MA 35: Spin Transport and Orbitronics, Spin-Hall Effects I (joint session MA/TT)

Time: Thursday 9:30–12:45 Location: H 2013

MA 35.1 Thu 9:30 H 2013

Fluctuation mediated spin-orbit torque enhancement in the noncollinear antiferromagnet Mn3Ni0.35Cu0.65N — Arnab Bose[1], Aga Shahee[1], Tom G. Saunderson[1], •Adithya Rajan[1], Dongwook Go[2], Aurélien Manchon[3], Yuriy Mokrousov[1,2], and Mathias Kläui[1] — [1]Institut für Physik, Johannes-Gutenberg-Universität Mainz, 55099 Mainz, Germany — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich, 52424 Jülich, Germany — [3]CINaM, Aix-Marseille Université, CNRS, Marseille, France

Spin fluctuations near magnetic phase transitions play a pivotal role in generating exotic phenomena. This study focuses on experimental investigation of temperature-dependent spin torques in the noncollinear antiferromagnet Mn3Ni0.35Cu0.65N (MNCN). Our findings reveal a significant and nontrivial temperature dependence of spin-orbit torques (SOT), peaking near MNCN's Néel temperature. This behavior cannot be explained by conventional scattering mechanisms of the SHE. Notably, a maximum SOT efficiency of 30 % is measured, surpassing that of commonly studied nonmagnetic materials like Pt. Theoretical calculations support a negligible SHE and a pronounced orbital Hall effect, explaining the observed spin torques. We propose a novel mechanism where fluctuating antiferromagnetic moments induce substantial orbital currents near the Néel temperature. These results provide a promising avenue for enhancing spin torques, with potential applications in magnetic memory.

MA 35.2 Thu 9:45 H 2013

First-principles calculation of the orbital current and orbital accumulation in metallic layers — •Daegeun Jo[1], Dongwook Go[2,3], Peter Oppeneer[1], and Hyun-Woo Lee[4] — [1]Department of Physics and Astronomy, Uppsala University, P.O. Box 516, SE-75120 Uppsala, Sweden — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [3]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany — [4]Department of Physics, Pohang University of Science and Technology, Pohang, South Korea

Recently, the orbital degree of freedom has emerged as a new element for the electrical control of magnetization in magnetic devices. Notably, magneto-optical measurements have demonstrated that the orbital angular momentum is accumulated by the orbital Hall effect in metallic films consisting of light elements such as Ti [Y.-G. Choi *et al.*, Nature **619**, 52-56 (2023)] and Cr [I. Lyalin *et al.*, Phys. Rev. Lett. **131**, 156702 (2023)]. However, the relationship between the orbital Hall current and the boundary orbital accumulation remains unclear. In this work, we present the theoretical calculations of the orbital Hall current and the current-induced orbital accumulation in various metallic films based on the first-principles calculations. We show that the orbital accumulation is properly described by considering the torque contribution from the crystal field in addition to the conventional orbital current.

MA 35.3 Thu 10:00 H 2013

Using first principles methods to describe spin-orbitronic and superconducting phenomena — •Tom G. Saunderson[1,2], Dongwook Go[1,2], Maria Teresa Mercaldo[3], Mario Cuoco[4], Martin Gradhand[1,5], and Yuriy Mokrousov[1,2] — [1]Institute of Physics, JGU, 55099 Mainz, Germany — [2]PGI and IAS, Forschungszentrum Jülich, Germany — [3]Universitá di Salerno, IT-84084 Fisciano, Italy — [4]CNR-SPIN, IT-84084 Fisciano (SA), Italy — [5]University of Bristol, Bristol BS8 1TL, UK

Recent advancements in orbitronics demonstrate remarkable efficiency gains using cost-effective materials [1], while spin-Hall mediated responses notably intensify near the superconducting transition [2]. Breaking inversion or time-reversal symmetry efficiently extracts these unconventional currents, however for material-specific predictions first principles techniques are essential. Although theoretical methods for orbital currents are well-established, first principles techniques for supercurrents are still in their infancy. This talk aims to explore two approaches. Firstly, we employ maximally localized Wannier functions to investigate the influence of p-d hybridizations on enhancing the orbital Rashba Edelstein effect on particular surfaces of known metallic systems. Secondly, we utilize a Green's function-based superconducting first principles code to induce unconventional triplet densities in superconductors featuring complex orbital degrees of freedom and inversion symmetry breaking. Such methods will pave the way for first principles-based modeling of superconducting spintronics. [1] Nature 619, 52 (2023) [2] ACS Nano 14, 15874 (2020)

