HL 57: Spintronics/Quantum information: Materials and methods (HL, jointly with TT)

Time: Wednesday 15:00–18:45 Location: H2

HL 57.1 Wed 15:00 H2

Onsager relations in a two-dimensional electron gas with spin-orbit coupling — •Cosimo Gorini[1,2], Roberto Raimondi[3], and Peter Schwab[1] — [1]Institut für Physik, Universität Augsburg — [2]CNRS and Université de Strasbourg — [3]Dipartimento di Fisica, Università di Roma Tre

Theory predicts for the two-dimensional electrons gas with only Rashba spin-orbit interaction a vanishing spin Hall conductivity and at the same time a finite inverse spin Hall effect. We show how these seemingly contradictory results are compatible with the Onsager relations: the latter do hold for spin and particle (charge) currents in the two-dimensional electron gas, although (i) their form depends on the experimental setup and (ii) a vanishing bulk spin Hall conductivity does not necessarily imply a vanishing spin Hall effect. We also discuss the situation in which extrinsic spin orbit from impurities is present and the bulk spin Hall conductivity can be different from zero.

[1] - C. Gorini, R. Raimondi, P. Schwab, arXiv:1207.1289 (to appear in PRL)

HL 57.2 Wed 15:15 H2

On the misinterpretation of the temperature dependence of T_2^* in time-resolved Faraday rotation — •Sebastian Kuhlen[1], Ralph Ledesch[1], Carla Schenk[1], Matthias Althammer[2], Sebastian T. B. Gönnenwein[2], Matthias Opel[2], Rudolf Gross[2], and Bernd Beschoten[1] — [1]II. Physikalisches Institut A, RWTH Aachen University, Aachen — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching

Time-resolved Faraday rotation (TRFR) is a well-established optical pump probe technique to generate and to probe spin coherence in semiconductors. Spin dephasing times T_2^* can easily be determined from TRFR if their values are comparable to the available pump-probe-delay. If, however, T_2^* exceeds the laser repetition time resonant spin amplification (RSA) can equally be used to extract T_2^*. We demonstrate that in ZnO these techniques have several tripping hazards resulting in deceptive results for T_2^*. We show that the temperature dependence of the amplitude ratio of two separate spin species can easily be misinterpreted as a strongly temperature dependent T_2^* of a single spin ensemble, while the two spin species have T_2^* values which are nearly independent of temperature. Additionally, consecutive pump pulses can significantly diminish the spin polarization, which remains from previous pump pulses. While this barely affects T_2^* values extracted from delay line scans, it results in seemingly shorter T_2^* values in RSA.

Work supported by DFG through SPP 1285.

HL 57.3 Wed 15:30 H2

All-electrical time-resolved spin generation and coherent spin manipulation in n-InGaAs — •Ivan Stepanov[1,2], Sebastian Kuhlen[1,2], Manfred Ersfeld[1,2], Stefan Göbbels[1,2], Mihail Lepsa[2,3], and Bernd Beschoten[1,2] — [1]II. Physikalisches Institut, RWTH Aachen University, 52056 Aachen, Germany — [2]JARA: Fundamentals of Future Information Technology, 52074 Aachen — [3]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich

Creation and manipulation of coherent spin information by electrical means are key tasks in semiconductor spintronics.

Here we demonstrate that a coherent spin polarization can be created and manipulated by two successive electric field pulses in n- InGaAs epilayer at zero external magnetic field. The first electric pulse $\parallel [1\bar{1}0]$ creates a current induced spin polarization (CISP) which is oriented in the plane of the sample. The subsequent electric field pulse $\parallel [110]$ generates a perpendicular magnetic field pulse [1] leading to a coherent precession of this spin polarization with 2-dimensional electrical control over the final spin orientation. Spin precession is measured by time-resolved Faraday rotation. We determine the build-up time of CISP during the first field pulse and extract the spin dephasing time and internal magnetic field strength during the spin manipulation pulse. The results are in good agreement with optical pump-probe experiments on the same device.

Work supported by DFG through FOR 912.

