MA 28: Spin-dependent Transport Phenomena

Time: Thursday 15:15–19:00 Location: H3

MA 28.1 Thu 15:15 H3

Magnetic properties and high room temperature TMR ratios of Co_2FeAl in magnetic tunnel junctions — •Daniel Ebke, Zoë Kugler, Patrick Thomas, Oliver Schebaum, Markus Schäfers, Dennis Nissen, Jan Schmalhorst, Andreas Hütten, and Andy Thomas — Thin Films and Physics of Nanostructures, Physics Department, Bielefeld University, Germany

Spintronic devices have found a lot of attention in the recent years due to the possible new applications, e.g. a magnetic random access memory (MRAM). Therefore, materials with a high spin polarization such as half metallic Heusler compounds are eligible.

In this work, we present low temperature tunnel magnetoresistance (TMR) values of up to 270% for MgO based magnetic tunnel junctions (MTJs) with Co_2FeAl and Co-Fe electrodes. A low temperature dependence leads to high room temperature TMR values of about 150%. The bulk magnetic moment and the element specific magnetic moment at the barrier interface were examined as a function of annealing temperature by alternating gradient magnetometer (AGM) and X-ray absorption spectroscopy (XAS) / X-ray magnetic circular dichroism (XMCD), respectively.

MA 28.2 Thu 15:30 H3

Direct measurement of the spin polarization of Co_2FeAl — •Oliver Schebaum[1], Daniel Ebke[1], Andrea Niemeyer[1], Günter Reiss[1], Jagadeesh S. Moodera[2], and Andy Thomas[1] — [1]Thin Films and Physics of Nanostructures, Bielefeld University, Germany — [2]Francis Bitter Magnet Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

Heusler compounds are of great interest in materials science due to the predicted 100% spin polarization. A high spin polarization of the tunneling current is necessary for a large tunnel magnetoresistance (tmr) ratio. A large tmr ratio is a key requirement for spintronic applications. Thus, Heusler compounds are considered promising candidates as ferromagnetic electrodes in future spintronic devices based on magnetic tunnel junctions (mtjs). Although the room temperature tmr ratio of Heusler based mtjs could be increased in the recent years the enormous effect expected for highly spin polarized electrodes has not been observed.

We directly measured the spin polarization of Co_2FeAl in contact with a MgO tunnel barrier by spin polarized tunneling into a superconducting Al-Si electrode. The BCS density of states of the superconductor is spin split in an in-plane magnetic field. Due to this Zeeman splitting a spin polarized tunneling current results in an asymmetry of the conductance vs. voltage measurements.

We found a spin polarization of the tunneling current of $P = 55\%$. This value is in good agreement with the spin polarization obtained from our tmr measurements and results published by other groups.

MA 28.3 Thu 15:45 H3

Ab-initio transport calculations of Fe/MgO/Fe tunnel junctions modified by Co and Cr interlayers — •Peter Bose[1,3], Jürgen Henk[2], Peter Zahn[1], and Ingrid Mertig[1,2] — [1]Martin Luther University Halle-Wittenberg, Germany — [2]Max Planck Institute of Microstructure Physics, Halle, Germany — [3]International Max Planck Research School for Science and Technology of Nanostructures

For spintronic device applications, large and tuneable tunnel magnetoresistance ratios (TMR) are inevitable. However, experimental TMR ratios of epitaxial Fe/MgO/Fe junctions can be strongly reduced by imperfect Fe/MgO interfaces. A way to increase the TMR ratio is the insertion of thin metallic layers at the Fe/MgO interfaces. With respect to their magnetic and electronic properties as well as their small lattice mismatch to Fe(001), Co and Cr interlayers have been preferably studied [1,2].

We report on systematic ab-initio investigations of Co and Cr interlayers focussing on the changes of the electronic structure and the transport properties. The results of spin-dependent ballistic transport calculations reveal options to specifically manipulate the TMR ratio. The observed effects are directly addressed and interpreted by means of electronic states with complex wave vectors.

[1] S. Yuasa et al., APL**87** 222508 (2005), [2] R. Matsumoto et al., PRB**79** 174436 (2009)

MA 28.4 Thu 16:00 H3

Inelastic Electron Tunneling Spectroscopy of CoFeB/ MgO/ CoFeB based magnetic tunnel junctions in high magnetic fields — •Marvin Walter[1], Vladyslav Zbarskyy[1], Markus Münzenberg[1], Michael Seibt[2], Volker Drewello[3], Markus Schäfers[3], Günter Reiss[3], and Andy Thomas[3] — [1]I. Phys. Inst., Georg-August-Universität Göttingen, 37077 Göttingen — [2]IV. Phys. Inst., Georg-August-Universität Göttingen, 37077 Göttingen — [3]Bielefeld University, Physics Department, 33501 Bielefeld

Magnetic tunnel junctions (MTJs) showing a high tunnel magnetoresistance (TMR) are important for the fabrication of MRAM devices when combined with current induced switching.

