MA 46: Spin: Transport, Orbitronics and Hall Effects I

Time: Thursday 9:30–13:00 Location: HSZ 403

MA 46.1 Thu 9:30 HSZ 403

Long-range phonon spin transport in ferromagnet - nonmagnetic insulator heterostructures — •Andreas Rückriegel[1] and Rembert A. Duine[1,2] — [1]Institute for Theoretical Physics and Center for Extreme Matter and Emergent Phenomena, Utrecht University, Utrecht, The Netherlands — [2]Department of Applied Physics, Eindhoven University of Technology, Eindhoven, The Netherlands

We investigate phonon spin transport in an insulating ferromagnet - nonmagnet - ferromagnet heterostructure. We show that the magnetoelastic interaction between the spins and the phonons leads to non-local spin transfer between the magnets. This transfer is mediated by a local phonon spin current and accompanied by a phonon spin accumulation. The spin conductance depends nontrivially on the system size, and decays over centimeter lengthscales for realistic material parameters, far exceeding the decay lengths of magnonic spin currents.

MA 46.2 Thu 9:45 HSZ 403

Compensating the planar Hall effect for better transport measurements — •Tobias Kosub, Jürgen Fassbender, and Denys Makarov — Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Dresden, Germany

The planar Hall effect (PHE) can lead to transverse voltage in transport measurements, whenever the studied film has anisotropic conductivity, even when the material conductivity tensor has zero off-diagonal components. Therefore, the PHE presents a complication for measurements of actual transverse components of the conductivity tensor, which are typically several order of magnitude smaller than the longitudinal conductivity (e.g. normal, anomalous Hall effects).

We show that compensating the PHE delivers significant benefits for transverse resistance measurements: For spin Hall magnetoresistance, the longitudinal and transverse components can be easily separated providing easy access to the complex spin mixing conductivity [1].

For Hall probe magnetometry in in-plane magnetic field, the PHE is the dominant error term and rejecting it improves readings greatly.

Compensation of the PHE is achieved using the Zero-Offset Hall [2] measurement mode of the Tensormeter device [3].

[1] T. Kosub et al., *Appl. Phys. Lett.* 113, 222409 (2018)
[2] T. Kosub et al., *Phys. Rev. Lett.* 115, 097201 (2015)
[3] More info on: *www.tensormeter.eu*

MA 46.3 Thu 10:00 HSZ 403

Spin Hall magnetoresistance in heterostructures consisting of noncrystalline paramagnetic YIG and Pt — •Michaela Lammel[1], Richard Schlitz[2], Kevin Geishendorf[1], Denys Makarov[3], Tobias Kosub[3], Savio Fabretti[2], Helena Reichlova[2], Rene Huebner[3], Kornelius Nielsch[1], Andy Thomas[1], and Sebastian T.B. Goennenwein[2] — [1]Leibniz Institute for Solid State and Materials Research Dresden (IFW Dresden) — [2]Institut für Festkörper- und Materialphysik, Technische Universität Dresden — [3]Helmholtz-Zentrum Dresden-Rossendorf e.V., Institute of Ion Beam Physics and Materials Research

The spin Hall magnetoresistance (SMR) effect arises from spin-transfer across the interface between a metal with large spin orbit coupling and an (insulating) magnet. While the SMR response of ferrimagnetic and antiferromagnetic insulators has been studied extensively, the SMR of a paramagnetic spin ensemble is not well established. We here experimentally investigate the magnetoresistance of sputtered yttrium iron garnet/platinum thin film heterostructures[1]. Although we find no evidence for crystalline order or spontaneous magnetization in the yttrium iron garnet layer, we observe a clear magnetoresistive response with a dependence on the magnetic field orientation characteristic for the SMR. We propose two models for the origin of the SMR response in paramagnetic insulator/platinum bilayers and critically compare them to our experimental data.

[1] Lammel et al., Appl. Phys. Lett. **114**, 252402 (2019)

MA 46.4 Thu 10:15 HSZ 403

Spin Hall magnetoresistance in ferromagnet/ Pt heterostructures with 4f moments — •Kevin Geishendorf[1], Richard Schlitz[2], Michaela Lammel[1], Dhavala Suri[3], Jagadeesh Moodera[3,4], Kornelius Nielsch[1], Sebastian T.B. Goennenwein[2], and Andy Thomas[1] — [1]Leibniz Institute for Solid State and Materials Research, Dresden — [2]Institut für Festkörper- und Materialphysik , Technische Universität Dresden — [3]Francis Bitter Magnet Laboratory and Plasma Science and Fusion Center, MIT — [4]Department of Physics, MIT

The spin Hall magnetoresistance (SMR) is a powerful tool to investigate a variety of magnetic systems. Previous experiments mainly focused on materials with d moments. d orbitals are usually the outermost magnetic electron shells and thus can overlap with the electron shells of neighbouring ions or atoms resulting in strong interactions. However, the interactions are considered to be weaker in magnetic materials with $4f$ moments due to the strong localization and screening of the $4f$ electrons. We measure the magnetoresistive response (MR) in GdN/Pt and EuS/Pt heterostructures to investigate the coupling between $4f$ moments and a spin accumulation. The GdN/Pt heterostructure exhibits a clear MR with a symmetry characteristic for SMR. In contrast, although having a similar magnetic response the EuS/Pt heterostructure exhibits a much smaller MR. We discuss the possible origin of the MR in both heterostructures in view of the presences or absence of d electron levels near the Fermi energy.

