MA 3: Spin Hall Effects

Time: Monday 9:30–11:45 Location: HSZ 403

MA 3.1 Mon 9:30 HSZ 403

YIG thickness dependence of spin pumping in YIG/Pt heterostructures — •Viktor Lauer[1], Matthias Benjamin Jungfleisch[1], Andrii Chumak[1], Andreas Kehlberger[2], Dong Hun Kim[3], Mehmet Cengiz Onbasli[3], Caroline Ross[3], Mathias Kläui[2], and Burkard Hillebrands[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Institute of Physics, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany — [3]Department of Materials Science and Engineering, MIT, Cambridge, MA 02139, USA

The transport and processing of spin information via magnons, as well as their generation and detection are at the heart of magnon spintronics. A very convenient method to detect magnon currents electrically is the combination of spin pumping and the inverse spin Hall effect (ISHE). In our studies the YIG thickness dependence of the spin-pumping effect in YIG/Pt structures was investigated in the nanometer range ($20-300$ nm YIG films), which is shorter then the exchange correlation length. The observed increase of the ISHE-voltage with increasing film thickness is compared to the theoretically expected behavior. The effective damping parameter of the YIG/Pt samples is found to be enhanced with decreasing film thickness. The investigated samples exhibit a spin mixing conductance of $g = (7.43 \pm 0.36) \times 10^{18}$ m^{-2} and a spin Hall angle of $\theta_{ISHE} = 0.009 \pm 0.001$.

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MA 3.2 Mon 9:45 HSZ 403

Temperature dependence of the spin Hall magnetoresistance in YIG / Pt hybrids — •Sibylle Meyer[1], Matthias Althammer[1], Stephan Geprägs[1], Matthias Opel[1], Rudolf Gross[1,2], and Sebastian T. B. Goennenwein[1] — [1]Walther - Meißner - Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik - Department, Technische Universität München, 85748 Garching, Germany

The generation and detection of pure spin currents represents a new paradigm for spin electronics. Within the last two years, the spin Hall magnetoresistance (SMR), a novel type of magnetoresistance based on the interplay between spin and charge transport in ferromagnetic insulator/normal metal hybrids, has become a powerful tool to access the spin transport properties of normal metals. Here we study the temperature dependence of the SMR in $Y_3Fe_5O_{12}$/Pt hybrid structures via magnetization orientation dependent magnetoresistance measurements. Our experiments show that the SMR amplitude decreases with decreasing temperature, which can be modeled in terms of a spin Hall angle in Pt decreasing from 0.11 at room temperature to 0.075 at 10 K, while the spin diffusion length and the spin mixing conductance of the ferrimagnetic insulator/normal metal interface remain almost constant.
Financial support by the Deutsche Forschungsgemeinschaft via SPP 1538 (project no. GO 944/4) and the German Excellence Initiative via the "Nanosystems Initiative Munich (NIM)" is gratefully acknowledged.

MA 3.3 Mon 10:00 HSZ 403

Spin-pumping induced inverse spin Hall effect at Fe/Pt interface: the influence of Pt thickness — •Evangelos Papaioannou, Viktor Lauer, Thomas Brächer, Philipp Pirro, and Burkard Hillebrands — Fachbereich Physik, Technische Universität Kaiserslautern, Erwin-Schrödinger-Str. 56, 67663 Kaiserslautern, Germany

The spin-pumping effect allows for the injection of a spin current from a ferromagnetic (FM) layer into an attached non-magnetic metal (NM) layer. [1] This spin current is subsequently transformed into a charge current by the inverse spin Hall effect (ISHE). Here, we examine the role of Pt thickness on the spin-pumping induced inverse spin Hall effect in Fe/Pt bilayers. Pt is grown epitaxially on top of Fe in order to maximize the ISHE efficiency [2]. The morphology of the Fe/Pt interface influences the effective spin mixing conductance. In magnetic field dependent measurements, the presence of a strong magnetic anisotropy gives rise to two distinct inverse spin Hall effect voltage peaks. The Pt thickness dependence on the ISHE-voltage from spin pumping is discussed with respect to proximity effects that can appear at the Fe/Pt interface.

[1] Y. Tserkovnyak, A. Brataas, and G. Bauer, Phys. Rev. Lett. 88, 117601 (2002). [2] E. Th. Papaioannou, P. Fuhrmann, M. B. Jungfleisch, T. Brächer, P. Pirro, V. Lauer, J. Lösch, and B. Hillebrands, Applied Physics Letters 103, 162401 (2013).