[1] S. Kuhlen *et al.*, Phys. Rev. Lett. 109, 146603 (2012).

HL 57.4 Wed 15:45 H2

Long hole spin lifetime in InGaAs/GaAs quantum wells probed by high field cyclotron resonance spectroscopy — •Oleksiy Drachenko[1], Dmitry Kozlov[2], Anton Ikonnikov[2], Kirill Spirin[2], Vladimir Gavrilenko[2], Harald Schneider[1], Manfred Helm[1], and Jochen Wosnitza[3] — [1]Helmholtz Zentrum Dresden Rossendorf, Inst Ion Beam Phys & Mat Res, D-01314 Dresden, Germany — [2]Russian Acad Sci, Inst Phys Microstruct, Nizhnii Novgorod 603950, Russia — [3]Helmholtz Zentrum Dresden Rossendorf, Dresden High Magnet Field Lab HLD, D-01314 Dresden, Germany

In this paper, we report long, milli-second range, hole spin relaxation time in InGaAs/GaAs quantum wells probed by cyclotron resonance-spectroscopy in high pulsed magnetic fields. In our experiments, we found strong hysteresis in the spectral weights of cyclotron resonance absorption lines when rapidly changing magnetic field is used for the experiment. The hysteresis vanishes when a much slower changing magnetic field is used. We attribute this behavior to a long energy relaxation time between two lowest spin-split hole Landau levels, i.e. a long hole spin relaxation time. We also present transition frequencies calculated using a 4x4 Luttinger Hamiltonian, which confirm our findings.

HL 57.5 Wed 16:00 H2

Magneto-optical study of the sp-d exchange interaction on 1.4 nm diameter Mn^{2+} doped $(CdSe)_{13}$ clusters — Rachel Fainblat[1], •Dino Iavarone[1], Jiwoong Yang[2], Taeghwan Hyeon[2], and Gerd Bacher[1] — [1]Werkstoffe der Elektrotechnik and CeNIDE, Universität Duisburg-Essen, Germany — [2]Nanomaterials Laboratory, Seoul National University, Korea

Magnetical doping of chemically synthesized nanostructures combines the optical and electronic properties of the host semiconductor with the magnetic characteristics of the doping ions. The mechanism of colloidal nanocrystal doping can be classified into doping at the "growth" or at the "cluster" stage and, in particular, the doping efficiency in small nanocrystals is controversially discussed. On one hand, the statistical adsorption of an impurity is expected to decrease with decreasing nanocrystal size [1], whereas a recent model points out that the dopant adsorption onto the sites of small clusters ($d < 2$ nm) is more efficient than the adsorption on larger nanocrystals ($d > 5$ nm) [2].

Here, we report on low temperature ($T = 5$ K) magneto-optical effects in so-called "magic size" Mn^{2+} doped $(CdSe)_{13}$ clusters. Both absorption and magnetic circular dichroism (MCD) spectra are dominated by a resonance peak related to the heavy hole excitonic transition at 3.65 eV. From the pronounced MCD signal a giant Zeeman splitting of about 15 meV at 1.5 T is extracted supporting the theory that the Mn^{2+} ions are doped directly into the $(CdSe)_{13}$ clusters.

[1] S. Erwin et al., Nature 436, 91-4 (2005)
[2] T. Singh et al., Appl. Phys. Lett. 100, 053105 (2012)

HL 57.6 Wed 16:15 H2

Influence of strong quantum confinement on the magnetic dopant-carrier exchange coupling in Mn^{2+} doped CdSe nanoribbons — Rachel Fainblat[1], •Franziska Muckel[1], Julia Frohleiks[1], Jung Ho Yu[2], Jiwoong Yang[2], Taeghwan Hyeon[2], and Gerd Bacher[1] — [1]Werkstoffe der Elektrotechnik and CeNIDE, Universität Duisburg-Essen, Germany — [2]Nanomaterials Laboratory, Seoul National University, Korea

Key materials for future spintronic applications might be magnetically doped semiconductors with a substantial coupling between the dopants and charge carriers of the host semiconductor. This interaction is expected to be significantly altered by quantum confinement, an issue which is controversially discussed since more than a decade.