MA 46.5 Thu 10:30 HSZ 403

Large spin Hall magnetoresistance in antiferromagnetic α-Fe_2O_3/Pt heterostructures — Johanna Fischer[1], Matthias Althammer[1], Nynke Vlietstra[1], Hans Huebl[1], Sebastian T. B. Goennenwein[2], Rudolf Gross[1], Stephan Geprägs[1], and •Matthias Opel[1] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Institut für Festkörper- und Materialphysik, Technische Universität Dresden, 01062 Dresden, Germany

We investigate the spin Hall magnetoresistance (SMR) at room temperature in thin film heterostructures of antiferromagnetic, insulating, (0001)-oriented α-Fe_2O_3 (hematite) and Pt. We measure their longitudinal and transverse resistivities while rotating an applied magnetic field of up to 17 T in three orthogonal planes. For out-of-plane magnetotransport measurements, we find indications for a multidomain antiferromagnetic configuration whenever the field is aligned along the film normal [1]. For in-plane field rotations, we clearly observe a sinusoidal resistivity oscillation characteristic for the SMR due to a coherent rotation of the Néel vector [1]. The maximum SMR amplitude of 0.25% is, surprisingly, twice as high as for prototypical ferrimagnetic $Y_3Fe_5O_{12}$/Pt heterostructures [1]. The SMR effect saturates at much smaller magnetic fields as in comparable antiferromagnets, making the α-Fe_2O_3/Pt system particularly interesting for room-temperature antiferromagnetic spintronic applications.

[1] J. Fischer *et al.*, arXiv:1907.13393, *submitted to* Phys. Rev. Appl.

MA 46.6 Thu 10:45 HSZ 403

Injection, transport, detection, and modulation of magnon spin currents in magnetic insulators — •Saül Vélez[1,3], Jialiang Gao[1], Juan Manuel Gomez-Perez[2], Charles-Henri Lambert[1], Luis E. Hueso[2], Morgan Trassin[1], Manfred Fiebig[1], Felix Casanova[2], and Pietro Gambardella[1] — [1]ETH Zürich — [2]CIC nanoGUNE — [3]saul.velez@mat.ethz.ch

Recent demonstration of efficient transport and manipulation of spin information by magnon currents has opened exciting prospects for processing information in devices. Magnon currents can be excited in magnetic insulators by applying charge currents in an adjacent metal layer. Here, by implementing a non-local device scheme, we study the magnon diffusion length (MDL) for electrically and thermally excited magnon currents in Y3Fe5O12 (YIG) and Tm3Fe5O12 (TmIG). In contrast to earlier reports, our temperature and thickness-dependence studies reveal that the MDL depends on the way the magnon currents are generated, evidencing that magnons of different energies are excited (sub-thermal and thermal for electrically- and thermally-driven magnon currents, respectively). Moreover, we demonstrate that the MDL of thermally induced magnons in YIG is the same regardless of the film thickness and growth conditions. We also evaluate the MDL of TmIG and find to be shorter (~300nm) and more susceptible to external fields than it is for YIG, which we attribute to the larger Gilbert damping of TmIG. Finally, by employing a third gate electrode, we demonstrate a current-driven spin-orbit torque modulation of the magnon conductivity in nanometre-thick TmIG films.

MA 46.7 Thu 11:00 HSZ 403

Non-local magnetoresistance in antiferromagnetic insulator/Pt heterostructures — •Richard Schlitz[1], Tobias Kosub[2], Artur Erbe[2], Denys Makarov[2], and Sebastian T. B. Goennenwein[1] — [1]Institut für Festkörper- und Materialphysik, Technische Universität Dresden and Würzburg-Dresden Cluster of Excellence ct.qmat, 01062 Dresden, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf e.V., Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany

Non-local magnon mediated magnetoresistance allows to study the transport properties of pure spin currents in ferromagnetic and antiferromagnetic insulators interfaced with a heavy metal like platinum [1, 2]. Recent results suggest that even spin superfluidity can be present in such bilayers, and that it can be detected via the non-local magnetoresistance [3].

