MA 48: Spin-dependent Transport Phenomena

Time: Friday 9:30–12:45 Location: H23

MA 48.1 Fri 9:30 H23

Electrical detection of inverse spin Hall effect induced by spin pumping — •Yuriy Aleksandrov[1,2], Jürgen Lindner[1], Michael Farle[3], Irina Rod[3], and Horst Zähres[3] — [1]HZDR, Dresden, Germany — [2]TU Dresden, Dresden, Germany — [3]Universität Duisburg-Essen, Duisburg, Germany

Spin pumping driven by ferromagnetic resonance (FMR) injects a spin current through a simple ferromagnetic (FM)/paramagnetic (PM) interface into a PM layer [1]. Due to the inverse spin Hall effect (ISHE), arising from the spin-orbit coupling in the PM layer, the spin current is converted into a charge current. As a result transverse electromotive force perpendicular to the applied magnetic field and to the microwave field is produced [2]. Here we present direct measurements of the ISHE induced by spin pumping in Py/Pt bilayer. We observe a 4mT FMR linewidth broadening for the samples with Pt capping layers due to spin pumping. We also find that the electromotive force varies systematically with changing microwave power and frequency, magnetic-field angle, or temperature. This is consistent with the predictions based on the Landau-Lifshitz-Gilbert equation combined with the models of the ISHE and spin pumping.

Financially suppoted by DFG, SFB 491.

[1]Tserkovnyak et al. PRL., 88:117601, Feb 2002.
[2]Mosendz et al. PR B 82, 214403, 2010

MA 48.2 Fri 9:45 H23

Spin-Hall effect in 4d and 5d transition metal systems — •Kristina Chadova, Diemo Ködderitzsch, and Hubert Ebert — Universität München, Department Chemie, Butenandtstr. 5-13, D-81377 München

We present a detailed analysis of different contributions to the extrinsic spin-Hall effect on the basis of first principles calculations. As an example, we consider Cu as a host with 5d impurities of different concentrations. The corresponding calculations are based on the Kubo-Středa equation [1] implemented within the fully relativistic Korringa-Kohn-Rostoker (KKR) Green's function formalism in combination with the Coherent Potential Approximation (CPA) alloy theory. The decomposition of the extrinsic spin-Hall conductivity is based on the scaling behavior as suggested for the anomalous Hall effect [2]. We discuss the applicability of the latter model by comparing to the full *ab initio* description. We also analyze the results with respect to a recent model of the extrinsic SHE in these systems [3].

[1] S. Lowitzer, D. Ködderitzsch and H. Ebert, Phys. Rev. Lett. **105**, 266604 (2010) [2] N. Nagaosa, J. Sinova, S. Onoda, A. H. MacDonald and N. P. Ong, Rev. Mod. Phys. **82**, 1539 (2010) [3] A. Fert and P. M. Levy, Phys. Rev. Lett. **106**, 157208 (2011)

MA 48.3 Fri 10:00 H23

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

To use the spin Hall effect (SHE) in possible spintronics devices, materials with a large spin Hall angle (SHA) are desirable. This quantity describes the efficiency of the charge to the spin current conversion. The largest experimental value of the SHA is 24%, which was measured recently in thin film Cu(Bi) alloys by Niimi et al. [1]. The giant SHE was predicted by *ab initio* calculations of the skew-scattering mechanism in bulk Cu with substitutional Bi impurities [2]. Recently, we have extended our calculations to the film geometry and showed that the SHE can be drastically increased in monolayer noble metal films with Pt impurities in comparison to the related bulk systems [3]. In the current work we continue our study and show that with an appropriate choice of impurities in 1ML noble metal films the SHA can be as large as 80%. Such *colossal* charge to spin current conversion is very promising for spintronics applications.