Here, we report on a clear evidence of a quantum confinement induced modification of both, s-d and s-p exchange interaction in two dimensional 1.4 nm thick Mn^{2+} doped CdSe quantum nanoribbons [1]. Both absorption and magnetic circular dichroism spectra are dominated by spectrally well-separated resonance peaks related to the heavy and the light hole excitonic transition. This allows a separate study of the s-d and the p-d exchange interaction constants. Taking into account the optical selection rules and the statistical orientation of the nanoribbons on the substrate, a remarkable change of the s-d exchange constant with respect to bulk is indicated. Room-temperature studies revealed an unusually high effective g-factor up to ∼13 encouraging

the implementation of the nanoribbons for spintronic applications.

[1] R. Fainblat et al., Nano Letters 12, 5311 (2012)

HL 57.7 Wed 16:30 H2

Electron spin-flip Raman scattering in a CdTe/(Cd,Mg)Te quantum well — •Dion Braukmann[1], J. Debus[1], D. Dunker[1], V. F. Sapega[2], D. R. Yakovlev[1,2], G. Karczewski[3], T. Wojtowicz[3], J. Kossut[3], and M. Bayer[1] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44227 Dortmund, Germany — [2]Ioffe Physical-Technical Institute, Russian Academy of Science, 194021 St. Petersburg, Russia — [3]Institute of Physics, Polish Academy of Sciences, 02668 Warsaw, Poland

The Raman scattering of the electron spin in a neutral exciton has been studied in a CdTe/(Cd,Mg)Te quantum well (QW). The mechanism of the electron spin-flip Raman scattering (SFRS) is experimentally evaluated from the circular polarization properties of the scattered light as well as dependence of the electron-SFRS line intensity on the magnetic field direction with respect to the QW growth axis. The spin-flip process is governed by acoustic phonon interaction and anisotropic electron-heavy-hole exchange interaction. The probability of the anisotropic exchange interaction depends on the g factors of the involved carriers. It shows a strong angular dependence due to the anisotropic heavy-hole g factor. Moreover, by application of above-barrier illumination in addition to the resonant excitation of the neutral QW excitons the intensity of the electron-SFRS line can be modulated significantly.

Coffee break

HL 57.8 Wed 17:00 H2

Ultrafast Spin Noise Spectroscopy — •Hendrik Kuhn, Fabian Berski, Jan G. Lonnemann, Petrissa Zell, Jens Hübner, and Michael Oestreich — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstr. 2, D-30167 Hannover

Spin Noise Spectroscopy (SNS) is a powerful experimental technique which explores the full dynamics of stochastically oriented carrier spins close to thermal equilibrium [1]. With the conventional spin noise probing scheme relying on continuous wave (cw) laser probing, the detectable temporal spin dynamic is limited by the electrical bandwidth of the photoreceiver. We advance all optical spin noise spectroscopy in semiconductors to detection bandwidths of several hundred gigahertz by employing an ingenious scheme of pulse trains from ultrafast laser oscillators as an optical probe [2]. As all SNS techniques, ultrafast SNS avoids the need for optical pumping. It enables nearly perturbation free measurements of extremely short spin dephasing times, e.g at high temperatures. We expand our measurements on highly n-doped (n = 8.2 x 10^{17} cm^3) bulk GaAs towards room temperature and demonstrate the feasibility of ultrafast SNS for spin lifetimes down to the order of a few ten picoseconds.

[1] G. M. Müller, M. Oestreich, M. Römer, and J. Hübner Physica 43, 569-587 (2010).
[2] F. Berski et al., arXiv:1207.0081v1 [cond-mat.mes-hall].