In this work, we discuss the thermally driven local and non-local magnetoresistance experimentally observed in antiferromagnetic insulator / Pt heterostructures. We observe the characteristic fingerprint of non-local transport via angle-resolved measurements of the non-local signal. Additionally, we address the impact of contact separation and magnetic field magnitude and critically compare our data to the results presented previously.

[1] L. J. Cornelissen *et al.*. Nature Physics **11**, 1022-1026 (2015)
[2] R. Lebrun *et al.*. Nature **561**, 222-225 (2018)
[3] W. Yuan *et al.*. Science Advances **4**, eaat1097 (2018)

15 min. break.

MA 46.8 Thu 11:30 HSZ 403

Anomalous spin Hall angle in a metallic ferromagnet determined by a multiterminal spin injection/detection device — •T. Wimmer[1,2], B. Coester[1], S. Geprägs[1], R. Gross[1,2,3,4], S. T. B. Goennenwein[5], H. Huebl[1,2,3,4], and M. Althammer[1,2] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, Technische Universität München, Garching, Germany — [3]Nanosystems Initiative Munich (NIM), München, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 München — [5]Institut für Festkörper- und Materialphysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany

The spin Hall effect and its characterizing parameter, the spin Hall angle, is crucial for spin to charge conversion processes in spintronics applications. Here, we report on the determination of the anomalous spin Hall angle in the ferromagnetic metal alloy cobalt-iron ($Co_{25}Fe_{75}$, CoFe). This is accomplished by measuring the spin injection/detection efficiency in a multiterminal device with nanowires of platinum (Pt) and CoFe deposited onto the magnetic insulator yttrium iron garnet ($Y_3Fe_5O_{12}$, YIG). Applying a spin-resistor model to our spin transport data, we determine the transport properties of YIG and the anomalous spin Hall angle of CoFe as a function of its spin diffusion length in a single device. Our experiments reveal a negative anomalous spin Hall angle of the ferromagnetic metal CoFe, but a vanishing ordinary spin Hall angle. Financial support by the DFG is gratefully acknowledged.

MA 46.9 Thu 11:45 HSZ 403

Stoner instability investigated by XRMR and XMCD — •Dominik Graulich[1], Jan Krieft[1], Anastasiia Moskaltsova[1], Tobias Peters[1], Johannes Demir[1], Jan Schmalhorst[1], Jose R. Linares Mardegan[2], Sonia Francoual[2], Padraic Shafer[3], Christoph Klewe[3], and Timo Kuschel[1] — [1]Center for Spineletronic Materials and Devices, Bielefeld University, Germany — [2]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [3]Advanced Light Source, LBNL, Berkeley, USA

X-ray resonant magnetic reflectivity (XRMR), in combination with x-ray magnetic circular dichroism, is a very sensitive technique to detect the proximity-induced spin polarization in heterostructures of heavy metals (HMs) in contact to ferromagnetic (FM) materials. This magnetic proximity effect (MPE), caused by the closeness of the HM to the FM instability within the Stoner description, was extensively studied for Pt within the hard x-ray range. Here, a linear dependence between the strength of the MPE, up to 0.7 μ_B per Pt atom, and the magnetic moment of the FM material, as well as a typical effective magnetic Pt thickness of around 1.2 nm were found. With the expansion of the XRMR analysis into the tender and soft x-ray range, the strength and magnetic depth profiles of further materials close to the FM instability (as, e.g., Pd, V, ...) have been investigated at the beamlines P09 (DESY) and 4.0.2 (ALS). This knowledge is crucial for the application of these materials in spintronic devices, where spin transport effects can be altered due to the additional magnetization of the nominal paramagnetic HM layer.

MA 46.10 Thu 12:00 HSZ 403

Asymmetric modification of the magnetic proximity effect in Pt/Co/Pt trilayers — •Ankan Mukhopadhyay[1], Sarathlal Koyiloth Vayalil[1], Dominik Graulich[2], Imran Ahamed[3], Sonia Francoual[4], Arti Kashyap[3], Timo Kuschel[2], and Anil Kumar P S[1] — [1]Indian Institute of Science, Bangalore, India — [2]Center for Spinelectronic Materials and Devices, Bielefeld University, Germany — [3]Indian Institute of Technology, Mandi, India — [4]Deutsches Elektronen-Synchrotron, Hamburg, Germany

Interfacial spin-orbit coupling in ferromagnet/nonmagnet (FM/NM) systems promotes remarkable spin-related phenomena and interactions which simultaneously provide the electrical manipulation of the magnetization to control magnetization switching by current-driven domain wall motion. The phenomenon of a nominally paramagnetic material getting spin-polarized in presence of an adjacent FM material by the exchange interaction, is known as magnetic proximity effect (MPE). The MPE in top and bottom Pt layers induced by Co in Ta/Pt/Co/Pt and Ta/Pt/Co/Cu/Pt multilayers has been studied by interface sensitive, element specific x-ray resonant magnetic reflectivity at the Pt L_3 absorption edge with an in-plane magnetic field. It has been observed that the induced magnetic moment in the bottom Pt layer decreases with the increase of the Ta buffer layer thickness in Ta/Pt/Co/Pt[1], while it decreases in the top Pt layer in Ta/Pt/Co/Cu/Pt due to the increase of the Cu spacer layer.

