HL 48: Focus Session: Spintronics (jointly with MA)

Time: Wednesday 10:00–13:15 Location: EW 201

HL 48.1 Wed 10:00 EW 201

Electron spin decoherence in SiC nuclear spin bath — •Nan Zhao, Christian Burk, and Joerg Wrachtrup — 3. Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart , Germany

The coherent control of electron spin of defect centers in SiC was reported very recently [1]. Here, we calculate the decoherence of defect center electron spin in SiC nuclear spin bath. In SiC, the nuclear spin bath consists of two types of spin-1/2 isotopes, Si-29 and C-13. The natural abundance of Si-29 is 4.7%, about four times larger than that of C-13. Intuitively, the spin decoherence in SiC nuclear spin bath would be faster than NV in diamond. However, our calculations demonstrate that, when nuclear spin bath dominates decoherence process, the averaged coherence time of electron spin in SiC will be comparable or even longer than that of NV in diamond. We show that the reason for this counter-intuitive result is the suppression of the hetero-nuclear spin flip-flop process in magnetic fields. Our research provides the possibility of further exploring the quantum coherent spin dynamics in SiC.

Reference:

[1] Koehl, W. F., Buckley, B. B., Heremans, F. J., Calusine, G., & Awschalom, D. D. Room temperature coherent control of defect spin qubits in silicon carbide. Nature, 479, 84 (2011).

HL 48.2 Wed 10:15 EW 201

Coherent spin states of vacancy defects in silicon carbide — •Sang-Yun Lee[1], Yuki Doi[2], Shuta Mori[2], Takaaki Shimooka[2], Torsten Rendler[1], Nan Zhao[1], Helmut Fedder[1], Singi Miwa[2], Yoshishige Suzuki[2], Norikazu Mizuochi[2], and Jörg Wrachtrup[1] — [1]University of Stuttgart, Stuttgart, Germany — [2]Osaka University, Osaka, Japan

Since the first demonstration of the single spin detection of vacancy defects in diamond, the electron spins in the carbon vacancy defects have been considered as a good candidate for the semiconductor qubit especially due to their long coherence time at room temperature. It has been believed that this outstanding property originates from its highly localized bound state deep in the bandgap which prevent spin states from being affected by various decoherence sources [1]. Similarly isolated states can be found in various wide bandgap semiconductors. Among them, the long coherence time ($T_2 \simeq 40\ \mu s$ at R.T.) of electron spin ensemble of divacancy defect states in the silicon carbide (SiC) has been reported recently [2]. We hereby report our recent results on coherent spin states of various silicon vacancy defects including divacancy defects and other vacancy-related defects in SiC. The optical transitions are used to observe the electron spin resonance from them at room temperature. The coherence times of those defect states at room and low temperatures will be presented, and discussion about the decoherence processes will be given.

[1] J. R. Weber, *et al.*, P. NATL. ACAD. SCI. USA 107, 8513 (2010)
[2] W. F. Koehl, *et al.*, Nature 479, 84 (2011)

HL 48.3 Wed 10:30 EW 201

Nuclear spin quantum registers with NV centers in diamond — •Helmut Fedder[1], Jan Honert[1], Nan Zhao[1], Junichi Isoya[2], and Jörg Wrachtrup[1] — [1]3. Physikalische Institut, Uni Stuttgart — [2]University of Tsukuba, Japan

Nitrogen-Vacancy centers in diamond are promising solid state systems for quantum information processing with long (several ms) spin coherence time at room temperature. The defect has a strong optical transition that can be used for preparation and readout of the electron spin [1]. Nearby nuclear spins can be used to realize quantum registers with few qubits [2]. Single shot nuclear spin readout has been demonstrated in high magnetic fields [3]. Here we present recent results towards multi nuclear spin qubit registers. Exploiting the long coherence time in isotopically clean diamond, we enable addressing of weakly coupled nuclear spins. A detailed account will be given on the decoherence mechanisms, dynamical decoupling techniques and robust manipulation using double quantum transitions.