We discuss inelastic electron tunneling spectroscopy (IETS) measurements on CoFeB/MgO/CoFeB magnetic tunnel junctions. The junctions are prepared by means of magnetron sputtering of CoFeB and e-beam evaporation of stoichiometric MgO. Structuring of the multilayer is done using a photolithography process and Argon ionmilling.

The IETS measurements are carried out at low temperatures down to 4.2 K, high magnetic fields up to 9 T and in parallel as well as antiparallel electrode configuration in order to distinguish between different kind of excitations such as e.g. magnons and phonons. Furthermore, oxygen vacancies in the MgO barrier are controlled through variation of the sample temperature during e-beam growth to investigate the influences of these vacancies on the tunneling spectra of MTJs. Research is supported by DFG SFB 602.

MA 28.5 Thu 16:15 H3

Tunneling spectroscopy and magnon excitation in Co_2FeAl/MgO/Co-Fe magnetic tunnel junctions — •Volker Drewello, Daniel Ebke, Markus Schäfers, Günter Reiss, and Andy Thomas — Bielefeld University, 33615 Bielefeld, Germany

Magnetic tunnel junctions with the Heusler compound Co_2FeAl as the soft electrode are prepared. Pinned Co-Fe is used as the hard reference electrode. The electronic transport is investigated by tunneling spectroscopy (dI/dV and d^2I/dV^2). In the parallel magnetic state the tunneling spectra are asymmetric with respect to the bias voltage, with a pronounced bias-independent region. In the antiparallel state the dependence on bias voltage is much stronger and the curves are symmetric. The findings can be explained with a gap in the minority density of states of Co_2FeAl.

MA 28.6 Thu 16:30 H3

X-ray microscopy and transport measurements in lateral spin valves including tunneling barriers — •Jeannette Wulfhorst[1], Andreas Vogel[1], Lars Bocklage[1], Peter Fischer[2], Ulrich Merkt[1], and Guido Meier[1] — [1]Institut für Angewandte Physik, Universität Hamburg, Jungiusstrasse 11, 20355 Hamburg, Germany — [2]Center for X-ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Various approaches to generate, manipulate, and detect spin currents are presently investigated. In lateral all-metal spin valves, generation and nonlocal detection of spin-polarized currents are realized with ferromagnetic materials, e.g., permalloy. The generated spin current is injected into a normal metal and can be manipulated by a perpendicular external magnetic field [1,2]. Transport measurements at temperatures of liquid helium are performed and the Hanle effect is observed. From the comparison of the experimental data amd theory, the spin-relaxation time and -length in copper are determined. High resolution transmission soft X-ray microscopy with magnetic contrast is used to image spin accumulation in copper [3]. The images show indications of spin accumulation at 933 eV after optimization of the magnetic contrast via energy scans. This work has been supported by DFG and by DOE.

[1] A. van Staa et al., Phys. Rev. B **77**, 214416 (2008)
[2] A. Vogel et al., Appl. Phys. Lett. **94**, 1225210 (2009)
[3] O. Mosendz et al., Phys. Rev. B **80**, 104439 (2009)

MA 28.7 Thu 16:45 H3

Magnetism and spin transport in spin filter/silicon heterostructures — •Martina Müller[1], Marc J. van Veenhuizen[2], Jagadeesh S. Moodera[2], and Claus M. Schneider[1] — [1]Institut

für Festkörperforschung, Forschungszentrum Jülich — [2]Francis Bitter Magnet Laboratory, MIT, USA

Controlling spin transport in ferromagnet(FM)/semiconductors(SC) systems is a key objective in the development of semiconductor spintronics. Recently, spin injection and -detection into silicon (Si) has been realized using FM/oxide tunnel contacts. Here, we present an alternative route to engineer functional spin tunnel contacts, which are based on magnetic insulator/Si heterostructures.

We fabricated EuS/Si and Co/EuS/Si embedded tunnel contacts on n-doped Si substrates. Ferromagnetic EuS tunnel barriers were grown by means of MBE, with thicknesses between d=2 to 6 nm. The transport experiments showed a characteristic metal-to-insulator transition of EuS at T<20 K, which clearly confirms a spin filter effect being in effect. I(V) measurements revealed a highly non-linear behavior indicative for tunnel transport. However, no totally symmetric I(V) curves were found under forward/reverse bias, which is due to an additional Schottky barrier present at the EuS/n-Si interface. MR measurements of Co/EuS/Si contacts yielded MR values up to 10% combined with a pronounced bias voltage dependence. This unique feature is due to superimposing spin tunneling pathes [1] and principally should allow the electrical injection of spins into silicon at elevated bias voltages.

