HL 4: Spintronics: Nanostructures and Optics

Time: Monday 9:30–13:00 Location: H13

HL 4.1 Mon 9:30 H13

Nuclear spin polarization in the electron spin-flip Raman scattering of singly charged (In,Ga)As/GaAs quantum dots

— •Philipp Waldkirch[1], J. Debus[1], D. Kudlacik[1], V. F. Sapega[2], D. Dunker[1], P. Bohn[1], F. Passmann[1], D. Braukmann[1], J. Rautert[1], D. R. Yakovlev[1,2], D. Reuter[3], A. D. Wieck[4], and M. Bayer[1,2] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44227 Dortmund, Germany — [2]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia — [3]Department Physik, Universität Paderborn, 33098 Paderborn, Germany — [4]Angewandte Festkörperphysik, Ruhr-Universität Bochum, 44780 Bochum, Germany

We show that resonant, two-color spin-flip Raman scattering (SFRS) cannot only be used to manipulate carrier spins in a singly charged ensemble of (In,Ga)As QDs [1], but can also sensitively indicate the coupling of carrier spins to the surrounding nuclear spin bath, i.e., to study the central spin problem [2]. This method allows for monitoring the dynamic nuclear spin polarization directly through the Overhauser shift of the electron-SFRS line, while its width is determined by nuclear spin fluctuations. The rapid temporal decay of the Overhauser shift with slightly increasing temperature is caused by phonon-induced electron spin-flips that depolarize the nuclear spin system. The mechanism of the two-color SFRS is discussed together with the electron-nuclear hyperfine interaction and Pauli exclusion principle.

[1] J. Debus et al., Phys. Rev. B **90**, 235404 (2014)

[2] J. Debus et al., Phys. Rev. B **92**, 195421 (2015)

HL 4.2 Mon 9:45 H13

Spin Dynamics in Single Wurtzite GaAs Nanowires

— •Florian Dirnberger, Stephan Furthmeier, Andreas Bayer, Joachim Hubmann, Benedikt Bauer, Moritz Forsch, Josef Zweck, Elisabeth Reiger, Christian Schüller, Tobias Korn, and Dominique Bougeard — Institut für Experimentelle und Angewandte Physik, Universität Regensburg, D-93040 Regensburg, Deutschland

Spin orbit coupling (SOC) in semiconductor nanowires (NWs) is currently attracting great interest regarding the application of spintronic and spin-orbitronic concepts. The action of this relativistic effect can be experimentally captured through its influence on the spin dynamics in the material. In contrast to electrical spin injection by means of ferromagnetic contacts, optical orientation with circularly polarized light provides a contact-free, non-invasive method to investigate the spin dynamics in semiconductors.

In this contribution, we demonstrate for the first time efficient optical spin orientation in single free-standing wurtzite (WZ) GaAs/AlGaAs core-shell nanowires. Our WZ nanowires are stacking-fault-free over lengths of several μm. We investigated the intrinsic spin dynamics in time-resolved micro-photoluminescence measurements on single NWs and observed long spin lifetimes up to $\tau_s = 1.5$ ns. The spin dynamics further reveal an anisotropic SOC for the studied NWs, which is counterintuitive compared to bulk WZ semiconductors. We present a model of the observed electron spin dynamics which highlights the major role of the interface SOC in these nanowires.

HL 4.3 Mon 10:00 H13

Fe doped InAs: what is the exchange interaction?

— •Ye Yuan[1], René Hübner[1], Kay Potzger[1], Fang Liu[1], Maciej Sawicki[2], Tomasz Dietl[2], Manfred Helm[1], and Shengqiang Zhou[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Institute of Physics, Polish Academy of Sciences, Warsaw, Poland

Fe doped InAs layers have been prepared by ion implantation and pulsed laser annealing. Fe ions exist in the +3 valence state when located in Indium sites, which indicates that Fe atoms do not introduce free carriers in the InAs layer and only act as the local spins. However, (In, Fe)As or (In, Fe)As n-type doped with Se exhibits properties typical to a blocked superparamagnet, as proven by both static and dynamic magnetic measurements. This is most probably due to the formation of Fe-rich nanoregions in the InAs matrix, similarly to the case of Cr-doped ZnTe [1]. However, the p-type doping with Zn increases both the saturation magnetization and the Curie temperature. A systematic comparison between (In, Fe)As, (In, Fe)As: Zn and (In, Fe)As: Se leads to the re-affirmation of the pd-exchange as the key gradient in dilute ferromagnetic semiconductors [2].

