15 min. break

MA 11.8 Tue 11:30 H18

Spin and orbital Hall effect in metal systems: extrinsic vs. intrinsic contributions
— •Sergiy Mankovsky and Hubert Ebert — LMU of Munich, 81377 Munich, Germany

Kubo's linear response formalism has been used to study the orbital Hall effect (OHE) for non-magnetic undoped and doped metallic systems, focusing on the impact of different types of disorder. Corresponding first-principles calculations of the orbital Hall conductivity (OHC) were performed making use of the KKR Green function method that allows in particular to monitor the impact of the vertex corrections on the OHC. The doping- and temperature-dependence of the OHC have been investigated and compared with corresponding results for the spin Hall conductivity (SHC). The temperature dependent properties of the OHC and SHC determined by thermally induced lattice vibrations (in non-magnetic materials) and spin fluctuations (in magnetic systems) have been accounted for making use of the alloy analogy model. For elemental systems at finite temperature a dominating role of the intrinsic contribution to the temperature-dependent OH and SH conductivities is found. In contrast, the OH and SH conductivities of doped systems at low temperatures are dominated by the SOC-driven extrinsic contributions strongly decreasing at higher temperatures due to the increasing impact of the electron-phonon scattering.

MA 11.9 Tue 11:45 H18

Simulations of spin transport in YIG
— •Ben Schwanewedel, Moumita Kundu, and Ulrich Konstanz — Fachbereich Physik, Universität Konstanz, Konstanz, Germany

Being synthesized first in 1957, YIG has the lowest Gilbert damping among all known materials. This makes it interesting for spintronic applications and long-range spin transport. In YIG's complex unit cell Fe atoms occupy 20 sublattices leading to 20 magnon bands between 0 and 25 THz. We develop an atomistic spin model for YIG based on exchange interactions from Ref. [1], which were determined through neutron scattering. Further parameters were adapted from Ref. [2]. We varify our study through investigation of the magnon dispersion and comparing it to the results of Ref. [1].

We use atomistic spin dynamics simulations for the model above based on the stochastic Landau-Lifshitz-Gilbert equation to unravel its spin dynamics and spin transport properties. The spin transport is triggered by thermal gradients and and local magnetic fields and it is analyzed using an observable which is proportional to the magnon population. Also, magnon dispersions far from equilibrium are evaluated and discussed.

[1] Princep, Andrew J., et al. "The full magnon spectrum of yttrium iron garnet." npj Quantum Materials 2.1 (2017): 63.

[2] Barker, Joseph, and Gerrit EW Bauer. "Thermal spin dynamics of yttrium iron garnet." Physical review letters 117.21 (2016): 217201.

MA 11.10 Tue 12:00 H18

Orbital Hall effect accompanying quantum Hall effect
— •Börge Göbel and Ingrid Mertig — Institut für Physik, Martin-Luther-Universität Halle-Wittenberg

The quantum Hall effect emerges when two-dimensional samples are subjected to strong magnetic fields at low temperatures: Topologically protected edge states cause a quantized Hall conductivity in multiples of e^2/h. Here we show that the quantum Hall effect is accompanied by an orbital Hall effect [1]. Our quantum mechanical calculations fit well the semiclassical interpretation in terms of “skipping orbits”. The chiral edge states of a quantum Hall system are orbital polarized akin to an orbital version of the quantum anomalous Hall effect in magnetic systems. The orbital Hall resistivity scales quadratically with the magnetic field making it the dominant effect at high fields.

The discussion can be generalized to systems with effective magnetic fields: The topological Hall effect caused by the emergent field of topological spin textures, such as magnetic skyrmions, is accompanied by an orbital Hall effect, as well [2].

[1] B. Göbel, I. Mertig, Phys. Rev. Lett. 133, 146301 (2024)

[2] B. Göbel, L. Schimpf, I. Mertig, arXiv pre-print: 2410.00820

MA 11.11 Tue 12:15 H18

Large Spin Hall Angle in Mn-based Antiferromagnetic Alloys
— •Nabil Menai[1], Martin Gradhand[2], and Derek Stewart[3] — [1]H. H. Wills Physics Laboratory, University of Bristol, Tyndall Ave, BS8-1TL, UK — [2]Institute of Physics, Johannes Gutenberg University Mainz, Staudingerweg 7, 55128 Mainz, Germany — [3]Western Digital Research Center, San Jose, California 95119, USA

Antiferromagnets (AFMs) have emerged as crucial materials for spintronic technologies for their ability to host spin-dependent transport phenomena, despite their zero net magnetization. Their robustness against external magnetic fields and ultrafast spin dynamics make them ideal for efficient spin-charge interconversion. In this theoretical study, we use density functional theory and Greens function methods to investigate the transport properties of Mn-based binary alloyed AFMs. Our focus is on the total spin Hall conductivity (SHC), accounting for both the intrinsic contributions from Berry curvature and the extrinsic effects from skew scattering and side-jump mechanisms. The objective is to identify AFM materials that exhibits a high spin Hall angle (SHA); with an efficient charge-to-spin Hall current conversion ratio. Our results reveal that doping MnPt with Ir significantly enhances the SHA, achieving a value of 8% at room temperature. In contrast, doping with Pd offers temperature stability with lower SHA values. Additionally, we examine the effects of substituting Mn atoms with magnetic transition metals such as Fe and Ni. These findings underscore the potential of antiferromagnetic alloys for efficient spin current generation.