MA 35.4 Thu 10:15 H 2013

Investigation of the topological transport properties for the MAB phase — •Fu Li, Ruiwen Xie, and Hongbin Zhang — Institute of Materials Science, Technology University of Darmstadt, 64287, Darmstadt, Germany

Compounds of MAB phases, i.e, Ternary transition metal borides with nano-laminated structures, have attracted significant attention due to their intriguing physical properties. In this work, we evaluate the topological transport properties(anomalous and spin Hall conductivities) of MAB compounds, aiming to uncover potential applications in the field of spintronics. After constructing the maximally localized Wannier functional automatically, the anomalous and spin Hall conductivities are obtained based on the Wannier interpolation. It is observed several compounds exhibit significant anomalous and spin Hall conductivities, which can be understood based on the underlying electronic structure. Furthermore, the influence of magnetization direction on spin Hall conductivity is studied for those compounds where the inversion symmetry is broken due to the antiferromagnetic ordering. We find that the magnitude of spin Hall conductivity can be tailored by the magnetization direction, offering possible applications in spintronics.

MA 35.5 Thu 10:30 H 2013

Unconventional Spin-Orbit Torques in CrPt3 — •Robin Klause[1], Yuxuan Xiao[2,3], Jonathan Gibbons[1,4], Axel Hoffmann[1], and Eric Fullerton[2] — [1]University of Illinois Urbana-Champaign — [2]University of California San Diego — [3]TDK Corporation — [4]Western Digital Corporation

Spin-orbit torques can efficiently control magnetization states using charge currents. However, with conventional spin-orbit torques, where charge current, spin current, and spin polarization are mutually perpendicular only in-plane magnetization parallel to the spin polarization can be switched field-free and deterministically. The topological semimetal CrPt3 has potential for generating unconventional spin-torques due to its ferrimagnetic ordering, topological band structure and high anomalous Hall conductivity. As CrPt3 exhibits ferrimagnetic behavior only in its chemically ordered phase while it is paramagnetic in its chemically disordered phase we can compare spin-torque generation in the two phases and investigate whether unconventional torques originate from the magnetic or crystal structure. We studied spin-torque generation in epitaxial CrPt3(110) films using angle dependent spin-torque ferromagnetic-resonance measurements with currents applied along specific crystal directions. We reveal unconventional spin-torques in both chemically ordered and disordered CrPt3 when current flows along the [1-11] and [-111] crystal directions. We conclude that the unconventional torque originates from the crystal order since these directions lack a mirror plane, allowing unconventional torques to be generated.

MA 35.6 Thu 10:45 H 2013

Spin and orbital Edelstein effect in a bilayer $SrTiO_3$ system — •Sergio Leiva[1], Börge Göbel[1], Jürgen Henk[1], Ingrid Mertig[1], and Annika Johansson[2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, D-06099 Halle (Saale), Germany. — [2]Max Planck Institute of Microstructure Physics, Halle, Germany

The spin and orbital Edelstein effect have proved promising phenomenons to generate spin and orbital polarization from a charge current in systems without inversion symmetry [1-5]. The present work studies the current-induced spin and orbital magnetization in a $SrTiO_3/LaAlO_3$ interface with a tight-binding model and the semiclassical Boltzmann theory. We studied a monolayer, a pseudo-monolayer, and a bilayer system for the STO to replicate experimental data from ARPES. For the bilayer model [6], we compare the orbital effect from the atomic-centered approximation (ACA) and the modern theory of orbital magnetization (MTOM)[7]. We found that the orbital Edelstein effect from ACA is larger than the spin Edelstein effect [5] and the orbital effect from MTOM. This difference between ACA and MTOM

shows the relevance of the modern theory for heterostructure systems.
[1] D. Go *et al.*, Sci. Rep. **7**, 46742 (2017)
[2] T. Yoda *et al.*, Nano Lett., **18**, 916 (2018).
[3] L. Salemi *et al.*, Nat. Commun. **10**, 5381 (2019)
[4] D. Hara *et al.*, Phys. Rev. B, **102**, 184404 (2020).
[5] A. Johansson *et al.*, Phys. Rev. Research, **3**, 013275 (2021).
[6] S. Leiva M. *et al.* arXiv:2307.02872 (2023).
[7] T. Thonhauser *et al.* Phys. Rev Lett. **95**, 137205 (2005).

