HL 14: Spintronics: Transport and Theory

Time: Monday 14:45–17:45 Location: H13

HL 14.1 Mon 14:45 H13

Investigation and direct mapping of the persistent spin helix in confined structures — •Markus Schwemmer, Matthias Weingartner, Roland Völkl, Martin Oltscher, Dieter Schuh, Dominique Bougeard, Tobias Korn, and Christian Schüller — Institute of Experimental and Applied Physics, Faculty of Physics, University of Regensburg, Germany

The spin-orbit field in GaAs-based quantum well (QW) structures typically consists of two different contributions: Dresselhaus and Rashba field. The geometry of the Dresselhaus field, which arises due to the bulk inversion asymmetry, is mostly determined by the growth direction of the quantum well. The Rashba field instead is caused by a structure inversion asymmetry, which can be controlled, e.g. by the modulation doping. For the specific case of a (001)-grown GaAs quantum well with equal strength of Dresselhaus and Rashba fields, the effective spin-orbit field is oriented along the in-plane [110] direction for all k values and the spin splitting for this direction vanishes. For optically injected spins, which are initially oriented perpendicular to the QW plane, a persistent spin helix (PSH) state forms. We use a femtosecond pulsed TiSa-Laser system combined with a magneto-optical Kerr effect microscope for time- and space-resolved mapping of the PSH. With this technique, we investigate the PSH behavior in confined structures, e.g., thin channels along the helix direction. Hence we find that lateral confinement increases the effective PSH lifetime drastically. In more complex structures, we observe that PSH formation is even stable under a forced direction change.

HL 14.2 Mon 15:00 H13

Effects of lateral confinement on the spin dynamics in GaAs based two-dimensional electron systems — •Patrick Altmann[1], Makoto Kohda[2,1], Matthias P. Walser[1], Christian Reichl[3], Werner Wegscheider[3], and Gian Salis[1] — [1]IBM Research-Zurich, Saeumerstrasse 4, 8803 Rueschlikon, Switzerland — [2]Department of Materials Science, Tohoku University, Sendai, Japan — [3]Solid State Physics Laboratory, ETH Zurich, Zurich, Switzerland

In two-dimensional electron systems (2DES), the diffusive motion of the electrons leads to a precession of their spins because of spin-orbit interaction (SOI). We use time-resolved Kerr microscopy with spatial resolution below the spin-orbit length to directly visualize these precessions [1]. By this, the strength and anisotropy of the SOI are mapped out and the dominant dephasing mechanism and the diffusion constant are determined. We study the impact of lateral confinement on the spin dynamics in a GaAs based 2DES at 20 K. We observe a transition from a 2D spin mode to a quasi-1D mode in wire structures narrower than the spin-orbit length. While in the 2D case both linear and cubic terms of the SOI contribute to spin dephasing, in the 1D case only the cubic contribution remains limiting the spin dephasing time [2]. In the special case of fully anisotropic SOI, known as the persistent spin helix case, dephasing due to linear terms is already suppressed. Thus, wire confinement cannot further enhance the dephasing time, but the dilution of spins due to diffusion is reduced [3].

[1] Walser et al., Nat. Phys. 8, 757 (2012), [2] Altmann et al., accepted PRB, [3] Altmann et al., PRB 90, 201306(R) (2014)

HL 14.3 Mon 15:15 H13

Spin injection devices with a two-dimensional electron gas channel in an (Al,Ga)As/GaAs heterostructure — •Thomas Kuczmik, Dino Popp, Martin Oltscher, Josef Loher, Dieter Schuh, Dominique Bougeard, Mariusz Ciorga, and Dieter Weiss — Universität Regensburg

In recent years spin injection phenomena in bulk semiconductors have been extensively studied. However, many spintronic device concepts, like the Datta-Das spin FET, require spin transport in a two-dimensional electron gas (2DEG).

We have recently demonstrated efficient spin injection into a high mobility 2DEG confined in an inverted (Al,Ga)As/GaAs heterostructure, using (Ga,Mn)As/GaAs Esaki diodes as spin selective contacts [2]. In this contribution we discuss some issues related to the design of the employed heterostructure and to sample fabrication that are critical to preparation of working spin injection devices with a 2D channel. Particular attention has to be devoted to avoiding a parasitic 3D-like conduction channel that can be parallel to the 2DEG channel and therefore can compromise spin transport in the latter. Such a parallel channel can be formed below the active channel, on the (Al,Ga)As side of the heterojunction, in the region of the delta-doping by illuminating the device. We compare the results of nonlocal spin valve measurements on samples with and without any parasitic channel and discuss in details how the presence of such a channel affects the measured spin signal.

[1] M. Oltscher et al., Phys. Rev. Lett. 113, 236602 (2014).