HL 57.9 Wed 17:15 H2

Spin Noise Spectroscopy: Towards Solid-State Entanglement — •Fabian Berski[1], Agnes Beichert[1], Jens Hübner[1], Andreas Wieck[2], and Michael Oestreich[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstr. 2, D-30167 Hannover, Germany — [2]Ruhr-Universität Bochum, Angewandte Festkörperphysik, Universitätsstr. 150, D-44780 Bochum, Germany

We study spin dynamics of naturally confined, non-interacting donor electrons in Gallium Arsenide at low temperatures by means of all optical spin noise spectroscopy [1]. The MBE grown sample shows the intriguing feature of localised spins in an environment of stochastically oriented magnetic moments: The orientation of the electron spin is lost on two different timescales which results from the interplay between the spin degree of freedom of the lattice and of the electron. The first timescale is attributed to the transversal component of the electron spin with respect to the nuclear magnetic field inside the donor volume and is determined to 4.5+-3ns. The second timescale is at least two orders of magnitude longer and is linked with the longitudinal component. An extension of the electron spin relaxation time would be possible via initilizing the surrounding spin bath by dynamic nuclear polarization which simplifies the generation and verification of entanglement [2].

[1] G. M. Müller, et al., Physica E: **43**, 569 (2010).
[2] S. Simmons, et al., Nature: **470**, 69 (2011).

HL 57.10 Wed 17:30 H2

Single Molecule Magnets meet Graphene — •Christian Cervetti[1], Andrea Cornia[4], Eberhard Ulrich Stützel[2], Stephan Rauschenbach[2], Fernando Luis[5], Martin Dressel[1], Marko Burghard[2], Klaus Kern[2,3], and Lapo Bogani[1] — [1]1. Physikalisches Institut, Universität Stuttgart — [2]Max Planck Institut für Festkörperforschung — [3]Institute de Physique de la Matière Condensée, Ecole Polytechnique de Lausanne, Switzerland — [4]Dipartimento di Chimica, Università di Modena e Reggio Emilia, Italy — [5]Instituto de Ciencia de Materiales de Aragón, Spain

Graphene has a strong potential as component of novel spintronics devices. Besides its use as conducting channel for coherent spin transport, graphene is furthermore of interest for the detection and manipulation of the spin within molecule magnets. This task requires an appropriate coupling between the sheets and the single molecular magnets. Here, we describe the assembly of a functionalized Fe4 cluster compound on graphene exploiting non-covalent π-stacking interaction. We demonstrate the control over the organization of the molecules by tuning the deposition parameters and the type of graphene. The graphene phononic environment is found to influence the magnetization dynamics of the molecular magnets as evidenced by μ-SQUID study at mK-temperatures. Finally, preliminary spin-transport experiments at low-temperature are presented.

HL 57.11 Wed 17:45 H2

Enhanced Infrared Magneto-Optical Response of the Nonmagnetic Semiconductor BiTeI Driven by Bulk Rashba Splitting — •L. Demko[1], G. A. H. Schober[3], V. Kocsis[4], M. S. Bahramy[5], H. Murakawa[5], J. S. Lee[2], I. Kezsmarki[4], R. Arita[2], N. Nagaosa[2], and Y. Tokura[1] — [1]Multiferroics Project, ERATO, JST, c/o Department of Applied Physics, University of Tokyo, Japan — [2]Department of Applied Physics, University of Tokyo, Japan — [3]Institute for Theoretical Physics, University of Heidelberg, Germany — [4]Department of Physics, Budapest University of Technology and Economics and Condensed Matter Research Group of the Hungarian Academy of Sciences, Hungary — [5]CMRG and CERG, RIKEN ASI, Japan

We study the magneto-optical (MO) response of the polar semiconducting BiTeI with giant bulk Rashba spin splitting at various carrier densities. Despite being nonmagnetic, the material is found to yield a huge MO activity in the infrared region under moderate magnetic fields (up to 3 T). Our first-principles calculations show that the enhanced MO response of BiTeI comes mainly from the intraband transitions between the Rashba-split bulk conduction bands. These transitions connecting electronic states with opposite spin directions become active due to the presence of strong spin-orbit interaction and give rise to distinct features in the MO spectra with a systematic doping dependence. We predict an even more pronounced enhancement in the low-energy MO response and dc Hall effect near the crossing (Dirac) point of the conduction bands.