[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 48.4 Fri 10:15 H23

Spin-Hall nano-oscillators — •Henning Ulrichs[1], Sergej Demokritov[1], Vladislav Demidov[1], Dietmar Baither[1], Guido Schmitz[1], Sergei Urazhdin[2], Vasil Tiberkevich[3], and Andrei Slavin[3] — [1]University of Muenster, Corrensstrasse 2-4, 48149 Muenster, Germany — [2]Emory University, Atlanta, GA 30322, USA — [3]Department of Physics, Oakland University, Rochester, MI, USA

Pure spin currents generated by the spin Hall effect have been recently utilized to suppress and enhance thermal magnetic fluctuations in magnetic nanodevices, and to reduce the dynamic damping in magnetic films [1].

Here, we experimentally study nano-devices driven by pure spin currents generated due to the spin Hall effect in a Pt electrode, and locally injected into an extended Permalloy film. By using micro-focus Brillouin light scattering spectroscopy, we demonstrate that above a certain current threshold, our device enters a single-mode coherent auto-oscillation regime [2]. The corresponding strongly-localized dynamic mode with the diameter below 100 nanometers, has characteristics reminiscent of the nonlinear stationary spin-wave "bullet"[3].

Our findings suggest a route for the implementation of novel magnetic nano-oscillators that have significant advantages over conventional spin-torque nano-oscillators (STNOs), whose geometry and structure are limited by the requirement that the spin current is accompanied by the electric current flowing through the ferromagnet.

1. Phys. Rev. Lett. 107, 107204 (2011), 2. Nature Materials 11, 1028 (2012), 3. Phys. Rev. Lett. 95, 237201 (2005)

MA 48.5 Fri 10:30 H23

Magnetotransport in hybrid ferromagnet/semiconductor heterostructures — •Alex Matos-Abiague and Jaroslav Fabian — Institute for Theoretical Physics, University Regensburg, 93040 Regensburg, Germany

The effects of the spin-orbit coupling (SOC) on the magnetotransport of hybrid ferromagnet/semiconductor heterostructures are discussed. In such systems the SOC fields at the ferromagnet/semiconductor interface lower the symmetry of the corresponding bulk materials. As a consequence anisotropic effects emerge in both spin and charge transport. We explore the symmetries of the SOC fields in structures with a single ferromagnetic layer and how they manifest in phenomena such as tunneling anisotropic magnetoresistance (TAMR) in magnetic tunnel junctions and anisotropic magnetoresistance (AMR) in lateral hybrid devices. Based on general symmetry considerations, we investigate how the dependence of the TAMR on the magnetization direction is determined by the specific form of the SOC field. With regard to the AMR in hybrid lateral devices we show that in addition to the usual magnetoresistance dependence on the angle between magnetization and charge current (noncrystalline AMR), a dependence on the current flow direction with respect to a reference crystallographic axis (crystalline AMR) emerges. The crystalline anisotropy of the anomalous Hall effect is also discussed.

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MA 48.6 Fri 10:45 H23

Anisotropy of Spin Relaxation in Metals — •Bernd Zimmermann, Phivos Maropoulos, Swantje Heers, Nguyen H. Long, Stefan Blügel, and Yuriy Mokrousov — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

We predict a giant anisotropy of the spin relaxation time T_1, i.e. the dependence of T_1 on the orientation of the electron-spin polarization relative to the crystal lattice [1], that has not been considered so far. Our theory is based on the spin-orbit caused Elliott-Yafet (EY) mechanism, which yields the relation $T_1^{-1} \sim b^2$, where we determine the EY spin-mixing parameter b^2 and its anisotropy by *ab initio* calculations employing the Korringa-Kohn-Rostoker Green function method.

We investigate various 5d and 6sp metals and find gigantic anisotropy values for hcp-metals (up to 830% for Hf), which means that T_1 can be adjusted within one order of magnitude by changing the spin-polarization direction. We identify the formation of extended spin-flip hot areas (i.e. parts of the Fermi surface where the states are almost fully spin mixed) at nested Fermi-surface sheets or hot loops at the hexagonal face of the Brillouin zone boundary as source of the extremely high anisotropy. Our explanation is based on the spin-flip part of spin-orbit coupling in combination with the reduced symmetry of the hcp-lattice. Our findings should also be important for other effects in spintronics, e.g. the spin Hall effect. Funding by HGF (VH-NG-513) and DFG (MO 1731/3-1) is acknowledged.