[1]A. Mukhopadhyay *et al.*, arXiv:1911.12187

MA 46.11 Thu 12:15 HSZ 403

Spin currents in collinear and non-collinear antiferromagnets — •Jakub Železný — Institute of Physics of the Czech Academy of Sciences, Prague 6, Czech Republic

Spin currents are one of the key concepts of spintronics. In the past, two types of spin currents have been predominantly discussed and utilized: the spin-polarized current in ferromagnetic materials and the spin Hall effect. In recent years it has been discovered that the phenomenology of spin currents is much richer than previously thought, and that more types of spin currents can occur. We have shown that the spin-polarized current can also exist in some antiferromagnetic materials and that a new type of spin Hall effect exists, which has origin in the magnetic order, and occurs in ferromagnetic and some antiferromagnetic materials [1]. This effect is now referred to as the magnetic spin Hall effect and has been recently experimentally demonstrated in non-collinear antiferromagnet Mn3Sn [2]. Furthermore, we have shown that the conventional spin Hall effect can exist in some non-collinear magnetic systems even in absence of the relativistic spin-orbit interaction [3]. Here we review the various types of spin currents that can occur in magnetic systems and give general conditions for their existence as well as a symmetry classification. In addition, we present calculations of these novel spin currents in various collinear and non-collinear antiferromagnets.

[1] J. Železný et al.: Phys. Rev. Lett. 119, 187204 (2017) [2] M. Kimata et al., Nature 565, 627 (2019) [3] Y. Zhang et al: New J. Phys. 20, 073028 (2018)

MA 46.12 Thu 12:30 HSZ 403

Crystal Hall effects from antiferromagnetism — •Libor Šmejkal[1,2], Tomáš Jungwirth[2,3], 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 — [3]School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, United Kingdom

Antiferromagnetic order is commonly pictured as magnetization projection arrows at the atomic positions in crystals. Here we show that the symmetry analysis arising from this picture is incomplete, and we need to consider the full ground-state magnetization density. We show that this magnetization density in magnets with low symmetry Wyckoff positions and low magnetic symmetry can generate large spontaneous Hall effect [1]. This mechanism revealed strong Hall conductivity from perfectly compensated collinear antiferromagnetism in a large class of spintronics promising materials previously anticipated to be prohibited from spontaneous Hall effect. We analyse the topological origin of the crystal Hall conductivity contributions in centrosymmetric RuO2 and chiral crystal CoNb3S6. Finally, we will discuss possible experimental discoveries of the effect and impact of the mechanism on other spintronics phenomena[2]. [1] L. Šmejkal, R. González-Hernández, T. Jungwirth, and J. Sinova, arXiv:1901.00445v1 (2019) [2]L. Šmejkal, Y. Mokrousov, B. Yan, and A. H. MacDonald, Nature Physics, 14, 242 (2018)

MA 46.13 Thu 12:45 HSZ 403

Structural, electrical transport and magnetization dynamic properties of epitaxial Mn3Ir/Ni3Fe heterostructures — •Sri Sai Phani Kanth Arekapudi[1], Fabian Ganss[1], Antje Oelschlägel[3], Anna Semisalova[3], Sven Stienen[3], Kilian Lenz[3], Jürgen Lindner[1], Manfred Albrecht[2], and Olav Hellwig[1,3] — [1]Institute of Physics, Technische Universität Chemnitz, 09107 Chemnitz, Germany — [2]Institute of Physics, University of Augsburg, Universitätsstraße 1,86159 Augsburg, Germany — [3]Institute for Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany

In spin-orbitronic devices, non-collinear antiferromagnets (AFM) such as Mn3Ir are used as active spin current injection electrodes for an efficient charge to spin current conversion [1]. Here we present a detailed procedure for the preparation of high-quality epitaxial thin films of cubic Mn3Ir (AFM) and Ni3Fe (FM) heterostructures. A comprehensive study of the crystal structure is performed using X-ray diffraction and high-resolution TEM imaging. Dynamic magnetic excitation studies of Mn3Ir/Ni3Fe heterostructures confirm the strong dependence of Gilbert damping and interfacial spin structure on the antiferromagnetic film thickness. Furthermore, we also reveal the role of AFM/FM interface spin-current transparency, which is pivotal for the spin Hall effect (SHE). [1] W. Zhang et al., Giant facet-dependent spin-orbit torque and spin Hall conductivity in the triangular antiferromagnet IrMn3. Sci. Adv. 2, e1600759 (2016).