HL 57.12 Wed 18:00 H2

Transport of dynamically generated pure spin current in single-layer graphene — •Masashi Shiraishi[1], Zhenyao Tang[1], Hiroki Ago[2], Kenji Kawahara[2], Yuichiro Ando[1], and Teruya Shinjo[1] — [1]Graduate School of Engineering Science, Osaka Univ., Japan — [2]Institute of Materials Chemistry and Engineering, Kyushu Univ., Japan

Electrical spin injection and generation of a pure spin current in graphene using non-local electrical technique has opened a new frontier in molecular spintronics [1-3], after the achievements, a number of interesting physics related with spin transport and spin relaxation have been studied. However, there are still many issues in spin transport in graphene that need to be clarified, and the establishment of a novel technique for spin injection and generation of a pure spin current in graphene is strongly desired for discussing spin transport phenomena in graphene. Here, we show a new approach for generating and transporting pure spin current in single-layer graphene at room temperature, the dynamical spin pumping method [4]. The dynamical spin transport was successfully demonstrated, and the estimated spin coherence in CVD-grown graphene at room temperature (RT) was 1.36 micrometers.This study is partly supported by JSPS "Nano Carbon Terahertz Science" program.

[1] M. Ohishi, M. Shiraishi et al., JJAP 46, L605 (2007). [2] N. Tombros et al., Nature 448, 571 (2007). [3] M. Shiraishi et al., Adv.

Func. Mat. 19, 3711 (2009). [4] Z. Tang, M. Shiraishi et al., Adv. Func. Mat. submitted.

HL 57.13 Wed 18:15 H2

Investigation of spin drift effect in highly doped Si — •Masashi Shiraishi[1], Makoto Kameno[1], Yuichiro Ando[1], Eiji Shikoh[1], Toshio Suzuki[2], Tohru Oikawa[3], and Tomoo Sasaki[3] — [1]Graduate School of Engineering Science, Osaka Univ., Japan — [2]AIT, Akita Industrial Technology Center, Japan — [3]TDK Corporation, Japan

Spin drift, which is usually negligible in spin transport in metallic systems, contributes significantly to spin transport and spin accumulation voltages in semiconductors like Si. Since an electric field gives rise to spin drift, investigating spin accumulation voltages as a function of the bias electric field (bias voltage) in Si spin devices can clarify how spin drift governs spin transport and accumulation properties. In this presentation, we report on quantitative analyses of spin drift effect and electric field dependence of spin injection signals in Si [1,2].

[1] M. Shiraishi et al., Phys. Rev. B83, 241204(R) (2011). [2] M. Kameno, M. Shiraishi et al., Appl. Phys. Lett. 101, 122413 (2012).

HL 57.14 Wed 18:30 H2

Investigation of ordinal and inverted Hanle spin signals in highly-doped Si — •Masashi Shiraishi[1], Makoto Kameno[1], Yasunori Aoki[1], Yuichiro Ando[1], Eiji Shikoh[1], Toshio Suzuki[2], Tohru Oikawa[3], and Tomoo Sasaki[3] — [1]Graduate School of Engineering Science, Osaka Univ., Japan — [2]AIT, Akita Industrial Technology Center, Japan — [3]TDK Corporation, Japan

Spin injection and spin transport in Si has been attracting much attention in recent several years, and spin physics in Si at room temperature is intensively argued. Whereas non-local 3-terminal method (NL3T) has been widely used for showing spin accumulation at room temperature (RT) [1], heated discussion is arising since the NL3T does not completely exclude spurious signals [2]. For proving spin injection and transport, observation of magnetoresistance in the NL-4T method (NL4T) and Hanle-type spin precession provide the most powerful evidence, and our group exhibited the first transport of pure spin current at RT [3]. In this presentation, we show the results of the detailed study on Hanle effects in NL3T by comparing that in NL4T, which strongly suggests that the results obtained by using NL3T has much room for discussion about their interpretations [4].

[1] S. Dash et al., Nature 462, 491 (2009). [2] M. Tran et al., 102, 036601 (2009). [3] T. Suzuki, M. Shiraishi et al., APEX4, 023003 (2011). [4] Y. Aoki, M. Shiraishi et al., Phys. Rev. B86, 081201(R) (2012).