

## HL 39: Quantum dots: Optical and transport properties

Time: Thursday 9:30–13:00

Location: BEY 81

HL 39.1 Thu 9:30 BEY 81

**Electrical injection of a spin polarized electron into a single quantum dot** — •JIE HUANG<sup>1</sup>, ROBERT ARIANS<sup>1</sup>, JÖRG NANNEN<sup>1</sup>, TILMAR KÜMMELL<sup>1</sup>, JAN WENISCH<sup>2</sup>, KARL BRUNNER<sup>2</sup>, and GERD BACHER<sup>1</sup> — <sup>1</sup>Werkstoffe der Elektrotechnik, Universität Duisburg-Essen — <sup>2</sup>Experimentelle Physik III, Universität Würzburg

The electrical injection of a carrier with a defined spin into a single quantum dot (SQD) is a fundamental step to electrically driven spin devices. By combining a diluted magnetic semiconductor (ZnMnSe) as a highly effective spin source with InAs quantum dots, we demonstrate a spinpolarized SQD emitter.

The structure is designed as a p-i-n diode with self organized InAs quantum dots embedded into the intrinsic GaAs region and with an n-doped ZnMnSe layer, serving as spin aligner. Nanoapertures in the top contact provide access to SQD emission. The device is placed into a magnetic field in Faraday geometry and biased in forward direction. The spin information can now be extracted directly from the circular polarisation degree of the electroluminescence signal of the SQD, where a spin polarized electron from n-ZnMnSe directly recombines with a hole from p-GaAs. At  $U_{bias} = 1.45$  V, we obtain a spin polarisation of nearly 100 % at  $T = 5$  K. We discuss the reduction of spin polarisation with rising temperature and at higher currents, and the possibility of biexciton formation in the SQDs.

HL 39.2 Thu 9:45 BEY 81

**Experimental realization of a spectrally resonant site-controlled quantum dot-micropillar cavity system** — •ALEXANDER HUGGENBERGER, CHRISTIAN SCHNEIDER, TOBIAS HEINDEL, PIA WEINMANN, CAROLINE KISTNER, MARTIN KAMP, STEPHAN REITZENSTEIN, SVEN HÖFLING, and ALFRED FORCHEL — Technische Physik, Universität Würzburg, Germany

We present a technology for the integration of site-controlled InAs quantum dots (QD) into GaAs/AlAs micropillar cavities in a spatially deterministic manner. QD formation at pre-defined positions is forced by patterning nano-holes as nucleation centres. The sample layout enabling the site-controlled growth of the QDs and retrieving them by cross markers for the incorporation into micro-pillars cavities are discussed. A combination of morphological studies like scanning electron microscopy and atomic force microscopy characterization is used to establish a fabrication process to precisely control the QD position for device integration. The emission of single QDs is probed by microPL spectroscopy and reveals clear spectra with single lines. An advanced technique has been developed to improve the optical quality of single site-controlled quantum dots. Vertically stacked but different sized and therefore spectrally detuned site-controlled QD layers have been grown. This allows for the selective interaction between only one single QD emission line and a cavity mode in the cavity quantum electrodynamics regime. By temperature tuning of the QD emission into resonance with the cavity mode an enhanced spontaneous emission is observed, thus demonstrating a site-controlled QD-micropillar cavity system.

HL 39.3 Thu 10:00 BEY 81

**Triggered single-photon source from a single quantum dot on silicon substrate** — •MOHAMED BENYOUCEF<sup>1,2</sup>, HONG SEOK LEE<sup>1</sup>, JULIANE GABEL<sup>1</sup>, ARMANDO RASTELLI<sup>1</sup>, and OLIVER G. SCHMIDT<sup>1</sup> — <sup>1</sup>Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstr. 20, D-01069 Dresden, Germany — <sup>2</sup>Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, D-70569 Stuttgart, Germany

Single quantum emitters have become an emerging area of fundamental research during the last years, driven by the need for nonclassical light sources delivering single-photons on demand for future implementation in the field of quantum information. Most of the work concerning photon statistics has been done on III-V materials such as (In,Ga)As quantum dots (QDs) embedded in GaAs matrix or integrated in microcavities. In contrast to this, only few studies on II-VI compounds have been reported. The short lifetime of II-VI QDs could allow operation at high repetition rates. From the technological point of view it would be desirable to obtain single-photons on demand from single QDs grown on Si(001) substrates. In this work, we report on the observation of triggered single-photon emission from a single CdTe QD

embedded in a ZnTe layer grown on Si(001). The emission wavelength of single dots can be locally tuned in a wide spectral range (more than 8 meV) by means of a focused laser beam. Moreover, we have carried out time-resolved PL measurements to investigate the lifetime of the single CdTe QDs. We find that, the single-photon emission and the lifetime are preserved after energy tuning of the QD emissions.