[1] B. Zimmermann *et. al* , PRL in press, preprint: arXiv:1210.1801

15 min. break.

MA 48.7 Fri 11:15 H23

Spin relaxation in ultrathin metallic films: Anisotropy and surface-state effects — •Phivos Mavropoulos, Nguyen H. Long, Bernd Zimmermann, Yuriy Mokrousov, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, D-52425 Jülich

We investigate the relaxation of conduction electron spins in nonmagnetic ultrathin metallic films. Within the framework of the Elliott-Yafet theory we calculate the spin-mixing parameter b^2 and the scattering matrix elements off adatoms. We show that the reduced dimensionality always leads to a significant anisotropy [1] of the relaxation rate with respect to the relative direction between the injected electron spin polarization and the crystallographic film axes. We further reveal the fundamental influence of surface states creating spin-polarization fields due to the Rashba effect. In certain cases we find unexpected even-odd effects with respect to the number of layers in the film as well as formation of spin-flip hot spots in monovalent metals. For our calculations we employ the Korringa-Kohn-Rostoker Green function method [2,3] within the local density approximation to density-functional theory. Funding from the DFG project MO 1731/3-1 is acknowledged.

[1] B. Zimmermann et al. PRL (2012, in press); arXiv:1210.1801.
[2] N. Papanikolaou, R. Zeller, and P.H. Dederichs, JPCM **14**, 2799 (2002); see also `http://www.kkr-gf.org`.
[3] S. Heers, Ph.D. Thesis, RWTH Aachen (2011); Online at: `http://darwin.bth.rwth-aachen.de/opus3/volltexte/2011/3827`

MA 48.8 Fri 11:30 H23

Spin-polarized conductance in 1D binary alloy systems — •Ilia N. Sivkov and Valeriy S. Stepanyuk — Max Planck Institute of Microstructure Physics, Halle, Germany

Spin-dependent transmission in 1D binary alloy nanowires and contacts is studied using non-equilibrium Green's function method and density functional theory. By the example of Ni-Pt wires suspended between Pt(001) leads it is shown, that transmission through binary wires is highly dependent on the wire's geometry. The physical origin of that strong dependence and the impact of electrodes on the transmission is discussed using the local density of electronic states.

Following the paper [PRL 94, 237201], predicting a half-metal to semiconductor transition in Gd-N bulk systems, we investigate transport properties of Gd-N nanowires and compare them to 1D Gd-N contacts. We find that infinite Gd-N zig-zag wires retain half-metallic behavior found in the bulk, which leads to a 100% spin polarization of the tunneling current. Upon stretching Gd-N wires also undergo the half-metal to insulator transition while retaining the spin-filter behavior in the whole half-metal range. To understand the importance of the interface, the infinite Gd-N nanowire is compared to a Gd-N nanowire suspended between electrodes.

MA 48.9 Fri 11:45 H23

Spin-disorder resistivity of ferromagnetic metals — •Josef Kudrnovsky[1], Vaclav Drchal[1], Ilja Turek[2], Sergei Khmelevskii[3], James Glasbrenner[4] und Kirill Belashchenko[4] — [1]Institute of Physics AS CR, Prague — [2]Charles University, Prague — [3]University of Technology, Venna — [4]University of Nebraska, Lincoln

The spin-disorder resistivity (SDR) of transition metal ferromagnets, rare-earth metals, ordered transition metal ferromagnets, and Ni-based Heusler alloys is determined from first principles. We identify the SDR at the Curie temperature with the residual resistivity of the corresponding system evaluated in the framework of the disordered local moment (DLM) model which has the zero spin-spin correlation function. The underlying electronic structure is determined in the framework of the tight-binding linear muffin-tin orbital method which employs the coherent potential approximation (CPA) to describe the DLM state. The DLM fixed-spin moment approach is used in the case when the DLM moment collapses. The Kubo-Greenwood approach is employed to estimate the resistivity. For bcc-Fe we shall also estimate the temperature-dependent of resistivity below the Curie temperature using semiempirical approach. Calculations are compared with an alternative supercell Kubo-Landauer approach developed recently as well as with available experimental data and overall good agreement is obtained.