[1] Jelezko et al. PRL 93, 130501 (2004)
[2] Neumann et al. Science 320, 1326 (2008), Multipartite Entanglement Among Single Spins in Diamond
[3] Neumann et al. Science 329, 542 (2010), Single-Shot Readout of a Single Nuclear Spin

HL 48.4 Wed 10:45 EW 201

Spin Hall Effect on Triangular Lattice — •Paul Wenk[1], Georges Bouzerar[1,2], and Stefan Kettemann[1,3] — [1]School of Engineering and Science, Jacobs University Bremen, Campus Ring 1, Bremen 28759, Germany — [2]Institut Néel, 25 avenue des Martyrs, B.P. 166, 38042 Grenoble Cedex 09, France — [3]Asia Pacific Center for Theoretical Physics and Division of Advanced Materials Science Pohang University of Science and Technology (POSTECH) San31, Hyoja-dong, Nam-gu, Pohang 790-784, South Korea

We investigate the intrinsic Spin Hall Effect on a two-dimensional triangular lattice in the presence of both Rashba and Dresselhaus spin-orbit coupling. This type of lattice is especially interesting due to the build-in geometrical frustration and absence of particle-hole symmetry. We analyze the Spin Hall Effect by applying Chebyshev expansion and Kernel Polynomial Method, which allows for the variation of spin-Hall conductivity as a function of disorder strength on large system sizes.

HL 48.5 Wed 11:00 EW 201

Extended spin dephasing times in a 110-grown high-mobility GaAs/AlGaAs quantum well under conditions of optical gating measured by resonant spin amplification technique — •M. Griesbeck[1], M. Glazov[2], E. Sherman[3], T. Korn[1], D. Schuh[1], W. Wegscheider[4], and C. Schüller[1] — [1]Institute for Experimental and Applied Physics, Regensburg University, Germany — [2]Ioffe Physical-Technical Institute, St. Petersburg, Russia — [3]Department of Physical Chemistry, The University of the Basque Country, Bilbao, Spain — [4]Solid State Physics Laboratory, ETH Zürich, Switzerland

Recently, very long spin dephasing times were discovered in a high-mobility two-dimensional electron system (2DES) embedded in a 30 nm wide symmetric (110)-grown GaAs/AlGaAs quantum well [1,2]. We have found that resonant spin amplification (RSA) [3] measurements are a convenient tool to determine all relevant parameters of anisotropic spin dynamics in our sample. Here, we show that a decrease of the carrier density by low-intensity above-barrier illumination (often referred to as optical gating) leads to a drastic increase of both the in-plane and the out-of-plane spin dephasing times. The observed spin dephasing time along the growth direction exceeds by far the previously reported values, what is most likely related to the high sample quality and the precise control of the band profile of the quantum well.

[1] R. Völkl et al., Phys. Rev. B 83, 241306 (2011)
[2] M. Griesbeck et al., preprint: http://arxiv.org/abs/1111.5438
[3] J. M. Kikkawa et al., Phys. Rev. Lett. 80, 4313 (1998)

Coffee Break (15 min)

HL 48.6 Wed 11:30 EW 201

Electric field-driven coherent spin reorientation and spin rephasing of optically generated electron spin packets in InGaAs — •Sebastian Kuhlen[1,3], Klaus Schmalbuch[1,3], Markus Hagedorn[1,3], Paul Schlammes[1,3], Marten Patt[1,3], Mihail Lepsa[2,3], Gernot Güntherodt[1,3], and Bernd Beschoten[1,3] — [1]II. Physikalisches Institut A, RWTH Aachen University, 52074 Aachen — [2]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich — [3]JARA: Fundamentals of Future Information Technology, 52074 Aachen

Full electric-field control of spin orientations is one of the key tasks in semiconductor spintronics. We demonstrate that electric field pulses can be utilized for phase-coherent 2π spin rotation of optically generated electron spin packets in InGaAs epilayers using time-resolved Faraday rotation. Through spin-orbit interaction, the electric-field pulses act as local magnetic field pulses (LMFP). By the temporal control of the LMFP, we can turn on and off electron spin precession and thereby rotate the spin direction into arbitrary orientations in a 2-dimensional plane [1]. Moreover, using two subsequent pulses of opposite polarity allows us to perform spin echo measurements by reversing the spin precession direction. Although our spin transport experiment is in the diffusive regime, we unexpectedly observe that electric field-induced spin dephasing is reversible to a large extent.

[1] S. Kuhlen *et al.* arXiv 1107.4307

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HL 48.7 Wed 11:45 EW 201

Time-resolved electrical detection of optically triggered spin coherence in InGaAs — •Ivan Stepanov[1], Stefan Göbbels[1], Tobias Wenz[1], Gernot Güntherodt[1], Mihail Lepsa[2], and Bernd Beschoten[1] — [1]II. Physikalisches Institut, RWTH Aachen University, Germany — [2]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich GmbH, Germany

Direct conversion of electron spin precession into a detectable electrical voltage plays an important role in many spintronic concepts. In previous experiments spin-dependent photocurrents were observed in DC measurements on 2DEGs and QWs and could be explained by the spin-galvanic effect (SGE) [1].