HL 39.4 Thu 10:15 BEY 81

**Electrically Tunable Single Quantum Dot - Photonic Crystal Nanocavity Systems in the Strong Coupling Regime** — •NORMAN HAUKE, ARNE LAUCHT, FELIX HOFBAUER, GERHARD BÖHM, MARKUS-CHRISTIAN AMANN, and JONATHAN JAMES FINLEY — Walter-Schottky-Institut, Garching, Germany

We present investigations of electrically tunable single quantum dot (QD) - photonic crystal (PC) nanocavity systems, operating in the strong coupling regime. The sample consists of a single layer of  $\text{In}_{0.4}\text{Ga}_{0.6}\text{As}$  self-assembled QDs embedded in the center of a 180nm thick p-i-n GaAs membrane, which is patterned by electron beam lithography and reactive ion etching to form a PC slab with a L3 defect nanocavity. Gold contacts are evaporated for electrical access, thus allowing us to create electric fields in the intrinsic GaAs region. By making use of the quantum confined Stark-effect, we can reversibly tune the optical emission of a single exciton into and out of spectral resonance with a nanocavity mode ( $Q \approx 11000$ ) at  $\approx 1200$  meV.

Optical measurements were performed by using low temperature confocal microscopy. In photoluminescence experiments, we observe a clear anticrossing between exciton and mode emission (vacuum Rabi splitting  $\approx 70$ - $130\mu\text{eV}$ ), which is a signature for strong coupling between emitter and cavity. We further investigated the pump power and temperature dependence of the vacuum Rabi-splitting, showing that dephasing processes destroy the strong interaction for high pump powers or high temperatures.

Supported financially by the DFG via SFB-631 and NIM

15 min. break

HL 39.5 Thu 10:45 BEY 81

**Single mode synchronized precession of electron spins in a quantum dot ensemble** — •STEFAN SPATZEK<sup>1</sup>, ALEX GREILICH<sup>1</sup>, IRINA YOGOVA<sup>2</sup>, ILYA A. AKIMOV<sup>1</sup>, DMITRI R. YAKOVLEV<sup>1</sup>, ALEXANDER L. EFROS<sup>3</sup>, DIRK REUTER<sup>4</sup>, ANDREAS D. WIECK<sup>4</sup>, and MANFRED BAYER<sup>1</sup> — <sup>1</sup>Experimentelle Physik II, Technische Universität Dortmund, 44221 Dortmund, Germany — <sup>2</sup>Institute of Physics, St. Petersburg State University, 198504 St. Petersburg, Russia — <sup>3</sup>Naval Research Laboratory, 20375 Washington DC, USA — <sup>4</sup>Angewandte Festkörperphysik, Ruhr-Universität Bochum, 44780 Bochum, Germany

Optically controlled electron spins in ensembles of quantum dots (QDs) provide an attractive proposal to implement quantum information technologies in a solid-state environment. However inhomogeneities within an ensemble lead to the rapid loss of coherence among the phase of the spins. Electron spin coherence in an inhomogeneous, singly charged (*InGa*)As/*GaAs* ensemble of dots was studied by means of time-resolved Faraday-Rotation technique [1].

The spin of all electrons confined in the dots can be driven into a single precession mode about a magnetic field. This precession regime is reached by allowing only a single mode within the electron spin precession spectrum of the QD ensemble to be synchronized with the excitation train of optical pulses. Under this condition a nuclear induced frequency focusing effect [2] leads to a shift of all spin precession frequencies to the synchronized mode. [1] A. Greilich et al., Science **313**, 341 (2006) [2] A. Greilich et al., Science **317**, 1896 (2007)

HL 39.6 Thu 11:00 BEY 81

**Application of an eight-band  $\mathbf{k} \cdot \mathbf{p}$ -model to study III-nitride semiconductor nanostructures** — •OLIVER MARQUARDT, TILMANN HICKEL, and JÖRG NEUGEBAUER — Max-Planck-Institut für Eisenforschung

The eight band  $\mathbf{k} \cdot \mathbf{p}$ -formalism is a well established continuum approach for investigations of the electrooptical properties of direct band gap material nanostructures. Though being unable to directly describe atomistic effects, in a previous study this approach has been shown

to be in excellent agreement with atomistic methods for III-nitride nanostructures with characteristic dimensions of a few nanometers [1]. We applied our plane-wave implementation of an eight-band  $\mathbf{k} \cdot \mathbf{p}$ -Hamiltonian to study various zero-, one- and two-dimensional nanostructures in the common zincblende and wurtzite crystal structures including effects arising from strain and polarization in order to understand light emission processes in realistic nanostructures. Special attention is paid to the investigation of alloy composition as well as strain and polarization effects on charge carrier localization and binding energies in InGaN/GaN quantum dots and films.

