HL 32: Transport Properties I (mainly Spin Physics and Magnetic Fields)

Time: Tuesday 10:00–13:15 Location: EW 203

HL 32.1 Tue 10:00 EW 203

A quantized 5/2 state in a two-subband electron system — •Johannes Nuebler[1], Benedikt Friess[1], Vladimir Umansky[2], Bernd Rosenow[3], Moty Heiblum[2], Klaus von Klitzing[1], and Jurgen Smet[1] — [1]Max-Planck-Institut für Festkörperforschung, Stuttgart — [2]Braun Centre for Semiconductor Research, Weizmann Institute of Science, Rehovot, Israel — [3]Institute for Theoretical Physics, University of Leipzig

We investigate the fractional quantum Hall effect in wide quantum well heterostructures with tunable electron density. In contrast to previous measurements [1] we observe that upon population of the second subband the two subbands show independent quantum Hall states [2]. In particular, the fully quantized 5/2 state of the lower subband is surprisingly unaffected by the presence of the additional second subband electron system whose density we can vary over a wide range. We use tilted magnetic fields to modify the subband interaction.

[1] J. Shabani et al., Phys. Rev. Lett. 105, 246805 (2010).

[2] J. Nuebler et al., accepted for publication in PRL.

HL 32.2 Tue 10:15 EW 203

Interaction-Induced Huge Magnetoresistance in a High Mobility Two-Dimensional Electron Gas — •Lina Bockhorn[1], Aida Hodai[1], Igor V. Gornyi[2], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover — [2]Institut für Nanotechnologie, Forschungszentrum Karlsruhe, 76021 Karlsruhe

We study magneto transport in a high mobility two-dimensional electron gas (2DEG). Hall geometries are created by photolithography on a GaAs/GaAlAs quantum well containing a 2DEG. The 2DEG has an electron density of n_e=3.1·10^{11}cm^{-2} and a mobility of μ_e=11.9·10^6cm^2/Vs at a temperature of 1.5 K. We observe a strong negative magnetoresistance at zero magnetic field. In lowering the electron density the magnetoresistance gets more pronounced and reaches values of more than 300 % [1]. We demonstrate that the negative magnetoresistance consists of a small peak induced by a combination of at least two types of disorder [2] and a huge magnetoresistance explained by the interaction correction to the conductivity for mixed disorder [3,4]. The huge magnetoresistance vanishes for increasing the temperature from 100 mK to 800 mK while the small peak remains unchanged.

[1] L. Bockhorn *et al.*, Phys. Rev. B 83, 113301 (2011)

[2] A. D. Mirlin *et al.*, Phys. Rev. Lett. 87, 126805 (2001).

[3] I. V. Gornyi and A. D. Mirlin, Phys. Rev. Lett. 90, 076801 (2003)

[4] I. V. Gornyi and A. D. Mirlin, Phys. Rev. B 69, 045313 (2004)

HL 32.3 Tue 10:30 EW 203

Magnetotransport of (Zn,Mn)Se:Cl under hydrostatic pressure — •Steve Petznick[1], Michael Hetterich[2], and Peter J. Klar[1] — [1]Institute of Experimental Physics I, Justus-Liebig University of Giessen, Germany — [2]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), Germany

As material n-doped MBE-grown (Zn,Mn)Se:Cl on an undoped (100) GaAs substrate was used. The manganese concentration of the 1050 nm thick layer was about 2 % and the carrier concentration at room temperature was $n = (4.3 \pm 0.3) \cdot 10^{17}\,\mathrm{cm}^{-3}$. For the hydrostatic pressure experiments the sample was mounted in a clamp pressure cell. For different pressure values between 0 and 16.5 kbar transport measurements were obtained at different temperatures between 1.6 K and 280 K in Van der Pauw geometry and in applied magnetic fields up to 10 T.

The dependence of the magnetoresistance and the carrier concentration are shown and discussed. The splitting of the spin-up and spin-down states hinders the hopping conductivity between the donor states and results in a high magnetoresistance at low temperatures. Moreover, at high pressure a sudden decrease of the carrier concentration is observed. It is likely that this behavior is due to carrier trapping, which occurs when the band gap is in resonance with inner d-shell transitions of the Mn^{2+} ions.

