HL 12: Quantum dots and wires: Optical properties I

Time: Monday 14:45–18:00 Location: H17

HL 12.1 Mon 14:45 H17

Origin of the excitonic dipole moment in InAs/GaAs Quantum Dots: A Tight-Binding Study — •Alexander Kleinsorge[1], Thomas Hammerscmidt[1], Peter Kratzer[2,1], and Matthias Scheffler[1] — [1]Fritz-Haber-Institut der MPG, Faradayweg 4-6, D-14195 Berlin, Germany — [2]Fachbereich Physik, Universität Duisburg-Essen, D-47048 Duisburg, Germany

With the help of electronic structure calculations, the electronic and optical properties of quantum dots (QDs) can be related to their atomic structure. We employ the empirical sp^3s^* tight-binding approach, including 2nd-nearest-neighbor interactions and spin-orbit coupling, preceded by structural relaxation using a potential of the Abell-Tersoff type. We are able to treat large systems (up to 10^6 atoms, folded-spectrum method). We apply our method to buried InAs QDs in GaAs, comparing different inverted pyramid shapes and composition profiles. Because of the different shape of the electron and hole wavefunctions (WF), the exciton is associated with a dipole moment which causes the experimentally observed Stark shift. We investigate how the relative position of an electron or hole state in a QD depends on its size in different inverted-pyramid shape boundaries. The presence of the wetting layer (WL) is found to affect the localization of the hole WF and thus the magnitude of the dipole moment, and for flat QD (height $<$ 4nm) even its sign. If an inversion of the dipole is observed experimentally for flat quantum dots, we interprete this as indication that the WL below the QD must have been dissolved.

HL 12.2 Mon 15:00 H17

Mode locking of electron spin coherences in singly charged InGaAs/GaAs quantum dots — •Alex Greilich[1], Dmitri Yakovlev[1], Andrew Shabaev[2], Alexander Efros[2], Irina Yugova[1], Ruth Oulton[1], Victorina Stavarache[3], Dirk Reuter[3], Andreas Wieck[3], and Manfred Bayer[1] — [1]Experimentelle Physik II, Universität Dortmund, D-44221 Dortmund, Germany — [2]Naval Research Laboratory, Washington, DC 20375, USA — [3]Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany

We report an optical technique based on time-resolved Faraday rotation measurements of the electron spin dynamics in an ensemble of QDs to recover the coherence time of a single QD. The measured spin coherence time T_2 is 3 microseconds, which is three orders of magnitude longer than the ensemble dephasing time of about 2 nanoseconds. A periodic train of circularly polarized light pulses from a mode-locked laser synchronizes the precession of the spins to the laser repetition rate T_R, transferring the mode-locking into the spin system. This synchronization leads to constructive interference of the electron spin polarization in time. The interference gives also the possibility for all-optical coherent manipulation of spin ensembles: the electron spins can be clocked by two trains of pump pulses with a fixed temporal delay T_D. After this pulse sequence, the QD ensemble shows multiple echo-like Faraday rotation signals with a period equal to the pump pulse separation.

HL 12.3 Mon 15:15 H17

Implementation and application of a $\mathbf{k}\cdot\mathbf{p}$-formalism to study electronic structure and Coulomb matrix elements for semiconductor nanostructures — •Oliver Marquardt, Tilmann Hickel, Blazej Grabowski, Sixten Boeck, and Jörg Neugebauer — Max-Planck Institut für Eisenforschung

In order to theoretically predict optical and electronic properties of semiconductor nanostructures such as quantum dots and wires, the eigenvalues and -states of the electrons and holes as well as the Coulomb interaction elements are needed. In order to investigate the effect of shape, size and material composition of larger nanostructures we employed $\mathbf{k}\cdot\mathbf{p}$ perturbation theory. For this purpose, we have extended our DFT package S/Phi/nX, which was originally developed as a plane wave-pseudopotential code, to calculate $\mathbf{k}\cdot\mathbf{p}$ kinetic energies both for zincblende and wurtzite structures. This strategy allows us to make use of fast minimization routines and the excellent preconditioners available in plane-wave codes as well as an efficient calculation of the Coulomb matrix in reciprocal space. Based on this approach we have studied a wide variety of quantum dots and nano wires with a particular focus on group-III-nitrides in the cubic and wurtzite phase. The results allow a direct interpretation of recent experiments on nitride based quantum dots.