[1]: Marquardt, Mourad, Schulz, Hickel, Czycholl, Neugebauer, Phys. Rev. B, in print (2008)

HL 39.7 Thu 11:15 BEY 81

**Exciton storage in a nano-scale Aharonov-Bohm ring with electric field tuning** — ANDREA M. FISCHER<sup>1</sup>, VALDO L. CAMPO JR.<sup>2</sup>, MIKHAIL E. PORTNOI<sup>3</sup>, and •RUDOLF A. ROEMER<sup>1</sup> — <sup>1</sup>Department of Physics and Centre for Scientific Computing, University of Warwick, Coventry, CV4 7AL, UK — <sup>2</sup>Departamento de Física, Universidade Federal de Sao Carlos-UFSCar, 13565-905 Sao Carlos, SP, Brazil — <sup>3</sup>School of Physics, University of Exeter, Exeter EX4 4QL, UK

We study analytically the optical properties of a simple model for an electron-hole pair on a ring subjected to perpendicular magnetic flux and in-plane electric field [1]. We show how to tune this excitonic system from optically active to optically dark as a function of these external fields. Our results offer a simple mechanism for exciton storage and read-out.

[1] AM Fischer, VL Campo Jr, ME Portnoi, RA Roemer, arXiv:0809.3863

HL 39.8 Thu 11:30 BEY 81

**Coulomb blockade due to lithographically aligned InAs quantum dots in GaAs/AlGaAs constrictions** — •SEBASTIAN GÖPFERT, LUKAS WORSCHCH, DANIELA SPANHEIMER, CHRISTIAN SCHNEIDER, MONIKA EMMERLING, SVEN HÖFLING, and ALFRED FORCHEL — Technische Physik, Universität Würzburg, 97074 Würzburg

By combination of site-controlled growth of InAs quantum dots with an accurate alignment to narrow constrictions defined in a modulation doped GaAs/AlGaAs heterostructures quantum dots with large Coulomb energies were realized. For that purpose, modulation doped GaAs/AlGaAs heterostructures were grown by molecular beam epitaxy. The position of the InAs quantum dots was controlled by defining nanoholes as nucleation centers <sup>1,2</sup>. After regrowth with InAs and a capping, narrow constrictions were etched relative to the site-controlled quantum dots with a position accuracy of 50 nm. The site-controlled InAs quantum dots serve as floating gate, and define electronic quantum dots in the narrow channel. By means of transport measurements single-electron addition energies in the order of 10 meV were observed.

[1]Lateral Alignment of Epitaxial Quantum Dots, edited by O. G. Schmidt, Springer, Berlin, 2007.

[2]C. Schneider, M. Strauß, T. Süner, A. Huggenberger, D. Wiener, S. Reitzenstein, M. Kamp, S. Höfling, A. Forchel, Appl. Phys. Lett. 92, 183101 (2008).

## 15 min. break

HL 39.9 Thu 12:00 BEY 81

**Time-resolved observation of electron tunneling from self-assembled QD using a 2DEG** — •BASTIAN MARQUARDT<sup>1</sup>, MARTIN GELLER<sup>1</sup>, AXEL LORKE<sup>1</sup>, and DIRK REUTER<sup>2</sup> — <sup>1</sup>Experimental Physics & CeNIDE, Universität Duisburg-Essen, Duisburg — <sup>2</sup>Angewandte Festkörperphysik, Ruhr-Universität Bochum, Bochum

We developed a novel technique to probe the tunneling dynamics of quantum dot carriers (QD) into a nearby two-dimensional electron gas (2DEG). This method employs the 2DEG as a detector for the tunneling charge into and out of the InAs-QD-layer. A time-resolved two-terminal resistance measurement allows us to investigate the tunneling times of the emission processes. Furthermore, this new technique allows us to probe samples with very slow tunneling times, in contrast to the commonly used frequency-dependent capacitance-voltage (CV) spectroscopy. The CV-spectroscopy has been proven to be a valuable tool to investigate coupled electron systems with *fast* tunneling times

( $\tau \ll 100$ ms). In the case of weakly coupled QD-2DEG electron systems with extremely slow tunneling times  $\tau > 1$ s, the CV-spectroscopy is not able to probe the tunneling dynamics because of the insufficient  $s/n$ -ratio for low frequencies. Additionally, in contrast to CV-spectroscopy the resistance of a 2DEG is given by its aspect ratio and not its size. This enables us to scale down the sample dimensions to few or even single QDs in the future. On the basis of the measured transients the tunneling times for different applied electrical fields are evaluated. Our technique makes it possible to study non-equilibrium tunneling into excited dot-states.