MA 48.10 Fri 12:00 H23

Anomalous Hall effect and its anisotropy in disordered tetragonal Fe-Co alloys — •Ilja Turek[1], Josef Kudrnovsky[2], and Vaclav Drchal[2] — [1]Institute of Physics of Materials, Acad. Sci. Czech Rep., Brno, Czech Republic — [2]Institute of Physics, Acad. Sci. Czech Rep., Prague, Czech Republic

We present results of *ab initio* calculations of zero-temperature transport properties for disordered body-centered tetragonal (bct) Fe-Co alloys by using the fully relativistic TB-LMTO method, the coherent potential approximation (CPA) and the Kubo-Středa formula [1]. Particular attention has been paid to the anomalous Hall conductivity (AHC) and to the alloy composition around 60 at.% Co, for which an enhanced value of the uniaxial magnetic anisotropy energy was predicted and observed in strained Fe-Co films [2]. We have found that the AHC values for the magnetization direction pointing along the tetragonal a and c axes can differ nearly three times for certain tetragonal distortions and alloy compositions. This anisotropy exceeds that calculated for pure tetragonal Fe and Co metals and it seems to be surprisingly stable with respect to the alloy disorder. Further aspects of the predicted behavior including its possible experimental verification will also be briefly discussed. [1] I. Turek et al., Phys. Rev. B 86, 014405 (2012). [2] I. Turek et al., arXiv:1210.1028 (2012).

MA 48.11 Fri 12:15 H23

Exploiting spin extraction for local spin valve structures — •Yori Manzke, Rouin Farshchi, Pawel Bruski, Jens Herfort, and Manfred Ramsteiner — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

We show that spin extraction [1] can serve as the spin generation mechanism in local spin valves. In contrast to electrical spin injection, which is commonly employed in such magnetoresistance devices, spin accumulation in a non-magnetic semiconductor (SC) is created upon an electron flow from the SC into a ferromagnetic metal Schottky contact. The investigated samples comprise ferromagnetic Heusler alloy (Co_2FeSi) contact stripes on an n-type GaAs channel. A current divider arrangement is used to generate spin polarized drift currents by spin extraction and to sense spin-induced changes in contact resistance at a subsequent ferromagnetic stripe. We discuss the extension of this scheme to spin valves based on multiple extraction events. Generally, the electrical output signal of our magnetoresistance devices depends on the relative orientation of the contact magnetizations and we obtain 2^{m-1} electrical output states for m ferromagnetic contacts. Our results suggest that multiple spin extraction may find its application in the generation of highly spin-polarized drift currents and as a read-out mechanism in magnetic data storage. This work was partially supported by the DFG via SPP 1538.

[1] J. Stephens *et al.*, Phys. Rev. Lett. **93**, 097602 (2004).

MA 48.12 Fri 12:30 H23

Spin Accumulation in transition Metal thin Films from First Principles — •Frank Freimuth, Stefan Blügel, and Yuriy Mokrousov — Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

We present first-principles calculations of the spin accumulation in paramagnetic transition metal thin films due to applied in-plane electric fields. Two contributions to the spin accumulation are identified: The first contribution is the accumulated spin current from the spin Hall effect and depends on the spin diffusion length. The second contribution arises from the surface Rashba and the bulk Rashba effects. It is not directly related to the spin current flowing towards the surfaces and independent of the spin diffusion length. The spatial distributions of spin accumulation and spin current are also discussed and compared to model predictions. Furthermore, we discuss spin accumulation and resulting torques in thin ferromagnetic layers stacked on top of paramagnetic layers. This work is supported by the HGF-YIG grant VH-NG-513.