MA 30: Spin-Torque Phenomena

Time: Wednesday 9:30–13:15 Location: H33

Invited Talk MA 30.1 Wed 9:30 H33

Spin-orbit torques and charge pumping in crystalline magnets — •Chiara Ciccarelli — Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge CB3 0HE

In magnetic crystals with an inversion asymmetric unit cell a non-zero global spin-polarization is generated by an electrical current, which acts with a torque on the magnetisation exciting magnetic dynamics [1]. This relativistic non-equilibrium spin phenomenon also has a reciprocal effect in which the excitation of magnons results in the pumping of a charge current [2].

I will start by reviewing our recent research on spin-orbit torques (SOTs) in crystalline magnets, in particular our very recent measurements of room temperature SOT in half-Heusler NiMnSb thin films. With this experiment we are able to fully characterise magnitude and symmetry of the SOTs [3, 4]. I will then talk about the first demonstration of magnonic charge pumping in crystal magnet GaMnAs [2]. In this effect, which is the reciprocal effect of SOTs, the precessing ferromagnet pumps a charge current. Differently from spin pumping, which is commonly used to electrically detect magnetization dynamics, in charge pumping magnons are converted within the ferromagnet into high-frequency currents via the relativistic spin-orbit interaction, without the need of a secondary spin-charge conversion element, such as heavy metals with large spin Hall angle.

References 1. Chernyshov et al., Nature Physics 5, 656 (2009). 2. Ciccarelli et al., Nature Nano 10, 50 (2014). 3. Fang et al., Nature Nano 6, 413 (2011). 4. Kurebayashi et al., Nature Nano 9, 211 (2014).

15 min. break

MA 30.2 Wed 10:15 H33

Spin-orbit effects in Pt/Co/AlOx as a function of temperature with varying ferromagnetic layer thickness — •Gurucharan V. Karnad[1], Roberto Lo Conte[1,2], K. Lee[1], S. Prenzel[1], T. Schulz[1], N.-H. Kim[3], K. Litzius[1,2], J.-S Kim[4], D.-S. Han[4], H.J.M. Swagten[4], C.-Y. You[3], and M. Kläui[1,2] — [1]Johannes Gutenberg Universität-Mainz, Institut für Physik, Staudinger Weg 7, 55128 Mainz, Deutschland — [2]Graduate School of Excellence Materials Science in Mainz (MAINZ), Staudinger Weg 9, 55128 Mainz, Deutschland — [3]Department of Physics, Inha University, Incheon 402-751, South Korea — [4]Department of Applied Physics, Center for NanoMaterials, Eindhoven University of Technology, PO Box 513, 5600 MB Eindhoven, The Netherlands

Material systems possessing perpendicular magnetic anisotropy and structural inversion asymmetry have attracted much attention due to the highly efficient current induced magnetization switching and fast domain wall motion observed in these systems. This has been attributed to spin orbit effects arising at the interface and in the bulk. Here, we report measurements of current induced domain wall motion and spin-orbit torques in Pt/Co(t)/AlOx, with varying thickness of the Co layer. We observe that the Dzyaloshinskii-Moriya interaction (DMI) decreases with increasing Co thickness, pointing to its interfacial origin. The current induced damping-like and field-like torques are also observed to be sensitive to temperature and Co thickness. This allows us to understand the relative contribution of spin-orbit effects originating at the interface and the bulk.

MA 30.3 Wed 10:30 H33

Investigation of Co thickness dependence of current induced domain wall motion in Co/Pt — •Caspar Florin[1], André Kobs[1,2], Carsten Thönnissen[1], Phillip Staeck[1], and Hans Peter Oepen[1] — [1]Institut für Nanostruktur- und Feskörperphysik, Universität Hamburg, Jungiusstr. 11, 20355 Hamburg, Germany — [2]Deutsches Elektronen-Synchrotron (DESY), Notkestraße 85, 22607 Hamburg, Germany

Spin orbit torque phenomena based on spin orbit coupling are in the very focus of present research due to their high potential for future logic and storage devices [1,2]. We present the Co thickness dependence of the spin orbit torque (SOT) in Pt (5nm)/Co (t_{Co})/Pt (3nm) sandwiches with perpendicular magnetic anisotropy at room temperature (0.5nm $\leq t_{\mathrm{Co}} \leq$ 0.9 nm). Utilizing micro-sized Co/Pt wires and current pulses with a duration of $\geq$ 2 ns the domain wall motion is investigated by means of a Kerr microscope. The domain wall velocity is determined as a function of current density and out-of-plane magnetic field in the creep and flow regime. By varying the Co thickness we are able to separate interfacial and volume contributions to the SOT that are caused by Rashba effect and spin Hall effect, respectively.[1] I. M. Miron et al., Nat Mater **9**, 230 (2010). [2] P. P. J. Haazen et al.,Nat Mater, **12**, 299 (2013).