[1] G.-X. Miao, M. Müller, J. S. Moodera, PRL 102, 076601 (2009)

15 min. break

MA 28.8 Thu 17:15 H3

Macroscopic theory for time-dependent noncollinear spin transport — •Steffen Kaltenborn, Yao-Hui Zhu, and Hans Christian Schneider — Department of Physics and Research Center OPTIMAS, TU Kaiserslautern

We employ a macroscopic theory based on the semiclassical Boltzmann equation for the spin-density matrix to analyze the propagation of signals encoded in a spin current, which flows through a multilayer structure with *noncollinear* magnetization and spin directions. [1] We find that, due to the wave-like character of spin currents, modifications of pure spin-diffusion dynamics may result, depending on the signal time-scale (or frequency). In particular, we determine the finite spin-signal propagation velocity, which is not possible in the framework of the spin-diffusion equation, and numerically study the dynamics of a pure spin current pumped into a nonmagnetic Cu layer by a precessing magnetization in an adjacent ferromagnetic permalloy layer for precession frequencies ranging from GHz to THz. Extensions of the theory to nanostructures will be discussed.

[1] Y.-H. Zhu, B. Hillebrands, and H. C. Schneider, Phys. Rev. B **79**, 214412 (2009)

MA 28.9 Thu 17:30 H3

***Ab initio* study of the spin-Hall effect in nonmagnetic 4*d* and 5*d* transition metals** — •Frank Freimuth, Yuriy Mokrousov, and Stefan Blügel — Institut für Festkörperforschung, & Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany

Due to the spin-orbit interaction an electrical current induces a transverse spin current leading to the appearance of spin accumulation on the lateral surfaces of current-carrying samples. This phenomenon is known as the spin-Hall effect and offers new perspectives for the design of spintronics devices. A quantitatively reliable theoretical description of the spin-Hall effect is desirable for computer-aided material design. However, in the presence of spin-orbit coupling the standard formulation of the spin current is unsatisfactory, because it does not meet the requirement of conservedness. Moreover, the relationship between spin current and spin accumulation is still an open question. We present DFT-based *ab initio* calculations of the spin-Hall conductivity in nonmagnetic bulk 4*d* and 5*d* transition metals. We compare various formulations of the spin current and discuss their relevance for the spin accumulation. Additionally, we describe our computational method, which is based on the Kubo formalism within a Green-function based implementation of the full-potential linearized augmented-plane-wave (FLAPW) method `FLEUR` (www.flapw.de). Our method is not restricted to bulk calculations, but we are able to tackle a huge spectrum of geometries (bulk, film, semi-infinite slab) and to calculate the spin current beyond linear response.

MA 28.10 Thu 17:45 H3

Ab initio description of the extrinsic spin Hall effect — •Martin Gradhand[1], Dimitry V. Fedorov[2], Peter Zahn[2], and Ingrid Mertig[1,2] — [1]Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, D-06120 Halle, Germany — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, D-06099 Halle, Germany

The gigantic Spin Hall effect for Au, measured by Seki et. al. [1], could not be explained by the intrinsic contribution described by the Berry curvature. The extrinsic mechanisms for the spin separation, namely the side jump and the skew scattering, must be responsible for the observed effect.

Here we present our relativistic ab initio approach to analyze the skew scattering at substitutional impurities. The iterative solution of a linearized Boltzmann equation leads to the extrinsic contribution to the spin Hall effect. Using that, a new explanation for the gigantic spin Hall effect in Au is proposed [2]. In addition, we show that a sign change of the spin Hall effect is generated by varying the type of the impurity atom and can be understood from the microscopic transition probabilities.