MA 35.7 Thu 11:00 H 2013

Electrically induced angular momentum flow between separated ferromagnets — •Matthias Grammer[1,2], Richard Schlitz[3], Tobias Wimmer[1,2], Janine Gückelhorn[1,2], Luis Flacke[1,2], Sebastian T.B. Goennenwein[4], Rudolf Gross[1,2,5], Hans Huebl[1,2,5], Akashdeep Kamra[6], and Matthias Althammer[1,2] — [1]Walther-Meißner-Institut, BAdW, Garching, Germany — [2]School of Natural Sciences, TUM, Garching, Germany — [3]Department of Materials, ETH Zürich, Zürich, Switzerland — [4]Department of Physics, University of Konstanz, Konstanz, Germany — [5]Munich Center for Quantum Science and Technology, München, Germany — [6]IFIMAC and Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, Madrid, Spain

The transfer of angular momentum between electrons, magnons and phonons is pivotal for spintronic devices making use of angular momentum currents. Here, we demonstrate angular momentum transfer between two isolated ferromagnetic metal strips on diamagnetic substrates [1]. Experimentally we apply a DC charge current at one of the magnetic electrodes which is converted into an electronic spin current and consequently transfered to the magnonic system. Using the inverse process at the second electrode, we can detect the induced angular momentum flow between the electrodes up to micron distances. We attribute this transfer mechanism to dipolar and potentially phononic interactions.
[1] R. Schlitz et al., arXiv:2311.05290(2023)

15 min. break

MA 35.8 Thu 11:30 H 2013

Orbital Hall effect and orbital edge states caused by *s* electrons — •Oliver Busch, Ingrid Mertig, and Börge Göbel — Institut für Physik, Martin-Luther-Universität, D-06099 Halle

An orbital current can be generated whenever an object has a translational degree of freedom and a rotational degree of freedom. In condensed matter physics, intra-atomic contributions to the transverse orbital transport, labeled the orbital Hall effect, rely on propagating wave packets that must consist of hybridized atomic orbitals [1]. However, interatomic contributions have to be considered as well because they give rise to an alternative mechanism for generating orbital currents [2].

As we show, even wave packets consisting purely of *s* electrons can transport orbital angular momentum if they move on a cycloid trajectory [3]. We introduce the kagome lattice with a single *s* orbital per atom as the minimal model for the orbital Hall effect and observe the cycloid motion of the electrons in the surface states.
[1] D. Go *et al.*, Physical Review Letters **121**, 086602 (2018)
[2] A. Pezo *et al.*, Physical Review B **106**, 104414 (2022)
[3] O. Busch *et al.*, Physical Review Research 5, 043052 (2023)

MA 35.9 Thu 11:45 H 2013

Spin-to-charge conversion in ferromagnetic heterostructures — •Misbah Yaqoob[1], Fabian Kammerbauer[2], Tom G. Saunderson[2], Vitaliy I. Vasyuchka[1], Dongwook Go[3], Hassan Al-Hamdo[1], Gerhard Jakob[2], Yuriy Mokrousov[2,3], Mathias Kläui[2], and Mathias Weiler[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany — [3]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Spin-orbit torques (SOTs) can be used for efficient control of magnetization and the electrical detection of spin dynamics through the inverse spin Hall effect (iSHE) [1]. We investigate spin-to-charge conversion in ferromagnetic heterostructures based on perpendicular magnetic anisotropy (PMA) multilayers of [Co/Ni] and [Co/Pt] that generate SOTs in adjacent CoFeB thin films with in-plane magnetic anisotropy (IPA). We extract the spin dynamics and SOTs [2] using vector network analyzer ferromagnetic resonance spectroscopy (VNA-FMR). In our experiments, we found that our multilayers generate SOTs comparable in magnitude to Pt, in agreement with first-principles calculations. Additionally, we observed a pronounced dependence of the SOT on the IPA CoFeB layer thickness.
[1] T. Jungwirth *et al.*, Nat. Mater. **11**, 382 (2012).
[2] A. J. Berger *et al.*, Phys. Rev. B **97**, 94407 (2018).