[1]. K. Kanazawa et al., Nanoscale, 6, 14667-14673 (2014) [2]. T. Dietl et al., Science, 287, 1019-1022 (2000)

HL 4.4 Mon 10:15 H13

Weak (Anti)Localization in Tubular Semiconductor Nanowires with Spin-Orbit Coupling

— •Paul Wenk[1], Michael Kammermeier[1], John Schliemann[1], Sebastian Heedt[2], and Thomas Schäpers[2] — [1]Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany — [2]Peter Grünberg Institute and JARA-Fundamentals of Future Information Technology, Forschungszentrum Jülich, 52425 Jülich, Germany

Motivated by recent experiments we compute analytically the quantum mechanical correction to the Drude conductivity in tubular semiconductor systems of zincblende type. Focusing on the lowest conduction band, we include linear Rashba and Dresselhaus spin-orbit coupling (SOC) and compare the results for nanorods of standard growth directions $\langle 100\rangle$, $\langle 111\rangle$ and $\langle 110\rangle$. The motion on the quasi two-dimensional surface is considered diffusive in both directions: transverse as well as along the cylinder axis. It is shown that both Dresselhaus and Rashba SOC affect the spin relaxation rates. We detect a crossover from weak localization to weak anti-localization depending on SOC strength as well as dephasing and scattering rate.

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[1] S. Kettemann, PRL **98** 176808 (2007)

[2] P. Wenk *et al.*, PRB **83** 115301 (2011)

[3] S. Heedt *et al.*, Nanoscale **7** 18188 (2015)

HL 4.5 Mon 10:30 H13

Spin-orbit coupling effects in nanowires using the k.p method

— •Tiago de Campos[1,3], Paulo Eduardo Faria Junior[1], Guilherme Sipahi[1,2], and Jaroslav Fabian[3] — [1]Universidade de São Paulo — [2]State University of New York at Buffalo — [3]Universität Regensburg

The search for Majorana fermions is a hot subject nowadays. One of the possibilities for realization of such experiments is a hybrid that couples a nanowire with a s-wave superconductor in the presence of an external magnetic field [1]. To understand the nanowire's role in this setup, we need a realistic band structures including spin-orbit effects. To consider the spin-orbit effects, it is common to use models that take into account only the first conduction band. Although these reduced models have been successfully in determine some physical properties, a more realistic description of the spin-orbit coupling between the bands is required to further investigate possible ways to realize the Majorana fermions. In this study we use a state of the art k.p Hamiltonian, which has the Dresselhaus and Rashba spin-orbit coupling built on the Hamiltonian from the beginning, together with the envelope function approach [2] to determine the band structure of zincblende InSb and wurtzite InAs nanowires. We analyze how the quantum confinement change the coupling between the bands and extracted the effective masses and the spin-splitting parameters that can be used in effective models.

[1] J. Alicea, Rep. Prog. Phys. 75, 076501 (2012). [2] P. E. Faria Junior and G. M. Sipahi, J. Appl. Phys. 112, 103716 (2012).

HL 4.6 Mon 10:45 H13

***g*-factor properties of electrons and holes confined in quantum dots emitting at telecom wavelengths**

— •Janina Schindler[1], Vasilii V. Belykh[1], Dmitri R. Yakovlev[1,2], Evgeny A. Zhukov[1], Matusala Yacob[3], Johann P. Reithmaier[3], Mohamed Benyoucef[3], and Manfred Bayer[1,2] — [1]Experimentelle Physik 2, TU Dortmund, 44227 Dortmund, Germany — [2]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia — [3]Institute of Nanostructure Technologies and Analytics, University of Kassel, 34132 Kassel, Germany

Spins in semiconductor quantum dots (QDs) are considered as highly attractive systems for future applications in the solid-state quantum information processing. In that context, the characterization of *g*-factors is very important to assess the spin dynamics for the semiconductor physics in general and for tailoring nanostructures in particular, since the dynamics are sensitive to shape anisotropies as well as spin-state mixing. We study electron and hole g-factors and dephasing times in a novel InAs/InAlGaAs/InP quantum dot ensemble by measuring time-resolved pump-probe ellipticity. The emission of the QDs lies in the telecommunication wavelength range around $1.55\,\mu$m, which is highly interesting for information-processing applications. We observe a surprisingly strong deviation of the electron g-factor from the Roth-Lax-Zwerdling equation, a strong dispersion of the hole g-factor and a significant out-of-plane anisotropy of the g-factors, in contrast to nearly isotropic in-plane properties.