MA 30.4 Wed 10:45 H33

Spin-orbit torques in $L1_0$-FePt/Pt thin films from first principles: effect of impurities — •Guillaume Géranton, Bernd Zimmermann, Frank Freimuth, Nguyen H. Long, Phivos Mavropoulos, Stefan Blügel, and Yuriy Mokrousov — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Spin-orbit torque (SOT) is an attractive way of manipulating the magnetization in spintronic devices. While the intrinsic contributions to the SOT have been investigated in the last years [1], little is known about the extrinsic contributions, i.e. the torques arising in the presence of impurities. Using the *ab initio* Boltzmann formalism, we compute the current-induced SOT in $L1_0$-FePt/Pt thin films in the presence of impurities. The transition rates between electronic states are obtained from the microscopic scattering rates computed from first principles [2]. This goes significantly beyond the standard description of extrinsic SOTs, which is usually based on the constant relaxation-time approximation [3]. We show the crucial dependence of the SOT on the distribution of impurities at the interface, demonstrate that a large part of the SOT is mediated by spin currents and observe a large spin accumulation in the Pt layers.

We gratefully acknowledge funding under the SPP 1538 programme of DFG.

[1] F. Freimuth et al., Phys. Rev. B **90**, 174423 (2014).
[2] N. H. Long et al., Phys. Rev. B **90**, 064406 (2014).
[3] G. Géranton et al., Phys. Rev. B **91**, 014417 (2015).

MA 30.5 Wed 11:00 H33

Spin transfer torque within the 3D-WKB electron tunneling model — Gabor Mandi[1] and •Krisztian Palotas[1,2] — [1]Budapest University of Technology and Economics, Department of Theoretical Physics, Budapest, Hungary — [2]Slovak Academy of Sciences, Institute of Physics, Bratislava, Slovakia

We introduce a calculation method for a combined description of charge and vector spin transport of tunneling electrons in magnetic scanning tunneling microscopy (STM) within the three-dimensional Wentzel-Kramers-Brillouin (3D-WKB) theory based on electronic structure data from first principles. Taking the Fe/W(110) surface, we show that the ratio between the spin transfer torque (STT) and the spin-polarized charge current is not constant and can be tuned by the bias voltage, tip-sample distance and magnetization rotation. Thus, we demonstrate the possible enhancement of the STT efficiency in magnetic STM junctions. We discuss our results in view of the indirect measurement of STT above the Fe/W(110) surface reported by Krause et al. in Phys. Rev. Lett. 107, 186601 (2011).

MA 30.6 Wed 11:15 H33

Terahertz nonlinear spin response in thulium orthoferrite — •Sebastian Baierl[1], Matthias Hohenleutner[1], Tobias Kampfrath[2], Anatoly Zvezdin[3], Alexey Kimel[4], Rupert Huber[1], and Rostislav Mikhaylovskiy[4] — [1]Department of Physics, University of Regensburg, 93053 Regensburg, Germany — [2]Department of Physical Chemistry, Fritz-Haber-Institut der MPG, Faradayweg 4-6, 14195 Berlin, Germany — [3]Prokhorov General Physics Institute, Russian Academy of Sciences, 119991 Moscow, Russia — [4]Radboud University Nijmegen, Institute for Molecules and Materials, Heyendaalseweg 135, 6525 AJ Nijmegen, the Netherlands

We show the first nonlinear spin response of a magnetically ordered system to intense terahertz (THz) fields. The oscillating carrier wave of ultrashort THz pulses coherently excites magnons in the canted antiferromagnet thulium orthoferrite. In its spin reorientation phase, the amplitude of the quasi-ferromagnetic mode is found to scale quadratically with the THz field, exceeding the strength of the Zeeman interaction by a factor of 7 for peak magnetic THz fields of 0.3 T. This finding marks a new regime of THz-induced spin dynamics beyond the

Zeeman interaction and the first observation of a THz field-triggered magnetic nonlinearity. We assign this intriguing effect to an ultrafast, THz electric-field-driven change of the magnetic anisotropy mediated by crystal field transitions within the thulium ions. By symmetry, the latter effect is only allowed if the crystal is situated in the spin reorientation phase. This novel driving mechanism points out unforeseen routes towards THz induced magnetic switching.