HL 39.10 Thu 12:15 BEY 81

**Single-parameter quantized charge pumping in magnetic fields** — •CHRISTOPH LEICHT<sup>1</sup>, BERND KAESTNER<sup>1</sup>, VYACHESLAVS KASHCHEYEV<sup>2,3</sup>, KLAUS PIERZ<sup>1</sup>, UWE SIEGNER<sup>1</sup>, and HANS WERNER SCHUMACHER<sup>1</sup> — <sup>1</sup>Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — <sup>2</sup>Institute for Solid State Physics, University of Latvia, Riga LV-1063, Latvia — <sup>3</sup>Faculty of Physics and Mathematics, University of Latvia, Zellu street 8, Riga LV-1002, Latvia

We present a study of high frequency quantized charge pumping through a GaAs/AlGaAs quantum dot in the presence of a perpendicular magnetic field. Application of a frequency signal in the GHz-range to one of two finger gates, crossing a narrow wire and confining a quantum dot, leads to quantized, pumped current plateaus in the gate characteristics. Magnetic fields up to around 6 T considerably enhance the quality and the number of observed current plateaus. A dimensionless quality factor is determined to rate the flatness of the first plateau and to indicate the achievable accuracy for metrological purposes.

HL 39.11 Thu 12:30 BEY 81

**Enhanced performance of a quantum dot based memory device with selective band engineering** — •JOHANNES GELZE<sup>1</sup>, ANDREAS MARENT<sup>1</sup>, TOBIAS NOWOZIN<sup>1</sup>, MARTIN GELLER<sup>2</sup>, and DIETER BIMBERG<sup>1</sup> — <sup>1</sup>Institut für Festkörperphysik, TU-Berlin, Hardenbergstraße 36, 10623 Berlin — <sup>2</sup>Department of Physics and CeNIDE, University of Duisburg-Essen, Lotharstraße 1, 47048 Duisburg

Recently, we have introduced a novel memory concept (QD-Flash) based on self-organized quantum dots (QDs) providing much better performance than nowadays Flash-memory. For InAs/GaAs-QDs we have demonstrated a write time of 6 ns. With an additional Al<sub>0.9</sub>Ga<sub>0.1</sub>As barrier, a hole storage time in InAs/GaAs-QDs of 1.6 s at 300 K were shown. The erase process in the QD-Flash is realized by tunnelling through the confining potential in an electric field. Both, storage time and erase time are determined by the activation energy of the charge carriers. Thus, a trade-off exists between storage time and erase time. To reduce this trade-off, we have investigated the influence of more complex barriers below the QDs by simulating the carrier emission rate, using a WKB-Method. Barriers are designed having a much higher emission rate for a given activation energy than originally used triangular barriers. To confirm these results we studied the influence of Al<sub>0.6</sub>Ga<sub>0.4</sub>As and Al<sub>0.9</sub>Ga<sub>0.1</sub>As barriers on the write/erase times of the QD-Flash by capacitance-voltage measurements. A reduction of the erase time in a good agreement with the simulation was observed, keeping the write time below 10 ns.

HL 39.12 Thu 12:45 BEY 81

**Noninvasive detection of molecular bonds in quantum dots** — •MAXIMILIAN C. ROGGE and ROLF J. HAUG — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover, Germany

We performed charge detection on a lateral triple quantum dot with starlike geometry. The setup allows us to interpret the results in terms of two double quantum dots with one common quantum dot. One double dot features weak tunnel coupling and can be understood with atomlike electronic states, the other one is strongly coupled forming moleculelike states. In nonlinear measurements we identified patterns that can be analyzed in terms of the symmetry of tunneling rates. Those patterns strongly depend on the strength of interdot tunnel coupling and are completely different for atomlike or moleculelike coupled quantum dots allowing the noninvasive detection of molecular bonds.

M. C. Rogge and R. J. Haug, Phys. Rev. B 78, 153310 (2008)

M. C. Rogge and R. J. Haug, Phys. Rev. B 77, 193306 (2008)