HL 19: Spin-controlled Transport I

Time: Tuesday 9:30–13:00 Location: H14

HL 19.1 Tue 9:30 H14

Sub-ns electrical spin control in a diluted magnetic semiconductor quantum well — •Yuansen Chen[1], Maciej Wiater[2], Grzegorz Karczewski[2], Tomasz Wojtowicz[2], and Gerd Bacher[1] — [1]Werkstoffe der Elektrotechnik and CeNIDE, Universität Duisburg-Essen, Bismarkstr.81,47057, Duisburg, Germany — [2]nstitute of Physics, Polish Academy of Science, Al. Lotnikow 32/46 02-668 Warsaw, Poland

To gain control over the spin degree of freedom is a key issue in semiconductor spintronics. We present an approach to electrically control spins on a sub-ns time scale and on a micrometer length scale in a diluted magnetic semiconductor quantum well (DMS QW). Microscale Au coils are defined atop a CdMnTe/CdMgTe DMS QW and by introducing a short current pulse through the coil, a local magnetic field can be generated enabling an electrical control of Mn2+ spin dynamics in the DMS QW. Due to the strong sp-d exchange interaction, the Mn2+ spin dynamics can be effectively probed by means of time- and polarization- resolved micro-photoluminescence measurements. Thanks to our high time-resolution, we are able to clearly separate the field induced spin alignment and the Mn2+ spin heating process . At zero external field the Mn2+ spin polarization can be switched on a time-scale of several hundred picoseconds, i.e. clearly below typical time scales expected for spin-lattice relaxation . Applying an external field of 100 mT, an additional slow component appears with typical time constants in the few 100 ns regime.

HL 19.2 Tue 9:45 H14

Time-resolved studies of current-induced spin polarization in strained InGaAs/GaAs structures — •Markus Hagedorn[1,2,3], Sebastian Kuhlen[1,3], Marten Patt[1,3], Paul Schlammes[1,3], Frederik Klein[1,3], Stefan Göbbels[1,3], Gernot Güntherodt[1,3], Mihail Lepsa[2,3], Thomas Schäpers[2,3], and Bernd Beschoten[1,3] — [1]II. Phys. Institut A, RWTH Aachen University — [2]Institut für Bio- und Nanosysteme (IBN-1), Forschungszentrum Jülich — [3]JARA - Fundamentals of Future Information Technology

Understanding the mechanisms of electron spin interactions and dephasing in nonmagnetic semiconductor heterostructures are crucial for building novel spintronic devices. Conventional all-optical pump/probe methods for the creation and detection of coherent spins are nowadays supplemented by means of electrical techniques.

The underlying mechanisms which enable the so-called current induced spin polarization (CISP) are internal effective magnetic fields evoked by the broken inversion symmetry of the zinc blende structure in III-V semiconductor materials (Dresselhaus term) and, additionally, by strain in, e.g., InGaAs/GaAs heterostructures.

Applying ultrafast current pulses (time-resolved CISP) to lateral transport devices without ferromagnetic contacts, we are able to create and manipulate phase coherent spin ensembles, which are probed by Faraday rotation.

Work supported by DFG through FOR912.

HL 19.3 Tue 10:00 H14

Selective Optical Excitation of In-Plane and Out-of-Plane Spin Polarizations with Linearly Polarized Light in InGaAs — •Stefan Göbbels[1,2], Frederik Klein[1,2], Philipp Schäfers[1,2], Markus Hagedorn[1,2], Klaus Schmalbuch[1,2], Gernot Güntherodt[1,2], Thomas Schäpers[3,2], Mihail Lepsa[3,2], and Bernd Beschoten[1,2] — [1]II. Physikalisches Institut A, RWTH Aachen University, 52056 Aachen — [2]Jülich-Aachen Research Alliance, JARA - Fundamentals of Future Information Technology — [3]Institut für Bio- und Nanosysteme IBN-1, Forschungszentrum Jülich, 52425 Jülich

Excitation with circularly polarized light is a standard technique for optical spin orientation in semiconductors. This method is based on the transfer of angular momentum from the photons to the electrons and yields a polar spin polarization directed along the propagation direction of the exciting laser beam.

Here we present linearly polarized all-optical pump-probe experiments to excite and detect coherent electron spins in InGaAs. We find the magnitude and the orientation of the spin polarization strongly dependent on the polarization axes of the exciting light. While in general the excited spin ensemble is composed of both polar and transverse spin components, the polarization axis of the exciting light can be chosen such that polar and transverse spin components can be excited separately. Thus, selective excitation of in-plane and out-of-plane spin polarizations is feasible with linearly polarized light.