HL 12.4 Mon 15:30 H17

Phonon dephasing in optical control of a single spin in a quantum dot — •Anna Grodecka[1,2], Carsten Weber[1], Paweł Machnikowski[2], and Andreas Knorr[1] — [1]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Institute of Physics, Wrocław University of Technology, Wybrzeze Wyspiańskiego 27, 50-370 Wrocław, Poland

Unique and designable properties of quantum dots together with the availability of fast optical control methods indicate that these systems may be considered as attractive candidates for use as qubits. It is advantageous to store the logical values in spin states of an electron in a quantum dot (due to the long decoherence time) and perform the operations using optical coupling to the charge degrees of freedom (short switching time). However, quantum dots are embedded in a surrounding crystal and the confined carriers interact with phonons, which leads to a loss of coherence.

Within a density matrix approach, we consider the carrier-phonon dynamics in the optical control of a single spin in a quantum dot. Using perturbative methods we study the phonon-induced decoherence accompanying a single qubit gate: an arbitrary rotation between two selected electron spin states performed via spin-flip Raman transitions and virtual excitation of a trion state.

HL 12.5 Mon 15:45 H17

Spin Injection into Single InGaAs Quantum Dots — Mohsen Ghali[1], Tilmar Kümmell[1], •Robert Arians[1], Gerd Bacher[1], Jan Wenisch[2], Suddhasatta Mahapatra[2], and Karl Brunner[2] — [1]Werkstoffe der Elektrotechnik, Universität Duisburg-Essen, Bismarckstraße 81, 47057 Duisburg — [2]Experimentelle Physik III, Universität Würzburg, Am Hubland, 97074 Würzburg

Single quantum dots are highly interesting candidates for potential spin-based devices. In order to implement a technology that utilizes the spin as an information carrier, one needs to initialize, store and detect a single spin. While diluted magnetic semiconductors like ZnMnSe have been proven to be an efficient source of spin polarized carriers, InAs-based quantum dots provide high spin stability with relaxation times up to milliseconds.

Using magneto-micro photoluminescence experiments, we found an efficient spin injection from a n-ZnMnSe layer into an InAs single quantum dot (SQD) in a p-i-n diode structure resulting in a circular polarization degree of up to 60% at B=5T. In contrast, no polarized light emission due to spin injection was obtained in an undoped reference structure. Furthermore, a pronounced dependence of the spin injection efficiency on the external bias is found resulting in a strong decrease of the SQD circular polarization degree when external biasing is applied in the forward direction. The experiments emphasize the impact of excess energy and current flow on the spin injection efficiency in a SQD.

HL 12.6 Mon 16:00 H17

Colloidal Quantum Dots in High-Q Pillar Microcavities — •Verena Kohnle[1], Matthias Kahl[1], Tim Thomay[1], Katja Beha[1], Jörg Merlein[1], Matthias Hagner[1], Andreas Halm[1], Alfred Leitenstorfer[1], Rudolf Bratschitsch[1], Jan Ziegler[2], Thomas Nann[2], Yuri Fedutik[3], Mikhail Artemyev[3], Ulrike Woggon[3], and Fabian Pérez-Willard[4] — [1]Fachbereich für Physik, Centrum für angewandte Photonik, Universität Konstanz, Konstanz, Germany — [2]School of Chemical Sciences and Pharmacy, University of East Anglia, Norwich, UK — [3]Experimentelle Physik IIb, Universität Dortmund, Dortmund, Germany — [4]DFG Center for Functional Nanostructures, Universität Karlsruhe, Karlsruhe, Germany

We have fabricated high-Q pillar resonators with colloidal CdSe/ZnS quantum dots or rods as light emitters by focused ion beam (FIB) milling. First, a planar dielectric cavity is formed by two Bragg mirrors, each consisting of sputtered pairs of alternating TiO2 and SiO2 layers. Subsequently, micropillar waveguides with diameters in the range from 5100 nm down to 610 nm are cut out of the planar resonator via FIB. Photoluminescence measurements of quantum dots in the resonator show a blue shift of the fundamental cavity mode with decreasing pillar diameter. This result demonstrates the presence of three-dimensional light confinement. The spectral position of the observed cavity modes may be calculated by modeling the pillar resonator as a waveguide with an effective refractive index. The theoretical results are in excellent agreement with the experimentally observed pillar mode patterns and frequencies.