HL 32.4 Tue 10:45 EW 203

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

Semiconductor spin noise spectroscopy (SNS) has evolved as a powerful experimental technique to explore the dynamics of carrier spins close to thermal equilibrium [1]. However, with the standard continous-wave (cw) laser probing scheme the detectable temporal spin dynamic is limited by the bandwidth of the photoreceiver. We advance SNS to detection bandwidths of several hundred gigahertz by replacing cw probe light with light from two ultrafast oscillators. The two oscillators are mode-locked with an adjustable phase which enables subsequent scanning of the temporal spin correlations via below band gap Faraday rotation. Our first measurements on highly n-doped (10^{17} cm^{-3}) bulk GaAs perfectly demonstrate the feasibility of SNS for spin lifetimes down to the order of a few ten picoseconds without the loss of information. These measurements pave the way for future experiments where optical excitation poses an obstacle for the detection of the true spin dynamics.

[1] G. M. Müller, M. Oestreich, M. Römer and J. Hübner, Physica E 43, 569 (2010).

HL 32.5 Tue 11:00 EW 203

Top Gates for InAs/InAlGaAs Heterostructures — •Jens S. Kienitz[1], Lasse Cornils[1], Till Benter[1], Christian Heyn[1], Katrin Groth[1], Dirk Reuter[2], Andreas Wieck[2], Ulrich Merkt[1], and Jan Jacob[1] — [1]Universität Hamburg, Institut für Angewandte Physik, Jungiusstraße 11, 20355 Hamburg — [2]Ruhr-Universität Bochum, Lehrstuhl für Angewandte Festkörperphysik, Universitätsstraße 150, 44780 Bochum

The intrinsic spin-Hall effect allows filtering of the electron spins in quasi one-dimensional electron systems. However the spin-Hall effect is only effective when the occupation of the transport modes is restricted to a small number. Hence control of the electron density is decisive. At the same time it is mandatory to keep the electron mobility high and to leave the spin-orbit coupling constant or to tune it in a precise and reproducible way. At liquid helium temperatures we determine from the Shubnikov-de Haas effect and the Hall effect the densities, the mobilities and the Rashba spin-orbit parameters [1] of electrons in InAs/InAlGaAs heterostructures with metallic top gates. The top gates are evaporated on insulating hydrogen silsesquioxane layers spun before onto the semiconductors. Our investigation includes InAs/InAlGaAs heterostructures with different innate electron densities and mobilities. The thickness of the InAlAs capping layer above the conducting InAs channel and the thickness of the insulating layer are also varied. [1] A. D. Wieck et al., Phys. Rev. Lett. **53**, 493 (1984)

Coffee Break (15 min)

HL 32.6 Tue 11:30 EW 203

Strain and Electric Field Control of the Spin-Dynamics in GaAs/AlGaAs Quantum Wells — •David English[1], Peter Eldridge[3], Jens Hübner[1], Richard Harley[2], and Michael Oestreich[1] — [1]Institute for Solid State Physics, Leibniz University Hannover, Appelstr. 2, 30167 Hannover, Germany — [2]School of Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ, UK — [3]Foundation for Research and Technology, IESL, PO Box 1527, 71110, Heraklion, Crete, Greece

We measure by spin quantum beat spectroscopy the anisotropy of the electron Landé g-factor and the spin relaxation rate, Γ^s, in (001) AlGaAs/GaAs quantum wells. The anisotropy is either induced by an applied electric field, applied strain or an asymmetrically grown quantum well. The anisotropy of g and Γ^s are produced by different microscopic mechanisms. In general an anisotropic g-factor implies an asymmetric conduction electron wavefunction, whereas the anisotropic spin relaxation rate requires a non-zero expectation value of the valence band potential gradient on the conduction band states. Therefore, a comparison of the two in-plane anisotropies provides insight into the effects on the band edges induced by the different perturbations.

We find that an electric field generates anisotropy of both g and Γ^s. However, it is shown that an asymmetric potential produces anisotropy in g but not Γ^s while the opposite occurs for strain which induces an in-plane anisotropy of Γ^s but leaves the g-factor isotropic. Therefore, we unambiguously reveal the different microscopic mechanisms of the three perturbations.