MA 35.10 Thu 12:00 H 2013

Modelling layer resolved spin-orbit torque assisted magnetization dynamics in Pt/Co bilayers — •Harshita Devda[1], Andras Deak[2], Leandro Salemi[3], Levente Rozsa[4], Laszlo Szunyogh[2], Peter M. Oppeneer[3], and Ulrich Nowak[1] — [1]University of Konstanz, Konstanz, Germany — [2]Budapest University of Technology and Economics, Budapest, Hungary — [3]Uppsala University, Uppsala, Sweden — [4]Wigner Research Centre for the Physics, Budapest, Hungary

Spin-orbit-torque(SOT) devices have acquired extensive attention for their unique features, encompassing low power consumption and efficient data storage capabilities. Recent discoveries of the Orbital Hall Effect and the Orbital Rashba-Edelstein Effect have added more intricacy to the understanding of magnetization switching mechanisms in these devices, especially in Nonmagnetic/Ferromagnet systems. To address this, we present a model for a Pt/Co bilayer system where we utilized Atomistic Spin Dynamics simulations, incorporating ab-initio calculated interaction parameters mapped to the Hamiltonian and electrically induced moments from first-principles calculations. Our descriptive model reveals the Spin and Orbital Hall Effect as the dominant mechanism behind magnetization switching in Pt/Co at low electric field strengths. Conversely, there is a significant magnetization dependence of the interface-generated moments at high field, leading to counterintuitive anti-switching behaviour with enhanced layer-resolved behavior in the presence of orbital moments.

MA 35.11 Thu 12:15 H 2013

Investigating Orbital Hall Effect Materials for Efficient Magnetization Control with In-plane and Perpendicular Magnetic Anisotropic Ferromagnets — Rahul Gupta[1], •J. Omar Ledesma Martin[1,2], Chloe Bouard[2], Fabian Kammerbauer[1], Sylvain Martin[2], Gerhard Jakob[1], Marc Drouard[2], and Mathias Kläui[1,3] — [1]Institute of Physics, Johannes Gutenberg University Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Antaios, 35 Chemin du Vieux Chêne, 38240 Meylan, France — [3]Center for Quantum Spintronics, Department of Physics, Norwegian, University of Science and Technology, NO-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 that of Pt.

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]3/Co/MgO/CoFeB/Ta/Ru, where the OHE materials are Ru, Nb, and Cr. Additionally, a sample wit Pt instead of OHE serves as a reference.

The results demonstrate an improvement in the Ru samples, exhibiting higher damping-like torque and 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.

MA 35.12 Thu 12:30 H 2013

Unlocking the Potential of Rare-Earth Dichalcogenides for Topological Spintronics and Orbitronics — Mahmoud Zeer[1,2], Dongwook Go[1,3], •Peter Schmitz[1,2], Tom G. Saunderson[3], Wulf Wulfhekel[4], Stefan Blügel[1,2], and Yuriy Mokrousov[1,3] — [1]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany — [2]Department of Physics, RWTH University, Aachen, Germany — [3]Institute of Physics, Johannes Gutenberg-University, Mainz, Germany — [4]Institute of Quantum Materials and Technologies, Karlsruhe Institute of Technology, Karlsruhe, Germany

We investigate the electronic, magnetic and transport properties of rare-earth dichalcogenides, specifically monolayers of H-phase EuX2 and GdX2 (X = S, Se, Te), using first-principle methods. We show that this family of materials exhibits high magnetic moments, wide bandgaps, and significant anomalous, spin, and orbital Hall conductivities. While the hybridization of p- and f- states in EuX2 occurs just below the Fermi energy, GdX2 displays a non-trivial p-like spin-polarized electronic structure at the Fermi level, which results in manifestly p-based magnetotransport properties. We unravel the role of correlations and strain in influencing the position and hybridization character between the p-, d-, and f-states, which has a direct impact on the quantized Hall response. Our findings suggest that rare-earth dichalcogenides hold promise as a platform for topological spintronics and orbitronics. [1,2] [1] Physical Review Materials 6 (7), 074004 [2] arXiv preprint arXiv:2308.08207.