15 min. break

MA 30.7 Wed 11:45 H33

Snell's Law for Spin Waves — •Johannes Stigloher[1], Martin Decker[1], Helmut Körner[1], Kenji Tanabe[2], Takahiro Moriyama[3], Takuya Taniguchi[3], Hiroshi Hata[3], Marco Madami[4], Gianluca Gubbiotti[4], Kensuke Kobayashi[5], Teruo Ono[3], and Christian Back[1] — [1]Department of Physics, Regensburg University, 93053 Regensburg, Germany — [2]Department of Physics, Nagoya University, Nagoya, Aichi 464-8602, Japan — [3]Institute for Chemical Research, Kyoto University, Uji, Kyoto 611-0011, Japan — [4]Dipartimento di Fisica e Geologia, Universita di Perugia, I-06123 Perugia, Italy — [5]Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan

Snell's law is well known in optics, it describes the refraction of light at the transition between two transparent media. In contrast to light, spin waves in the dipolar regime have an anisotropic dispersion relation and are expected to behave differently at the transition between two media. In our experiments, we model an interface for spin waves by a thickness step: Spin waves are excited in a 60 nm thick Permalloy film by a microwave antenna and propagate into a 30 nm thick film. Utilizing time-resolved scanning Kerr microscopy we can directly track the wave fronts and therefore deduce the changes in the angle of propagation and in the wave vector amplitude at the transition to the thinner film. By measuring the refraction for varying incident angles, we determine Snell's law for spin waves.

MA 30.8 Wed 12:00 H33

Radiative damping in waveguide-based ferromagnetic resonance measured via analysis of perpendicular standing spin waves in sputtered permalloy films — Martin Schoen[1,2], Justin Shaw[1], Hans Nembach[1], •Mathias Weiler[3], and T.J. Silva[1] — [1]Quantum Electromagnetics Division, National Institute of Standards and Technology, USA — [2]Institute of Experimental and Applied Physics, University of Regensburg, Germany — [3]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, D-85748 Garching, Germany

In ferromagnetic resonance measurements one often neglected contribution to the measured damping is the damping enhancement due to inductive coupling between the precessing magnetization and the waveguide, the radiative damping. We investigate the radiative damping by measuring perpendicular standing spin waves in uniform 75 nm, 120 nm, and 200 nm Ni(80)Fe(20) films with multiple cap and seed layer configurations and compare the measured radiative damping to the one calculated in a simple model. The measurement of spin waves allows us to observe a direct proportionality of the damping enhancement to the spin wave inductance, as predicted by our model. Furthermore we present a method to directly measure radiative damping by decreasing the inductive coupling between sample and wave guide. Though inherently small for thin films (0.0003 for a 10 nm Permalloy film) the radiative damping can be a significant contribution to the total damping in materials with small intrinsic damping or large saturation magnetization, like yttrium-iron-garnett or Co(25)Fe(75).

MA 30.9 Wed 12:15 H33

Spin pumping into high conductivity polymers — •Mohammad Qaid[1], Tim Richter[1], Christoph Hauser[1], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg,Von-Danckelmann-Platz 3, 06120Halle — [2]Interdisziplinäres Zentrum für Materialwissenschaften, Martin-Luther-Universität Halle-Wittenberg, Heinrich Damerow Straße 4, 06120 Halle

Conducting polymers seem ideal candidates for application as spin charge converters using the inverse spin-Hall-effect, as they are flexible, easy to apply and can be obtained at low cost. Recently, the ISHE has been demonstrated in poly (3,4-ethylenedioxythiophene): poly(styrenesulfonate) (PEDOT:PSS) [1]. We have studied spin pumping and ISHE in hybrid structures composed of thin film yttrium-iron garnet (YIG) and PEDOT:PSS of various conductivities which can be varied by doping with high boiling solvents. The spin pumping is studied using the uniform mode of the ferromagnetic resonance but also for different magnon modes which can be excited in the experiment. As we show in our results using PEDOT:PSS leads to additional damping most likely due to spin pumping, however extreme care must be taken to distinguish between the real effects and side effects like damping by eddy currents or thermovoltages which can be much bigger than the inverse spin-Hall effect.