HL 32.7 Tue 11:45 EW 203

Electron Transport in Side-Gated Quantum-Point Contacts on InAs/InAlGaAs Heterostructures — •Jens S. Kienitz[1], Hauke Lehmann[1], Christian Heyn[1], Dirk Reuter[2], Andreas D. Wieck[2], Ulrich Merkt[1], and Jan Jacob[1] — [1]Universität Hamburg, Institut für Angewandte Physik, Jungiusstraße 11, 20355 Hamburg — [2]Ruhr-Universität Bochum, Lehrstuhl für Angewandte Festkörperphysik, Universitätsstraße 150, 44780 Bochum

Quantum-point contacts exhibiting conductance quantization of quasi one-dimensional electron systems have been studied extensively in GaAs/GaAlAs heterostructures [1], but not so in InAs/InAlGaAs heterostructures. The spin-orbit interaction in InAs is much stronger than in GaAs. Thus for applications in spintronics InAs is the material of choice. Nevertheless spin-dependent phenomena are only visible when few or just one transport modes contribute. In order to be able to count the number of occupied transport modes, well-defined conductance steps are mandatory. We define quantum-point contacts by side gates of different widths along InAs quantum wires and of different distances to these wires. Transport measurements at different temperatures between 15 mK and 4 K in high magnetic fields are presented. They hint at a stronger quantization for lower temperatures and higher magnetic fields. [1] B. van Wees et al., Phys. Rev. Lett. **60**, 848 (1988)

HL 32.8 Tue 12:00 EW 203

Dyakonov-Perel electron spin relaxation in a wurtzite semiconductor: From the nondegenerate to the highly degenerate regime — •Jörg Rudolph[1], Jan Heye Buss[1], Sebastian Starosielec[1], Arne Schaefer[1], Fabrice Semond[2], and Daniel Hägele[1] — [1]AG Spektroskopie der kondensierten Materie, Ruhr-Universität Bochum, Bochum, Germany — [2]Centre de Recherche sur l'Hétéro-Epitaxie et ses Applications, Valbonne, France

The doping density dependence of the electron spin lifetime in n-type semiconductors gives insight into the interplay between spin-orbit coupling, phase space filling and momentum scattering. We measure electron spin lifetimes in bulk n-type GaN as a prototypical semiconductor with wurtzite structure by time-resolved Kerr-rotation spectroscopy for a wide range of doping densities from 5×10^{15} to 1.5×10^{19} cm^{-3}. The spin lifetime follows a non-monotonic density dependence with a maximum at the onset of degeneracy. The maximum is found to shift toward higher densities for increasing lattice temperature. The additional determination of momentum scattering times in the degenerate regime allows for a direct comparison to an analytical expression for the density-dependent spin relaxation tensor for wurtzite semiconductors. Quantitative agreement is found up to the highest densities without any fitting parameter.[1]

[1] J. H. Buß *et al.*, Phys. Rev. B **84**, 153202 (2011)

HL 32.9 Tue 12:15 EW 203

Electrical Spin Injection into Semiconductor Nanowires — •Sebastian Heedt[1,3], Isabel Wehrmann[1,3], Torsten Rieger[1,3], Kamil Sladek[1,3], Daniel Bürgler[2,3], Detlev Grützmacher[1,3], and Thomas Schäpers[1,3,4] — [1]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich, 52425 Jülich, Germany — [3]JARA-Fundamentals of Future Information Technology — [4]II. Physikalisches Institut, RWTH Aachen, 52056 Aachen, Germany

In order to drive a spin-polarized current into InAs nanowires prepared in a bottom-up approach, ferromagnetic injector and detector electrodes are deposited onto the semiconductor structures. To ensure a well-defined magnetization axis a novel contact preparation process has been conceived employing hydrogen silsesquioxane resist in order to planarize the nanowires. By means of doping and the application of a gate voltage the carrier concentration in the nanowires can be controlled. The spin accumulation is probed in a four terminal non-local measurement geometry. To this end, controlling the interface resistance between the ferromagnet (Co) and the nanowire is of outmost importance. Native indium oxide is removed by in situ Ar^+ sputtering. Subsequently an ultra-thin layer of Al_2O_3 (or MgO respectively) is evaporated in order to overcome the conductivity mismatch between the semiconductor beneath and the ferromagnetic metal above the tunnel barrier. A further unequivocal evidence of spin injection is aspired by measuring the dephasing of the injected spin ensemble in a Hanle setup.