30 min. Coffee Break

HL 4.7 Mon 11:30 H13

Low Field Nuclear Magnetic Resonance in Gallium Arsenide detected via Spin Noise Spectroscopy — •Fabian Berski[1], Jens Hübner[1], Michael Oestreich[1], Arne Ludwig[2], A. D. Wieck[2], and Mikhail Glazov[3] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstr. 2, D-30167 Hannover, Germany — [2]Angewandte Festkörperphysik, Ruhr-Universität Bochum, 44780 Bochum, Germany — [3]Ioffe Institute, Polytechnicheskaya 26, 194021 St.-Petersburg, Russia

The hyperfine interaction between donor electron spins and lattice magnetic moments in III-V semiconductor materials is a challenge for quantum information processing. However, the ubiquitous interaction also provides all-optical access to the spin dynamics of the nuclear system, which may serve as long-lived solid-state qubits.

We present highly sensitive spin noise measurements on an ensemble of non-interacting donor bound electrons (D^0X) in a nearly perfect, high purity Gallium Arsenide host matrix [1]. The experiment distinctly reveals the finite Overhauser shift of an electron spin precession at zero external magnetic field and a second contribution around zero frequency stemming from the electron spin components parallel to nuclear spin fluctuations. Moreover, at very low frequencies, features related with time-dependent nuclear spin fluctuations are clearly resolved making it possible to study the intricate nuclear spin dynamics at zero and low magnetic fields.

[1] Berski, et al., Phys. Rev. Lett. **115**, 176601 (2015).

HL 4.8 Mon 11:45 H13

Elliott-Yafet spin relaxation revisited — •Svenja Vollmar[1,2] and Hans Christian Schneider[1] — [1]Department of Physics and Research Center of OPTIMAS, University of Kaiserslautern — [2]Graduate School of Excellence Materials Science in Mainz

By computing the dynamics of the reduced electronic density matrix, we present a new analysis of the Elliott-Yafet spin relaxation mechanism, i.e. the spin relaxation due to incoherent electron-phonon scattering [1,2,3]. In our approach spin dynamics is described correctly without approximating mixed spin states by pure spin states, as done in Yafet's original treatment [3]. Our approach is therefore also valid for pronounced spin mixing. The central new quantity introduced in our calculation is a torque matrix element that determines the spin dynamics in a transparent fashion.

For the special case of Kramers degenerate bands we use this result to derive a novel expression for the close-to-equilibrium spin relaxation-time. To this end, we determine the reduced density matrix for a spin polarized system with arbitrary spin mixing in quasi-equilibrium [4].

[1] A. W. Overhauser, Phys. Rev. 89, 689 (1953).

[2] R. J. Elliott, Phys. Rev. 96, 266 (1954).

[3] Y. Yafet, Solid State Physics 14, 1 (1963).

[4] A. Baral, S. Vollmar, S. Kaltenborn, H.C. Schneider, arXiv: 1505.01432.

HL 4.9 Mon 12:00 H13

Impurity dominated spin dynamics in GaAs in the vicinity of the metal-to-insulator transition — •Jan Gerrit Lonnemann[1], Eddy Patrick Rugeramigabo[2], Jens Hübner[1], and Michael Oestreich[1] — [1]Institute for Solid State Physics, Leibniz Universität Hannover, Appelstr. 2, D-30167 Hannover, Germany — [2]Laboratory of Nano and Quantum Engineering, Leibniz Universität Hannover, Schneiderberg 39, D-30167 Hannover, Germany

Several theoretical works treat the spin dynamics in zinc-blende semiconductors. We present extremely low excitation Hanle depolarization measurements on well characterized n-doped MBE grown GaAs in the vicinity of the metal-to-insulator transition (MIT). This doping concentration regime is of special interest because around the MIT at $2{*}10^{16}\,\mathrm{cm}^{-3}$ extremely long spin lifetimes are experimentally observed [1]. Spin relaxation in this regime is dominated by the impurity states because the merging of impurity and conduction band does not take place below $8 * 10^{16}\,\mathrm{cm}^{-3}$. We conclude from our measurements that the well known D'yakonov Perel mechanism is dominating in slightly metallic samples. Furthermore there is no evidence of spin relaxation by hopping transport (HT) above the MIT that has been predicted as the main mechanism of relaxation for the impurity band regime [2]. In contrast our measurements show a metal-like behavior of the electrons in the impurity band.