This work has been supported by DFG through FOR 912.

HL 19.4 Tue 10:15 H14

Spin-flip tunneling in quantum dots — •Lars Schreiber[1], Floris Braakman[1], Tristan Meunier[1], Victor Calado[1], Werner Wegscheider[2], and Lieven Vandersypen[1] — [1]Kavli Institute of NanoScience, Delft, The Netherlands — [2]Institute for Experimental and Applied Physics, University of Regensburg, Germany

Electron spins in a gate-defined double quantum dot formed in a GaAs/(Al,Ga)As 2DEG are promising candidates for quantum information processing as coherent single spin rotation and spin swap has been demonstrated recently. In this system we investigate the two-electron spin dynamics in the presence of microwaves (5..20 GHz) applied to one side gate. During microwave excitation we observe characteristic photon assisted tunneling (PAT) peaks at the (1,1) to (0,2) charge transition. Some of the PAT peaks are attributed to photon tunneling events between the singlet S(0,2) and the singlet S(1,1) states, a spin-conserving transition. Surprisingly, other PAT peaks stand out by their different external magnetic field dependence. They correspond to tunneling involving a spin-flip, from the (0,2) singlet to a (1,1) triplet. The full spectrum of the observed PAT lines is captured by simulations. This process offers novel possibilities for 2-electron spin manipulation and read-out.

HL 19.5 Tue 10:30 H14

Nonlinear transport effects in ferromagnetic multiple quantum well structures — •Christian Ertler[1,2] and Jaroslav Fabian[1] — [1]Institut für Theoretische Physik, Universität Regensburg, Universitätsstrasse 31, 93040 Regensburg, Germany — [2]Institut für Theoretische Physik, Karl-Franzens Universität Graz, Universitätsplatz 5, 8010 Graz, Austria

Heterostructures made of both magnetic and nonmagnetic semiconductors provide rich opportunities for controlling and tuning their spin-dependent transport properties [1]. In the case that the ferromagnetic order in the quantum wells (e.g., made of GaMnAs) is mediated by the itinerant carriers, the resonant tunneling transport and the magnetic properties become strongly interconnected [2]. Here, we show that in coupled multiple quantum well structures this can lead to interesting dynamical effects, such as self-sustained current oscillations or moving magnetoelectric domain walls. The requirements for the occurrence of these effects and for their possible experimental observation are discussed. This work has been supported by the DFG, SFB 689.

[1] J. Fabian, A. Matos-Abiague, C. Ertler, P. Stano and I. Zutic, Acta Phys. Slov. 57, 565 (2007).

[2] C. Ertler and J. Fabian, Phys. Rev. Lett. 101, 077202 (2008).

HL 19.6 Tue 10:45 H14

DC measurements on InAs two-stage spin-filter cascades — •Jan Jacob, Hauke Lehmann, Marc-Antonio Bisotti, Toru Matsuyama, Guido Meier, and Ulrich Merkt — Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg, Jungiusstraße 11, 20355 Hamburg

For spintronics it is a prerequisite to create devices capable of generating and detecting spin-polarized currents. We present an all-semiconductor nanostructure based on an InAs heterostructure, which can be used to generate spin-polarized currents all-electrically utilizing the intrinsic spin Hall effect in a Y-shaped junction. By cascading two spin filters the first acts as a generator of spin-polarized currents while the second acts as an all-electrical detector [1]. Measurements applying an AC voltage to the two-stage spin-filter cascade have proven the feasibility of these devices as efficient generators and detectors for spin-polarized currents [2]. For the investigation of the influence of magnetic and electric fields in different directions it is essential to use DC voltages to direct the electron flow in constant direction instead of alternating directions in the AC case and thereby keeping the geometric relation between the current flow and the applied field constant. To enable lock-in technique we apply a DC voltage with AC modulation to the spin-filter cascade.

[1] A. Cummings, R. Akis, D. Ferry, J. Jacob, T. Matsuyama, U. Merkt, and G. Meier. J. Appl. Phys., **104**, 066106 (2008).
[2] J. Jacob, G. Meier, S. Peters, T. Matsuyama, U. Merkt, A. Cummings, R. Akis, and D. Ferry. J. Appl. Phys., **105** 093714 (2009).