HL 14.4 Mon 15:30 H13

Hanle spin precession in two-dimensional electron gas — •Martin Oltscher, Josef Loher, Dieter Schuh, Mariusz Ciorga, Dominique Bougeard, and Dieter Weiss — University of Regensburg, 93040 Regensburg, Germany

Effective electrical spin injection into two-dimensional electron systems is prerequisite for many new functionalities in possible spintronic devices, with a Datta-Das spin field effect transistor being a primary example. We have recently demonstrated efficient spin injection into high mobility 2DEG confined in the inverted (Al,Ga)As/GaAs structure. In this contribution we present the results of further investigations on that system, focusing on nonlocal Hanle measurements of spin precession in an out-of-plane magnetic field. We observe that not only the amplitude of the precession signal but also its full-width-at-half-maximum strongly changes with the bias voltage V_{3T} applied across the injector. Narrowest curves are observed in the region of the enhanced signal for negative bias. In the region of low bias -0.1 V $< V_{3T} <$ 0.1 V, on the other hand, no precession curves are observed. What is more, spin life time values extracted from the measurements ($\sim$ 23 ns for the narrowest curve) differ by orders of magnitude from the values expected for 2DEGs and from the value of 24 ps extracted earlier from spin-valve measurements. We discuss the results in connection to dynamic nuclear polarization effects in the system, which are known to narrow the experimental Hanle curves. The work has been supported by German Science Foundation (DFG) through the project SFB689.

HL 14.5 Mon 15:45 H13

Exchange coupling between soft magnetic materials and hard magnetic Dysprosium layers — •Markus Ehlert, Thomas Hupfauer, Markus Schitko, Günther Bayreuther, and Dieter Weiss — Institute of Experimental and Applied Physics, University of Regensburg, Germany

The control of the magnetic properties of thin ferromagnetic films is crucial for the functionality of spintronic devices, e.g., for the detection of the spin Hall effect [1]. The goal of our work is to improve the magnetic stability of commonly used soft ferromagnets by making use of the exchange coupling between soft and hard magnetic materials. We report on measurements of the magnetic interplay between soft magnetic Fe or Co layers and hard magnetic Dysprosium (Dy) layers. Microstructured thin films of Fe/Dy and Co/Dy multilayers were prepared by electron-beam lithography and ultra-high vacuum sputtering. The magnetic properties of the materials were determined by means of the Anisotropic Magnetoresistance (AMR) effect. By analyzing and comparing the corresponding AMR data we show that the presence of a Dy layer on top of a soft magnetic material significantly influences its magnetic properties. In our experiments we could enhance, e.g., the in-plane coercive field by one order of magnitude. We investigated the exchange coupling in the ferromagnetic (T<90 K) and antiferromagnetic (T>90 K) phase of Dy and also its dependence on the thickness of the soft magnetic material. All experimental results can consistently be explained with the model of the AMR effect.

[1] M. Ehlert *et al.*, Phys. Status Solidi B **251**, 1725-1735 (2014).

30 min. Coffee Break

HL 14.6 Mon 16:30 H13

Spin-orbit fields at semiconductor interfaces — •Martin Gmitra and Jaroslav Fabian — University of Regensburg

Solids without space inversion symmetry exhibit spin-orbit fields, which are emerging manifestations of spin-orbit coupling of the underlying atomic structure. Primary examples of spatially asymmetric systems are interfaces, which are omnipresent in electronic devices. As the device dimensions scale down, interfaces imprint their symmetries into the transport channel by proximity effects. Proximity spin-orbit fields already play important roles in anisotropic magnetoresistance of ultrathin structures such as Fe/GaAs, in the physics of Majorana fermions and Andreev reflection of semiconductor/superconductor junctions, in Skyrmion textures in ferromagnets, or in spin-orbit torques. It is thus of vital interest to gain qualitative insight and realistic quantitative description of the interfacial spin orbit fields for various materials hybrid settings. We have proposed a methodology to extract spin-orbit fields, both their magnitudes and directions, and applied it to investigate Fe/GaAs junctions. Only at low momenta the traditional description of the fields in terms of linear Rashba and Dresselhaus works. At generic momenta the fields exhibit what we call butterfly patterns, conforming to the interfacial symmetry. Remarkably, the spin-orbit fields depend rather strongly on the magnetization orientation. We will also discuss our recent results on the spin-orbit coupling in zinc-blende and wurtzite semiconductor nanostructures.

The work is supported by the DFG SFB 689.