HL 32.10 Tue 12:30 EW 203

Interplay of spin and orbital magnetogyrotropic photogalvanic effects in InSb-based quantum wells — •Sebastian Stachel[1], Peter Olbrich[1], Christina Zoth[1], Ursula Hagner[1], Thomas Stangl[1], Cynthia Karl[1], Peter Lutz[1], Vasily Bel'kov[2], Leonid Golub[2], Steve K. Clowes[3], Tim Ashley[4], Adam M. Gilbertson[5], and Sergey D. Ganichev[1] — [1]Terahertz Center, University of Regensburg, Regensburg, Germany — [2]Ioffe Institute, St. Petersburg, Russia — [3]Advanced Technology Institute and SEPNet, University of Surrey, UK — [4]School of Engineering, University of Warwick, UK — [5]Blackett Laboratory, Imperial College, UK

Here we report on the observation and detailed study of the magnetic-field induced photocurrents in n-doped InSb/InAlSb quantum wells (QWs). We show that the intraband absorption of terahertz radiation in QWs causes a *dc* electric current in the presence of an in-plane magnetic field. While at moderate magnetic fields B the photocurrent depends linear on B, at high magnetic fields it becomes nonlinear and inverses its sign. The generation of this current is analyzed in terms of electron gas heating and asymmetric scattering in k-space [1]. We show that due to the narrow gap, strong magnetic proberty and strong spin-orbit coupling this effect is substantially enhanced compared to other III-V materials. It is demonstrated that the strong nonlinear behavior is due to a nonlinear Zeeman spin splitting. [1] V.V. Belkov and S.D. Ganichev, Sem. Sci. Tec. **23**, 114003 (2008)

HL 32.11 Tue 12:45 EW 203

Exchange interaction of electrons with Mn in hybrid AlSb/InAs/ZnMnTe structures — •P. Olbrich[1], C. Zoth[1], Ya. V. Terent'ev[2], V. V. Bel'kov[2], C. Drexler[1], V. Lechner[1], P. Lutz[1], M. S. Mukhin[2], S. A. Tarasenko[2], A. N. Semenov[2], V. A. Solov'ev[2], G. V. Klimko[2], T. A. Komissarova[2], S. V. Ivanov[2], and S. D. Ganichev[1] — [1]University of Regensburg, Regensburg, Germany — [2]Ioffe Institute, St. Petersburg, Russia

Here we report on the fabrication an investigation of Manganese modulation doped structures with an InAs two-dimensional electron gas (2DEG) channel. The quantum wells were grown applying III-V/II-VI "hybrid" technique and Mn layers have been inserted into the II-VI barrier. To explore the magnetic properties of the 2DEG we investigated spin polarized electric currents induced by microwave (mw) and terahertz (THz) radiation [1]. Our measurements show that hybrid AlSb/InAs/(Zn,Mn)Te QWs are characterized by enhanced magnetic properties which can be changed by tuning of the spatial position of the Mn-doping layer as well as by the variation of temperature. We demonstrate that the exchange interaction is due to penetration of the electronic wave function into the (Zn,Mn)Te layer and can be controllably varied by the position and density of Mn^{2+} ions [2].

[1] S. D. Ganichev *et al.*, *Phys. Rev. Lett.* **102**, 156602 (2009)

[2] Ya. V. Terent'ev *et al.*, *Appl. Phys. Lett.* **99**, 072111 (2011)

HL 32.12 Tue 13:00 EW 203

Realization of a persistent spin helix in InGaAs/InAlAs quantum wells — •V. Lechner[1], M. Kohda[2], Y. Kunihashi[2], J. Nitta[2], L.E. Golub[3], V.V. Bel'kov[3], K. Richter[1], D. Weiss[1], C. Schönhuber[1], I. Caspers[1], P. Olbrich[1], and S.D. Ganichev[1] — [1]University of Regensburg, Germany — [2]Tohoku University, Sendai, Japan — [3]Ioffe Institute, St. Petersburg, Russia

Here we report on the realization of the persistent spin helix in InAs quantum wells (QWs) hosting a two dimensional electron gas. The sample consists of a 4 nm wide $In_{0.53}Ga_{0.47}As$ QW with $In_{0.52}Al_{0.48}As$ barriers and was grown strain free on a (001)-oriented InP substrate. A persistent spin helix can emerge if the $\boldsymbol{k}$-linear Rashba and Dresselhaus spin orbit interactions are of equal strength ($\alpha = \beta$). The realization of this condition has been proved by magneto-transport measurements, where the transition from weak anti-localization to weak localization and back to weak anti-localization was observed under a variation of the gate voltage. This result was confirmed by measurements of the anisotropy of THz radiation induced photocurrents, the circular photogalvanic and the spin-galvanic effect, applying the methods of [1]. Via these methods the relative strength of α and β was estimated in a wide temperature range from 5 K up to room temperature. We also analyzed the importance of the $\boldsymbol{k}$-cubic Dresselhaus terms.

[1] S. Giglberger et al., Phys. Rev. B **75**, 035327 (2007).