References: [1]- K. Ando, S.Watanabe, S.Mooser, E. Saitoh, and H. Sirringhaus, Nat. Mater. 12, 622 (2013)

MA 30.10 Wed 12:30 H33

Spin-transfer torque based damping control of parametrically excited spin waves in a magnetic insulator — •Viktor Lauer[1], Dmytro A. Bozhko[1,2], Thomas Brächer[1], Philipp Pirro[1], Vitaliy I. Vasyuchka[1], Alexander A. Serga[1], Matthias Benjamin Jungfleisch[1], Milan Agrawal[1], Yurii V. Kobljanskyj[3], Gennadii A. Melkov[3], Carsten Dubs[4], Burkard Hillebrands[1], and Andrii V. Chumak[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Germany — [2]Graduate School Material Science in Mainz, Germany — [3]Faculty of Radiophysics, Electronics and Computer Systems, Taras Shevchenko National University of Kyiv, Ukraine — [4]Innovent e.V., Jena, Germany

Our experimental studies address the spin-wave damping control in a macroscopically sized YIG(100nm)/Pt(10nm) bilayer, based on the spin Hall effect (SHE) and spin-transfer torque (STT). The application of a dc current to the Pt film leads to the formation of a spin-polarized electron current normal to the film plane due to the SHE. This spin current exerts a STT in the YIG film and, thus, changes the spin-wave damping. The variation of the spin-wave relaxation frequency is determined via the threshold of the parametric instability measured by Brillouin light scattering (BLS) spectroscopy. We show that depending on the polarity of the applied dc current with respect to the magnetization direction, the damping can be increased or decreased.

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MA 30.11 Wed 12:45 H33

Investigation of spin wave dispersions in Co thin films on W(110) from first-principles — •Flaviano José Dos Santos, Manuel Dos Santos Dias, and Samir Lounis — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, D-52428 Jülich, Germany

We computed spin wave dispersions of a few monolayers of Co deposited on the W(110) surface in the adiabatic approximation. The magnetic exchange interactions are obtained via first-principles electronic structure calculations using the Korringa-Kohn-Rostoker Green function method. We analyze the strength and oscillatory behavior of the intra-layer and inter-layer magnetic interactions and investigate the resulting dispersion of spin waves as a function of the thickness of Co films. We compare our results to recent measurements [1] based on electron energy loss spectroscopy. In particular, we demonstrate the strong impact of hybridization of the electronic states at the interface of Co and W on the magnetic exchange interactions and on the spin-waves dispersion curve. The distance dependence of the magnetic interactions is found to be strongly anisotropic, which we connect to the presence of quantum well states in the Co films.

Work supported by the Coordenadoria de Aperfeiçoamento de Pessoal de Nível Superior - CAPES (BRAZIL) and HGF-YIG Programme FunSiLab - Functional Nanoscale Structure Probe and Simulation Laboratory (VH-NG-717). [1] E. Michel, H. Ibach, and C. M. Schneider, Phys. Rev. B 92, 024407 (2015).

MA 30.12 Wed 13:00 H33

Mixed Berry curvatures from first principles — •Jan-Philipp Hanke, Frank Freimuth, Stefan Blügel, and Yuriy Mokrousov — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Both spin-orbit torques (SOT) and Dzyaloshinskii-Moriya interaction (DMI) arise in systems combining broken inversion symmetry and spin-orbit coupling. In a Berry phase theory the two phenomena are intimately related through the mixed Berry curvature which incorporates wave function derivatives with respect to crystal momentum $\boldsymbol{k}$ and magnetization direction $\hat{\boldsymbol{m}}$ [1]. Performing the differentiation with respect to magnetization direction, however, renders the first-principles

evaluation of the mixed Berry curvature a conceptually difficult task. Here, we present a scheme that grants efficient but accurate access to general mixed (and pure) Berry curvatures. Starting from the first-principles electronic structure, we employ higher-dimensional Wannier functions (HDWFs) [2] as minimal basis to treat the aforementioned wave function derivatives on an equal footing. We apply our method to Mn/W(001) where we analyze the mixed Berry curvature throughout $(\boldsymbol{k}, \hat{\boldsymbol{m}})$ phase space. Using the Berry phase expressions, we further compute SOT and DMI in the system and study the anisotropy with respect to magnetization direction.

[1] F. Freimuth *et al.*, J. Phys. Condens. Matter **26**, 104202 (2014)
[2] J.-P. Hanke *et al.*, Phys. Rev. B **91**, 184413 (2015)