MA 3.4 Mon 10:15 HSZ 403

Colossal spin Hall effect in ultrathin noble metal films — •Christian Herschbach[1], Dmitry Fedorov[1], Martin Gradhand[2], and Ingrid Mertig[3,1] — [1]Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, 06120 Halle, Germany — [2]H. H. Wills Physics Laboratory, University of Bristol, Bristol BS8 1TL, United Kingdom — [3]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06099 Halle, Germany

The application of the spin Hall effect (SHE) in spintronics devices requires materials with a large spin Hall angle (SHA). This quantity describes the conversion efficiency from a charge current into a spin current. Recently, Niimi et al. [1] measured a large SHA ($\sim 20\%$) in thin film Cu(Bi) alloys. Such a giant SHE was predicted by *ab initio* calculations of the skew-scattering mechanism in bulk Cu with substitutional Bi impurities [2]. We extended the method to the film geometry and showed the SHE to be significantly increased in one monolayer (ML) noble metal films with Pt impurities with respect to related bulk systems [3].

Here, we resume our study and show that Bi impurities in 1ML noble metal films can generate a SHA of up to 80% caused by skew scattering. This *colossal* SHE can be attributed to scattering at relativistic $p_{1/2}$ impurity states.

[1] Y. Niimi et al., PRL **109**, 156602 (2012)
[2] M. Gradhand et al., PRL **104**, 186403 (2010)
[3] C. Herschbach et al., PRB **85** 195133 (2012)

MA 3.5 Mon 10:30 HSZ 403

Phase shift model for the spin Hall effect in dilute metal alloys — •Dmitry Fedorov[1], Christian Herschbach[1], Annika Johansson[2], Martin Gradhand[3], Kristina Chadova[4], Diemo Ködderitzsch[4], Hubert Ebert[4], and Ingrid Mertig[2,1] — [1]Max Planck Institute of Microstructure Physics, Halle, Germany — [2]Martin Luther University Halle-Wittenberg, Halle, Germany — [3]University of Bristol, Bristol, United Kingdom — [4]Ludwig-Maximilians University, Munich, Germany

A renewed interest to the resonant scattering model, derived originally for the description of the anomalous Hall effect, was initiated by Fert and Levy [1]. They considered it for the spin Hall effect in dilute metal alloys. Expressed initially for resonant d scatterers in terms of nonrelativistic phase shifts with a perturbative treatment of spin-orbit coupling (SOC), their model was reformulated later for strong p scatterers using relativistic phase shifts [2].

We developed [3,4] an extension of the relativistic and nonrelativistic resonant scattering model to arbitrary impurity atoms for the skew-scattering mechanism. Despite the generalization, a successful application of the model is restricted to dilute alloys based on host crystals with weak SOC and a free-electron like Fermi surface. This is illustrated by a comparison between the model and our first-principles calculations.

[1] A. Fert and P.M. Levy, PRL **106**, 157208 (2011); [2] Y. Niimi *et al.*, PRL **109**, 156602 (2012); [3] D.V. Fedorov *et al.*, PRB **88**, 085116 (2013); [4] C. Herschbach *et al.*, PRB **88**, 205102 (2013).

MA 3.6 Mon 10:45 HSZ 403

Phase-sensitive detection of both inductive and non-inductive ac voltages in ferromagnetic resonance — •Mathias Weiler, Justin M. Shaw, Hans T. Nembach, Martin A. Schoen, Carl T. Boone, and Thomas J. Silva — Electromagnetics Division, National Institute of Standards and Technology, Boulder, CO 80305

Spin pumping causes significant damping in ultrathin ferromagnetic/normal metal (NM) multilayers via spin-current generation of both dc and ac character in the NM system. While the nonlinear dc component has been investigated in detail by utilization of the inverse spin Hall effect (iSHE) in NMs, much less is known about the linear ac component that is presumably much larger in the small-excitation limit. We measured generated ac voltages in a wide variety

of Permalloy/NM multilayers via vector-network-analyzer ferromagnetic resonance. We employ a custom, impedance-matched, broadband microwave coupler that features a ferromagnetic thin film reference resonator to accurately compare ac voltage amplitudes and phases between varieties of multilayers. We find that inductive signals are major contributors in all investigated samples. It is only by comparison of the phase and amplitude of the recorded ac voltages between multiple samples that we can extract the non-inductive contributions due to spin-currents. Voltages due to the ac iSHE in Py(10nm)/Pt(5nm) bilayers are of the same order of magnitude as inductive signals, in agreement with recent theoretical predictions.