15 Min. Coffee Break

HL 19.7 Tue 11:15 H14

The Rashba Effect in the Magnetization of an Asymmetric InGaAs/InP Quantum Well — •Benedikt Rupprecht[1], Christian Heyn[2], Hilde Hardtdegen[3], Thomas Schäpers[3], Marc A. Wilde[1], and Dirk Grundler[1] — [1]Lehrstuhl für Physik funktionaler Schichtsysteme, Physik Department, Technische Universität München, James-Franck-Strasse 1, D-85747 Garching b. München — [2]Institut für Angewandte Physik, Universität Hamburg, Jungiusstrasse 11, D-20355 Hamburg — [3]Institute for Bio- and Nanosystems (IBN-1) and JARA Jülich-Aachen Research Alliance, Research Centre Jülich GmbH, D-52425 Jülich

The measurement of the magnetic susceptibility was proposed by Bychkov and Rashba in 1984 to observe the spin splitting induced by the spin-orbit interaction (SOI) in a two-dimensional electron system (2DES). The detection of the corresponding beatings in the magnetization M is experimentally challenging. Magnetization data obtained on a high mobility 2DES in an AlGaAs/GaAs heterostructure revealed these beatings in M only at high tilt angles δ between the sample normal and the external field B. By using micromechanical cantilever magnetometry we were able recently to measure the magnetization of an asymmetric InGaAs/InP quantum well showing SOI induced beating patterns in M at small δ. From the data we extract the bandstructure parameters effective mass m^*, Landé g-factor g^* and Rashba parameter α_R. The work was supported via SPP 1285 "Halbleiter-Spintronik" (GR1640/3) and the German Excellence Cluster "Nanosystems Initiative Munich" (NIM).

HL 19.8 Tue 11:30 H14

Interplay of Intrinsic and Extrinsic Mechanisms to the Spin Hall Effect in a Two-Dimensional Electron Gas — •Peter Schwab[1] and Roberto Raimondi[2] — [1]Institut für Physik, Universität Augsburg, 86135 Augsburg, Germany — [2]CNISM and Dipartimento di Fisica, Università Roma Tre, Via della Vasca Navale 84, 00146 Roma, Italy

In recent years spin-orbit interaction in semiconductors has attracted considerable attention due to its potential for controlling the spin degrees of freedom by electric fields. The spin Hall effect due to the structure inversion asymmetry (Rashba term) has been intensively studied, and it has been established that the spin Hall current vanishes in the static limit. The situation is different when both extrinsic and intrinsic effects are present. We provide a theory for this situation.

We derive drift-diffusion equations for the spin density in the presence of intrinsic spin-orbit coupling as well as skew scattering and side-jump contributions (extrinsic effects). We calculate the electric-field induced spin polarization and the spin Hall conductivity. First, the result by Edelstein for the spin polarization is strongly modified by the presence of the extrinsic spin-orbit interaction. Second, our expression for the spin Hall conductivity correctly reproduces the known limits. For realistic parameters the spin Hall conductivity is mainly due to the side-jump contribution.

[1] R. Raimondi, P. Schwab, EPL **87**, 37008 (2009).

HL 19.9 Tue 11:45 H14

Spin Hall drag in electronic bilayers — •Samvel M. Badalyan[1,2] and Giovanni Vignale[3] — [1]Department of Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Department of Radiophysics, Yerevan State University, 1 A. Manoukian Street, Yerevan, 375025 Armenia — [3]Department of Physics and Astronomy, University of Missouri, Columbia, Missouri 65211, USA

In electronic bilayers an electric current, driven in one of the layers, induces via inter-layer Coulomb scattering a charge accumulation in the other layer. This phenomenon known as Coulomb drag is of fundamental interest as a probe of electron correlations. Another effect of great interest is the Spin Hall Effect, i.e. the generation of spin accumulation by an electric current. This is due to spin-orbit interactions and has recently received great attention for its usefulness as a source of spin-polarized currents. Here we predict a new effect in electronic bilayers: spin Hall drag. The effect consists of the generation of spin accumulation across one layer by an electric current along the other layer. It arises from the combined action of spin-orbit and Coulomb interactions. Our theoretical analysis identifies two main contributions to the spin Hall drag resistivity: the side-jump contribution, going as T^2, and the skew-scattering contribution, as T^3. The induced spin accumulation, while generally quite small, should be observable in optical rotation experiments.

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HL 19.10 Tue 12:00 H14

The spin-dependent recombination between phosphorus donors in silicon and Si/SiO$_2$ interface states — •Felix Hoehne[1], Hans Huebl[2], Bastian Galler[1], Christian Huck[1], Christoph Pellinger[1], Martin Stutzmann[1], and Martin Brandt[1] — [1]Walter Schottky Institut, München — [2]Walther-Meissner-Institut, München

Electrically detected magnetic resonance (EDMR) is a well known tool to detect small numbers of spins. In this approach to spin resonance, the spin state is transferred to a charge state via a spin-dependent process governed by the Pauli principle involving two paramagnetic states. So far, the identification of such correlated states has only been achieved indirectly in EDMR. Here, we investigate the spin species relevant for the spin-dependent recombination used for the electrical readout of coherent spin manipulation in phosphorus-doped silicon. Via a multi-frequency pump-probe experiment in pulsed electrically detected magnetic resonance, we demonstrate that the dominant spin-dependent recombination transition occurs between phosphorus donors and Si/SiO$_2$ interface states. Combining pulses at different microwave frequencies allows us to selectively address the two spin subsystems participating in the recombination process and to coherently manipulate and detect the relative spin orientation of the two recombination partners.