[1] T. Seki et al., Nature Materials 7, 125 (2008)
[2] M. Gradhand et al., submitted to PRL (2009)

MA 28.11 Thu 18:00 H3

Anisotropy of anomalous Hall conductivity in $L1_0$ 3d-Pt alloys from first principles — •Hongbin Zhang, Stefan Blügel, and Yuriy Mokrousov — Institut für Festkörperforschung & Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany

Using first-principles calculations, we investigate the anisotropy of the intrinsic anomalous Hall conductivity (AHC) in ordered and disordered ferromagnetic bimetallic $L1_0$ 3d-Pt (3d = Cr, Mn, Fe, Co and Ni) alloys. The AHC is calculated via the Wannier interpolation procedure with consequent Brillouin zone integration of the Berry curvature [1]. We find very large anisotropies of the AHC both upon rotating the magnetization away from the easy [001]-axis (axis along the stacking direction of the ordered alloys) to in-plane, as well as for some alloys upon rotating the magnetization in the plane normal to the stacking direction. To elucidate the origin of this anisotropy, we study in detail the contributions from different atoms and the role of spin-scattering transitions in the vicinity of the Fermi surface. At last, we provide a simple interpretation of obtained chemical trends of the AHC and its anisotropy based on a toy tight-binding model.

[1] X. Wang, J. R. Yates, I. Souza, D. Vanderbilt *Phys. Rev. B* 74, 195118 2006.

MA 28.12 Thu 18:15 H3

Spin dependent transport of hot electrons in bcc Fe(100) and bcc $Fe_{34}Co_{66}$(100) — •Emanuel Heindl, Johann Vancea, and Christian H. Back — Department of Physics, University of Regensburg, 93040 Regensburg, Germany

We investigate hot electron spin filtering in thin bcc Fe(100) and bcc $Fe_{34}Co_{66}$(100) layers using Ballistic Electron Emission Microscopy. An STM tip is used as a tunable constant current source of hot electrons being injected into single crystalline metallic spin valve structures. The subsequent ballistic hot electron transport is recorded and separated from thermalized electron transport by means of a metal semiconductor junction whose Schottky barrier acts as a spectrometer. Electron transport is carried out with the main transport axis along the [100]-axis of the ferromagnetic layers at electron energies between 1 eV and 2.5 eV above the Fermi level. Parallel and antiparallel magnetization configurations of the spin valve are readily adjustable with an external magnetic field as revealed by Kerr effect and magnetocurrent measurements.

When the $Fe_{34}Co_{66}$ electrode is replaced by Fe the spin contrast drops by more than a factor of 5 in the studied energy interval. We interpret this observation to the spin asymmetry of unoccupied states and to the electron velocity being distinct for majority and minority spins. By cooling down from room temperature to 130 K ballistic currents become significantly enhanced for both materials in the parallel and the antiparallel magnetization configuration, while hot electron spin polarization is enhanced for $Fe_{34}Co_{66}$, only.

MA 28.13 Thu 18:30 H3

Angular dependence of the tunneling anisotropic magnetoresistance — •Alex Matos-Abiague, Martin Gmitra, and Jaroslav Fabian — Univesrity of Regensburg, Regensburg, Germany

A phenomenological model in which the tunneling anisotropic magnetoresistance (TAMR) effect originates from the presence of spin-orbit interaction is developed. The model is based on general symmetry considerations and reveals the dependence of the TAMR in tunnel junctions with a single magnetic lead on the magnetization orientation. Some relevant cases of spin-orbit interaction induced by structure and/or bulk inversion asymmetries are investigated.

Acknowdlegments: This work was supported by the DFG via SFB 689.

MA 28.14 Thu 18:45 H3

Magnetic anisotropy and tunneling anisotropic magnetoresistance in 3d-5d bimetallic antiferromagnets Mn_2Au and MnIr. — •Alexander Shick[1], Sergii Khmelevskiy[2], Joerg Wunderlich[3], and Tomas Jungwirth[1,4] — [1]Institute of Physics ASCR, Praha, Czech Republic — [2]Wien Univ. of Technology, Wien, Austria — [3]Hitachi Cambridge Laboratory, Cambridge, UK — [4]Univ. of Nottingham, Nottingham, UK

Full-potential relativistic density functional theory is employed to study the magnetic anisotropy energies (MAE) and tunneling anisotropic magnetoresistance (TAMR) in the 3d-5d bimetallic antiferromagnets Mn_2Au and MnIr. The electronic and magnetic structure are calculated making use of the full-potential linearized augmented plane wave FP-LAPW method. The torque approach is employed to evaluate the element-specific MAE. We find strong uniaxial MAE and attribute these anisotropies to combined effects of large moment on the Mn $3d$ shell and large spin-orbit coupling of the $5d$ shell. The sizable TAMR ratio (up to 50 %) associated with the strong uniaxial MAE is evaluated assuming its proportionality to the anisotropy in the density of states. Furthermore, we apply the in-plane strain in Mn_2Au and find sizable changes in the MAE and TAMR. Based on these results we propose a concept for building spintronics in compensated antiferromagnets in which the staggered moment orientation is controlled via the response of the MAE to induced lattice strains and sensed by antiferromagnetic TAMR in nanoscale devices.