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MA 3.7 Mon 11:00 HSZ 403

Experimental observation of a large ac-spin Hall effect — •Dahai Wei[1], Martin Obstbaum[1], Christian Back[1], and Georg Woltersdorf[1,2] — [1]Universität Regensburg, 93053 Regensburg, Germany — [2]Martin-Luth-Universität Halle, 06120 Halle, Germany

Spin pumping is the most popular approach to inject pure spin currents into various classes of nonmagnetic materials. The polarization direction of the injected spin currents is time dependent and contains only a very small dc-component [1]. This dc-component has been intensely studied in recent years. However in contrast, the two orders of magnitude larger ac-component has escaped experimental detection so far. Here we show that the large ac-component of the spin currents can be detected very efficiently using the inverse spin Hall effect (ISHE) leading to signals one order of magnitude larger than the conventional dc-ISHE measured on the same device. The spectral shape, angular dependence, power scaling behavior and absolute magnitude of the signals are in line with spin pumping and ISHE theory. Our results demonstrate that FM-NM junctions are very efficient sources of pure spin currents in the GHz frequency range.

[1] H. Jiao and G. E. Bauer, Phys. Rev. Lett., 110, 217602 (2013)

MA 3.8 Mon 11:15 HSZ 403

Experimental test of the spin mixing interface conductance concept — •Michael Schreier[1], Mathias Weiler[1], Matthias Althammer[1], Johannes Lotze[1], Matthias Pernpeintner[1], Sibylle Meyer[1], Hans Huebl[1], Rudolf Gross[1,2], Akashdeep Kamra[1,3], Jiang Xiao[4], Yan-Ting Chen[3], HuJun Jiao[3], Gerrit E. W. Bauer[3,5], and Sebastian T. B. Goennenwein[1] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, DE — [2]Physik-Department, TU München, DE — [3]Kavli Institute of Nanoscience, Delft University of Technology, NL — [4]Department of Physics and State Key Laboratory of Surface Physics, Fudan University, CHN — [5]Institute of Materials Research and WPI-AIMR, Tohoku University, JP

Spin pumping (SP), spin Hall magnetoresistance (SMR) and the spin Seebeck effect (SSE) originate from spin transfer across the interface between a ferromagnet and a normal metal. The spin mixing conductance $g^{\uparrow\downarrow}$ in particular determines the rate by which spin accumulation on one side of the interface can relax to the other. Until now, however, a comprehensive, quantitative experimental test of the spin mixing interface conductance concept has been missing. Here, we present an in-depth analysis and experimental study of SP, SMR and SSE experiments conducted on a series of YIG/Pt samples from which we extract the relevant spin transport parameters (spin diffusion length, spin Hall angle and $g^{\uparrow\downarrow}$). Our findings strongly support the spin mixing interface conductance concept, i.e. the purely spintronic nature of all three effects [Weiler *et al.*, Phys. Rev. Lett. 111, 176601 (2013)].

MA 3.9 Mon 11:30 HSZ 403

Spin Hall and spin Nernst effect in 5d transition-metal thin films — •N. H. Long, P. Mavropoulos, B. Zimmermann, D. S. G. Bauer, S. Blügel, and Y. Mokrousov — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Spin Hall effect (SHE), where a transverse spin current is created in a nonmagnetic metal by an applied electrical field has developed into one of the most effective ways for spin-manipulation in nano-devices. In the nonmagnetic transition-metal alloys, one important contribution to the SHE is the skew-scattering due to impurities. A similar phenomenon, namely, the spin Nernst effect (SNE), has also been theoretically predicted and studied during the past years. Instead of applying an electric field, a transverse spin current can be produced by an applied temperature gradient via the SNE. Using our newly developed relativistic full-potential KKR Green function method, in this work we investigate the extrinsic SHE and SNE in 5d transition-metal thin films caused by the skew-scattering off adatom impurities. The conductivity tensor is calculated in terms of the Boltzmann equation at the dilute impurity concentration. The analysis is concentrated on the role played by the electronic structure of thin films as well as the surface states on the SHE and SNE. The calculated results allow the prediction of the emergence of large spin Hall as well as spin Nernst conductivities in these materials. We acknowledge funding from SPP 1538 SpinCaT programme and HGF-YIG Programme VH-NG-513.