HL 14.7 Mon 16:45 H13

Spin-orbit coupling and spin relaxation in phosphorene — •Marcin Kurpas, Martin Gmitra, and Jaroslav Fabian — Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany

We employ first principles density functional theory calculations to study intrinsic and extrinsic spin- orbit coupling in monolayer phosphorene. We also extract the spin-mixing amplitudes of the Bloch wave functions to give realistic estimates of the Elliott-Yafet spin relaxation rate. The most remarkable result is the anisotropy in both spin-orbit coupling and spin relaxation rates, which could be tested experimentally in spin injection experiments. We also identify spin hot spots in the electronic structure of phosphorene at accidental bands anticrossings. We compare the Elliott- Yafet with Dyakonov-Perel spin relaxation times, obtained from extrinsic couplings in an applied electric field. We also compare the results in phosphorene with those of black phosphorous. This work is supported by the DFG SPP 1538, SFB 689, and by the EU Seventh Framework Programme under Grant Agreement No. 604391 Graphene Flagship.

HL 14.8 Mon 17:00 H13

Enabling spin-to-charge conversion in semiconductor spintronics through time-reversal and structure-inversion asymmetry: Fe on Ge(111) — •Ashis K. Nandy[1], Nguyen H. Long[1], Simon Oyarzun[2], Jean-Marie George[3], Henri Jaffres[3], Stefan Blügel[1], and Matthieu Jamet[2] — [1]Peter Grünberg Institute and Institute for Advanced Simulation, FZJ & JARA, D-52425 Jülich, Germany — [2]Univ. Grenoble Alpes, INAC-SP2M, F-38000 Grenoble, France — [3]Univ. Paris-Sud, F-91405 Orsay, France

One important goal of semiconductor spintronics is the realisation of the Si based spin-field-effect transistor. Its realisation is challenged by the small spin-Hall effect in bulk Si and Ge. Using first-principles theory based on DFT we show that the surface of Ge(111) introduces a large snowflake-like Rashba effect with a locking of momentum vector **k** to mostly out-of-plane spin components, whose energy dispersion shows a k^3-dependence in the vicinity of $\bar{\Gamma}$. Breaking the time-inversion symmetry by depositing Fe films on Ge(111) we exhibit a strong hybridization of Fe-d with Ge-p states, leading to a spin-splitting of the Ge Rashba states, where the majority snowflake-like Rashba states are occupied. The joint effect of exchange and Rashba spin-orbit interaction leads to an electronic structure with a lack of mirror symmetry in the plane normal to the surface and in the direction of the in-plane magnetization. Considering the asymmetry of the Fermi surface and the k^3-dependence of part of the electronic structure, we present arguments supporting experimentally observed large charge currents when generated by intrinsic spin-pumping in the interfacial electron gas.

HL 14.9 Mon 17:15 H13

Deterministic entanglement generation between spatially separated electronic spins — •Mónica Benito[1], Martin Schütz[2], Gloria Platero[1], Geza Giedke[2,3], and Ignacio Cirac[2] — [1]Insituto de Ciencia de Materiales de Madrid, CSIC, 28049 Madrid, Spain — [2]Max Planck Institut für Quantenoptik, Hans-Kopfermann Strasse I, D-85748, Garching, Germany — [3]Donostia International Physics Center DIPC, Paseo Manuel de Lardizabal 4, 20018 Donostia-San Sebastián, Spain

We propose a scheme for deterministic entanglement generation between two electronic spin qubits confined in spatially separated quantum dots. The mechanism is based on electron transport through an ancilla system driving the system spins into an entangled target steady-state. Since the entangle- ment is actively stabilized by purely dissipative dynamics, our scheme is inherently robust against noise and imperfections.

HL 14.10 Mon 17:30 H13

Proximity Anisotropic Magnetoresistance in Graphene — •Jeongsu Lee and Jaroslav Fabian — Institute for Theoretical Physics, University of Regensburg, Regensburg, Germany

We theoretically investigate charge transport in graphene that is on a ferromagnetic-insulator substrate. The substrate induces spin polarization in graphene-ferromagnetic proximity effect-as demonstrated recently experimentally [1]. We show, using realistic models [2, 3], that the presence of spin-orbit coupling in proximity ferromagnetic graphene leads to anisotropic magnetoresistance whereby graphene's resistance changes with varying magnetic field orientation (both in and out of plane). We evaluate the magnitude as well as the angular dependence of this novel effect using conventional transport models [4] and propose specific experimental schemes to measure it. This work is supported by DFG SFB 689.

[1] Z. Wang, C. Tang, R. Sachs, Y. Barlas, and J. Shi, Phys. Rev. Lett. 114, 016603, (2015)

[2] M. Gmitra, D. Kochan, and J. Fabian, Phys. Rev. Lett. 110, 246602 (2013).

[3] M. Gmitra, S. Konschuh, C. Ertler, C. Ambrosch-Draxl, and J. Fabian, Phys. Rev. B 80, 235431, (2009)

[4] S. Adam, E. H. Hwang, V. M. Galitski, and S. Das Sarma, Proc. Natl. Acad. Sci. U.S.A., 104, 18392, (2007)