Here we report on the first time-resolved electrical measurement of the spin-dependent photo-voltage 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 photo-voltage oscillations using a phase-triggered sampling oscilloscope as a probe. The magnetic field dependence of phase and amplitude of the photo-voltage along $[1\bar{1}0]$ agree well with the predictions of the SGE. Time-resolved Faraday rotation (TRFR) measurements on the same sample under identical experimental conditions show good agreement between the measured spin dephasing times and the g-factor in the photo-voltage probes and the TRFR.

This Work has been supported by DFG through FOR 912

[1] S.D. Ganichev *et al.*, Nature **417**, p. 153 (2002)

HL 48.8 Wed 12:00 EW 201

Anisotropic spin-orbit coupling probed by time-resolved photovoltage measurements in InGaAs/GaAs heterostructures — •Stefan Göbbels[1], Ivan Stepanov[1], Christopher Franzen[1], Gernot Güntherodt[1], Mihail Lepsa[2], and Bernd Beschoten[1] — [1]II. Physikalisches Institut, RWTH Aachen University, Germany — [2]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich GmbH, Germany

Electrical detection of spin polarization is a central issue in developing spintronic devices. The spin-orbit coupling (SOC) in III-V semiconductors opens a pathway for electrical spin detection with nonmagnetic electrodes via the spin-galvanic effect (SGE), which directly converts spin polarization into an electrical voltage [1].

Here, we report on the first observation of spin precession by time-resolved photovoltage measurements, which unveils more information about spin dynamics than obtained by previous static measurements. Our results on *n*-InGaAs/GaAs heterostructures reveal a strong crystal anisotropy of the photovoltages. While in the $[1\bar{1}0]$-direction the SGE is observed, arising from the in-plane spin polarization, we find in the [110]-direction that the photovoltage signal originates from an out-of-plane spin polarization and increases linearly with an in-plane magnetic field. Thus, two different SOC effects are observed along different crystal axes, which cannot be distinguished by phase-insensitive static measurements.

This work has been supported by DFG through FOR 912.

[1] S. D. Ganichev *et al.*, Nature **417**, 153 (2002)

HL 48.9 Wed 12:15 EW 201

Dark-bright mixing of interband transitions in [111] grown semiconductor quantum dots — •Bernhard Urbaszek[1], Gregory Sallen[1], Misha Glazov[2], Eougeniious Ivchenko[2], Takashi Kuroda[3], Takaaki Mano[3], Sergej Kunz[1], Kazuaki Sakoda[3], Xavier Marie[1], and Thierry Amand[1] — [1]Toulouse University, LPCNO-CNRS, France — [2]Ioffe Institute, St.-Petersburg, Russia — [3]NIMS, Tsukuba, Japan

Due to their inherently high symmetry, quantum dots grown along the [111] crystal axis have been indentified as suitable sources of entangled photon pairs via the exciton-biexction cascade [1]. We show that the underlying crystal symmetry does also result in highly unusual carrier spin physics probed in polarization resolved single dot photoluminescence spectroscopy. We observe for symmetric [111] grown GaAs/AlGaAs quantum dots in longitudinal magnetic fields applied along the growth axis in addition to the expected bright states also nominally dark transitions for both charged and neutral excitons. We uncover a strongly non-monotonous, sign changing field dependence of the bright neutral exciton splitting resulting from the interplay between exchange and Zeeman effects [2]. Our theory shows quantitatively that these surprising experimental results are due to magnetic-field-induced $\pm 3/2$ heavy-hole mixing, an inherent property of systems with C_{3v} point-group symmetry.

[1] Schliwa et al., PRB 80, 161307 (2009) & Singh and Bester, PRL 103, 063601 (2009) & Mohan et al., Nat. Photon. 4, 302 (2010)
[2] G. Sallen et al, Phys. Rev. Lett. 107, 166604 (2011)

HL 48.10 Wed 12:30 EW 201

Spin relaxation dynamics in spin-LEDs — •Henning Höpfner[1], Carola Fritsche[1], Arne Ludwig[2], Astrid Ebbing[2], Frank Stromberg[3], Heiko Wende[3], Werner Keune[3], Dirk Reuter[2], Andreas D. Wieck[2], Nils C. Gerhardt[1], and Martin R. Hofmann[1] — [1]Photonics and Terahertz Technology, Ruhr-University Bochum, Germany — [2]Applied Solid State Physics, Ruhr-University Bochum, Germany — [3]Faculty of Physics and Center for Nanointegration Duisburg-Essen, University of Duisburg-Essen, Germany

In recent years, spin-optoelectronics has been a field of both extensive and intensive research. In particular, the fabrication of spin light-emitting diodes (LEDs) has been intensively investigated.