MA 11.12 Tue 12:30 H18

Competing ordinary and Hanle magnetoresistance in Pt and Ti thin films
— •Sebastian Sailler[1], Giacomo Sala[2], Denise Reustlen[1], Richard Schlitz[1], Min-Gu Kang[2], Pietro Gambardella[2], Sebastian T.B. Goennenwein[1], and Michaela Lammel[1] — [1]Department of Physics, University of Konstanz — [2]Department of Materials, ETH Zurich

One of the key elements in spintronics research is the spin Hall effect, allowing to generate spin currents from charge currents. A large spin Hall effect is observed in materials with strong spin orbit coupling, e.g. Pt. Recent research suggests the existence of an orbital Hall effect, the orbital analogue to the spin Hall effect, which also arises in weakly spin orbit coupled materials like Ti, Mn or Cr. In any of these materials, a magnetic field perpendicular to the spin or orbital accumulation leads to additional Hanle dephasing and thereby the Hanle magnetoresistance. Here, we studied the magnetoresistance (MR) of Pt thin films over a wide range of thicknesses. Careful evaluation shows that the MR of our textured samples is dominated by the so-called ordinary MR, while the Hanle effect does not play a significant role. Analyzing the intrinsic properties of Pt films deposited by different groups, we find that next to the resistivity, also the structural properties of the film influence which MR dominates. We further show that this correlation can also be found in orbital Hall active materials like Ti. We conclude that in all materials exhibiting a spin or orbital Hall effect, the Hanle MR and the ordinary MR coexist, and that the sample's purity and crystallinity determines which MR dominates.

MA 11.13 Tue 12:45 H18

Orbital Hanle magnetoresistance in Mn thin films — •Min-Gu Kang, Federica Nasr, Giacomo Sala, and Pietro Gambardella — Department of Materials, ETH Zurich, 8093 Zurich, Switzerland

Momentum-space orbital texture, or orbital character of electrons, enables the orbital Hall effect (OHE), a current-induced flow of nonequilibrium orbital angular momentum in centrosymmetric systems with negligible spin-orbit coupling. This orbital current, which can be orders of magnitude larger than its spin counterpart, offers transformative potential for spin-orbitronics, yet the mechanisms of orbital relaxation remain unclear. In this work, we present temperature-dependent orbital Hanle magnetoresistance and associated orbital relaxation mechanisms in Mn thin films. The results clearly show that the orbital Hanle magnetoresistance depends on the structure of the Mn thin films and can be associated with competing Dyakonov-Perel and Elliott-Yafet orbital relaxation effects. Our study highlights the critical role of orbital relaxation in determining the magnitude of current-induced orbital effects in 3d transition metal films.

MA 11.14 Tue 13:00 H18

Tuning of spin transport properties in 2D ferromagnet VSe_2 by structural polytypes of TaS_2 electrodes — •Biplab Sanyal and Masoumeh Davoudiniya — Department of Physics & Astronomy, Ångströmlaboratoriet, Uppsala University, Box-516, 75120 Uppsala, Sweden

2D magnets and their heterostructures are promising materials for future spintronic applications. Here, we present a study of spin transport through a ferromagnetic monolayer of 1T-VSe_2 with two structural polytypes of TaS_2 electrodes stacked in van der Waals heterostructures. Using density functional theory coupled with the nonequilibrium Green function framework, we explore the impact of TaS_2 electrode polytypes on the device's quantum transport properties. We observe that devices with 1T-TaS_2 electrodes exhibit higher spin-dependent transmission compared to 2H-TaS_2 electrodes. Incorporating MoS_2 as a tunnel barrier, anisotropic tunnel magnetoresistance enhances significantly, reaching 168% for the 1T-device and 1419% for the 2H-device. Spin-transfer torque (STT) analysis shows that its magnitude is highest at 90° (-702 μeV/V for 1T and -1561 μeV/V for 2H devices) and decreases towards 180°. The 1T-device shows superior performance with lower Gilbert damping, reduced critical current density and voltage for magnetization switching, compared to the 2H-device, which requires significantly higher current and voltage. Our predictions reveal the potential of 1T-VSe_2-based heterostructures for advanced spintronic applications.