[1] M. Römer et al.; *Phys. Rev. B*, **81**, 075216 (2010).

[2] G.A. Intronati et al.; *Phys. Rev. Lett.*, **108**, 016601 (2012).

HL 4.10 Mon 12:15 H13

Novel properties of the Mn^{2+} spin-flip Raman scattering in ZnMnSe quantum wells — •Henning Moldenhauer[1], Carolin Lüders[1], Philipp Waldkirch[1], Dennis Kudlacik[1], Victor Sapega[2], Jörg Debus[1], Andreas Waag[3], and Manfred Bayer[1,2] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44227 Dortmund, Germany — [2]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia — [3]Institut für Halbleitertechnik, Technische Universität Braunschweig, 38106 Braunschweig, Germany

Diluted magnetic semiconductors (DMS) are promising materials for novel types of devices based on the tailoring of their spin properties leading to the field of semiconductor spintronics. Even though there has been a continuous study on Mn-based DMS during the last decades, several questions on the carrier-Mn ion interactions are still unanswered. We extend considerably the picture of the spin-flip Raman scattering (SFRS) of the Mn^{2+} ions by studying it in Faraday and tilted geometries in ZnMnSe quantum wells with Mn concentrations below 4%. We demonstrate that the paramagnetic Mn^{2+} resonances are caused by exchange interactions with conduction band electrons as well as hyperfine interactions with the Mn^{2+} nuclear spins. To verify this mechanism we apply radio-frequency (RF) fields, combined with resonant SFRS, to observe an impact of the nuclear spin depolarization on the Mn^{2+} SFRS signals. Surprisingly, the anti-Stokes Mn^{2+} scattering process is observed and also affected by the RF-fields.

HL 4.11 Mon 12:30 H13

Hole spin coherence in coupled GaAs/AlAs quantum wells — •Christian Gradl, Michael Kempf, Johannes Holler, Dieter Schuh, Dominique Bougeard, Christian Schüller, and Tobias Korn — Universität Regensburg, 93040 Regensburg, Germany

Due to its p-like character, the valence band in GaAs-based heterostructures offers rich and complex spin-dependent phenomena. Especially for some low-symmetry growth directions, a strong anisotropy of the hole g factor with respect to the in-plane magnetic field direction is theoretically predicted. Therefore, we perform time-resolved Kerr rotation measurements on an undoped [113]-grown double quantum well (QW) structure to resolve the spin dynamics of hole ensembles at low temperatures. Our gated system consists of two QWs with different well widths, which we use for the spatial separation of the optically excited electron-hole pairs. Thus, we are able to create hole ensembles with spin lifetimes of several hundreds of picoseconds in the broader QW without any doping. This allows the observation of a strong hole g factor anisotropy by varying the magnetic field direction in the QW plane. The experimental g factor values are in very good agreement with theoretical predictions. Furthermore, we observe an unexpected additional non-precessing component in the Kerr signal for certain in-plane magnetic field directions. This might have its origin in a precession axis that is tilted relative to the magnetic field due to the crystal structure of this low-symmetry growth direction.

HL 4.12 Mon 12:45 H13

Time-resolved electrical detection of the Spin Galvanic effect after ps optical excitation — •Manfred Ersfeld[1], Ivan Stepanov[1], Mihail Lepsa[2], and Bernd Beschoten[1] — [1]2nd Institute of Physics, RWTH Aachen University, Germany — [2]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich GmbH, Germany

Direct conversion of electron spin precession in semiconductor heterostructures into a detectable electrical voltage plays an important role in many spintronic concepts. Here we report on the first time-resolved electrical measurement of the spin galvanic effect (SGE) probed by spin dependent photo-voltages in n-InGaAs. Phase triggering of electron spin coherence is achieved by circularly polarized picosecond laser pulses. Electron spin precession in a transverse external magnetic field can be directly monitored as voltage oscillations using a phase-triggered sampling oscilloscope as a probe. The strong crystal axis anisotropy of the spin-orbit interaction allows analyzing the predicted dependence of the spin-dependent photo-voltage on the strength of the spin-orbit interaction. In contrast to previous theoretical predictions, the amplitude of the SGE does not depend on the spin-orbit coupling strength.