Financial support by SFB 631 is gratefully acknowledged.

HL 19.11 Tue 12:15 H14

Anisotropic electron spin relaxation in bulk GaN — •Jan Heye Buss, Jörg Rudolph, and Daniel Hägele — AG Spektroskopie der kondensierten Materie, Ruhr Universität Bochum, Germany

The wide-gap semiconductor GaN has attracted growing interest during the last years. Besides its potential for short-wavelength optoelectronics, the spin related properties make GaN a promising material for spintronics.[1] Above room-temperature ferromagnetism is predicted for rare-earth or transition-metal doping,[2] and due to the weak spin-orbit coupling long spin relaxation times are expected. We investigate the electron spin dynamics in n-type c-oriented wurtzite GaN epilayers by time-resolved Kerr-rotation measurements at $T = 80$ K. The electron spin lifetime shows a sudden increase if an external magnetic field is applied in the sample plane. This enhancement is explained by anisotropic Dyakonov-Perel spin relaxation in bulk GaN as a direct consequence of the special anisotropy of spin-orbit coupling in semiconductors with wurtzite structure.[3]

[1] I. Zutic et al., Rev, Mod. Phys. **76**, 323 (2004)
[2] T. Dietl et al., Science **287**, 1019 (2000)
[3] J. H. Buss et al., Appl. Phys. Lett. **95**, 192107 (2009)

HL 19.12 Tue 12:30 H14

Spin correlations due to Dyakonov-Perel and spin noise spectroscopy in semicoductor quantum wells — •Tobias Hartenstein, Michael Krauss, and Hans Christian Schneider — Department of Physics and Research Center OPTIMAS Kaiserslautern University of Technology,PO Box 3049, 67653 Kaiserslautern, Germany

We present a theoretical investigation of dynamical electronic spin-spin correlations in quantum wells resulting from the Dyakonov-Perel mechanism due to electron-impurity interactions in the presence of external magnetic fields. We set up the coupled equations of motion for the different spin-spin correlation functions, and solve them numerically. Since spin-noise measurements are sensitive to the spin-spin correlation functions, our results provide a microcscopic basis for this measurement technique [1], but also allow us to study how the Dyakonov-Perel relaxation mechanism affects non-trivial electronic spin correlations and correlation waves that can be induced by the absorption of non-classical polarization-squeezed light [2].

[1] G. M. Müller, M. Römer, D. Schuh, W. Wegscheider, J. Hübner,

and M. Oestreich, Phys. Rev. Lett **101**, 206601 (2008).
[2] E. Ginossar, Y. Levinson, and S. Levit, Phys. Rev. B **78**, 205204 (2008)

HL 19.13 Tue 12:45 H14

Fourth-order frequency correlation spectroscopy at radiofrequencies — •Sebastian Starosielec, Rachel Fainblat, Jörg Rudolph, and Daniel Hägele — AG Spektroskopie der kondensierten Materie, Ruhr-Universität Bochum, Germany

The study of fluctuations, like e.g. Spin Noise Spectroscopy has proved to be a valuable tool for determining intrinsic properties of dynamical systems even in thermal equilibrium. The measurement of higher order correlations, like the "noise of the noise", promises the access to additional hidden dynamics in the fluctuating signals. We find that higher order correlations are useful for characterizing e.g. the dynamics of a noise-driven nonlinear system or the critical dynamics of systems around a phase transition. The measurement of the covariance of noise intensity at different frequencies is especially appealing, since recent developments in parallel computing on commercially available graphics hardware allow the calculation of two-dimensional correlation spectra of fourth order. Depending on frequency range and resolution, high coverage rates up to real-time processing may be achieved at sample rates up to 180 MHz. As a demonstration, we find strong correlations in frequency modulated radio signals and investigate thermal resistor noise. We envision application to the study of magnetic phase transitions, incoherent spin waves, spin noise in semiconductors, and $1/f$ noise in various devices. The latter is of high interest since the origin of $1/f$ noise is still debated, and higher order correlations might distinguish between proposed mechanisms.