Here we present a detailed investigation of spin injection into spin quantum dot LEDs. Our samples are GaAs based pin-type diodes and consist of a MgO tunnel barrier capped with a Fe/Tb multilayer injector operating in magnetic remanence and InAs quantum dots in the active region. The Fe/Tb multilayer allows us to operate our devices in magnetic remanence, which enables the separation of spin injection and relaxation effects from parasitic effects due to external magnetic fields (Appl. Phys. Lett. 99 (5), 051102 (2011)).

In this study we focus on spin relaxation during transport to the active region and spin relaxation in the active region prior to carrier recombination. Using a series of samples with varying injection path length we analyze relaxation during transport, while the ratio of carrier lifetime to spin lifetime determines the degree of polarization of the emission from the device.

HL 48.11 Wed 12:45 EW 201

Hot carrier effects on lateral electron spin diffusion in n-type GaAs — •Tobias Henn, Jan-Henrik Quast, Tobias Kiessling, and Wolfgang Ossau — Physikalisches Institut (EP3) der Universität Würzburg, 97074 Würzburg, Germany

We report on spatially resolved two-color Hanle-MOKE studies of low temperature electron spin diffusion in bulk n-type GaAs. We investigate the influence of lattice temperature and external magnetic fields on the lateral electron spin diffusion for a broad range of donor concentrations covering the insulating and metallic regime.

Our results demonstrate that the commonly used standard drift-diffusion model **[1,2]** is not capable of describing the lateral spin diffusion profiles observed under non-resonant optical spin injection. We find that the non-resonant optical excitation results in a local heating of the electron system with respect to the lattice which persists over length scales comparable to the spin diffusion length. Consideration of this hot carrier effect is demonstrated to be crucial for reliable extraction of spin propagation parameters from optical experiments.

[1] S. A. Crooker and D. L. Smith, PRL, **94** (2005), 236601
[2] M. Furis et al., NJP, **9** (2007), 347

HL 48.12 Wed 13:00 EW 201

Orts- und polarisationsaufgelöste PL-Messungen an Mn-dotiertem GaAs — •Franz Münzhuber[1], Georgy Astakhov[1], Tobias Kiessling[1], Vladimir Korenev[2] und Wolfgang Ossau[1] — [1]Physikalisches Institut (EP3) der Universität Würzburg, 97074 Würzburg, Germany — [2]A. F. Ioffe Physico-Technical Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia

Bei der Beobachtung von Spin-Diffusion in Halbleitern hat man oftmals damit zu kämpfen, dass intrinsische Effekte durch die elektrisch oder optisch induzierten, extrinsischen Ladungsträger überlagert oder verfälscht werden. Eine p-Dotierung führt zu einem rein extrinsischen Elektronensystem, welches aber aufgrund des starken BAP-Mechanismus sehr schnell depolarisiert. Dotiert man GaAs jedoch mit Mangan, können die Löcher mit den Mn-Rümpfen koppeln, so dass die die Relaxationszeit τ_S um bis zu zwei Größenordnungen ($\tau_S > 150$ ns) steigt [1]. In PL-Messungen konnten wir feststellen, dass die an den beiden das Spektrum dominierenden (X und $e - A_{Mn}$) Übergängen beteiligten Elektronen erheblich voneinander abweichende Polarisationsgrade sowie unterschiedliche τ_S besitzen. Diese überraschende Erkenntnis widerspricht der Argumentation von Paget [2], nach der der Spinaustausch zwischen angeregten Elektronen sehr viel schneller als die Rekombination vonstattengeht. Weiterhin lässt sich eine erhebliche Verbreiterung des räumlichen Profils des $e - A_{Mn}$-Übergangs gegenüber dem Profil der Anregung und der Exzitonen erkennen.

[1] G. V. Astakhov et al., PRL **101**, 076602 (2008)
[2] D. Paget, PRB **24**, 3776 (1981)