15 min. break

HL 12.7 Mon 16:30 H17

A Gallium Nitride Single-Photon Source Operating at 200 K — •Stephan Götzinger[1], Charles Santori[1], Yoshihisa Yamamoto[1], Satoshi Kako[2], Katsuyuki Hoshino[2], and Yasuhiko Arakawa[2] — [1]E. L. Ginzton Laboratory, Stanford University, Stanford, California 94305, U.S.A. — [2]Institute of Industrial Science, University of Tokyo, 4-6-1 Komaba, Meguro-ku. Tokyo,153-8505, Japan

Nitride semiconductors have emerged as important materials for blue and ultraviolet light-emitting diodes with numerous commercial applications. However, their large bandgaps make these materials also interesting for quantum information applications, such as quantum cryptography.

We report on a single-photon source based on a gallium nitride semiconductor quantum dot emitting at a record-short wavelength of 355nm. The power dependence of the second order coherence function suggests a two-level model for photon antibunching, where the antibunching timescale converges to the exciton decay time in the weak-excitation limit. This is supported by fluorescence lifetime measurements on single quantum dots. In temperature dependent measurements, photon antibunching was observed up to 200K, a temperature easily reachable with thermo-electric cooling [1].

[1] S. Kako et. al., Nature Materials 5, 887 (2006).

HL 12.8 Mon 16:45 H17

Single quantum dot lasing effects in high quality AlAs/GaAs micropillar cavities — •Carolin Hofmann[1], Stephan Reitzenstein[1], Steffen Münch[1], Andreas Löffler[1], Martin Kamp[1], Anatoli Bazhenov[1,2], Alexander Gorbunov[1,2], Vladimir Kulakovski[1,2], and Alfred Forchel[1] — [1]Technische Physik, Universität Würzburg, Würzburg, Germany — [2]Institute for Solid State Physics, Russian Academy of Science, Chernogolovka, Russia

We report on lasing effects based on individual quantum dots (QDs) in optically pumped high-Q micropillar laser-structures. The laser-structures are based on planar GaAs/AlAs microcavities with a low density layer of InGaAs QDs embedded as active material in the center of a λ-cavity. Lasing associated with ultra-high spontaneous coupling factors is identified by the change of a linear to a superlinear input-output characteristic at the transition from spontaneous emission to laser operation. We will show that laser characteristics such as threshold pump power are strongly influenced by the gain-contribution of single QDs. In particular, the threshold pump power can be controlled by the spectral detuning between a single QD and the lasing mode with a lowering of the threshold power when the QD is brought on resonance. The single dot influence is confirmed by photon correlation experiments which show a transition from antibunching with $g^{(2)}(0) = 0.36$ at low excitation powers to $g^{(2)}(0) = 1$ at about 4 times the threshold power in the on-resonance case.

HL 12.9 Mon 17:00 H17

Dephasing of the Nonlinear Optical Spin Dynamics in Doped Semiconductor Quantum Dots — •Carsten Weber[1], Anna Grodecka[1,2], Paweł Machnikowski[2], and Andreas Knorr[1] — [1]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin — [2]Institute of Physics, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

An understanding of the dephasing processes of the states involved in spin optical control schemes is essential for applications in quantum information theory and spintronics. We study the phonon-induced decoherence effects on the nonlinear dynamics and pump-probe spectra of a doped semiconductor quantum dot used for optical control of a spin, using density-matrix theory. While the consideration of the Coulomb coupling is exact, the electron-phonon interaction is treated perturbatively for low temperatures. The mediation between the two electronic spin states is achieved via the excitation of a trion state which interacts with the environment.

HL 12.10 Mon 17:15 H17

Coulomb corrections to group velocity slow-down in quantum-dot quantum coherence — •Stephan Michael[1], Hans Christian Schneider[1], and Weng Wah Chow[2] — [1]Physics Department, Kaiserslautern University, P.O. Box 3049, 67653 Kaiserslautern, Germany — [2]Sandia National Laboratories, Albuquerque, NM 87185-1086

Coherent effects such as electromagnetically induced transparency (EIT) and amplification without inversion (AWI) are well known in atomic few-level systems. This talk presents theoretical results on the realization of EIT and group-velocity slowdown in self organized quantum-dot systems. Many-particle effects introduce differences to the independent-particle treatment typically used for describing atomic quantum coherence. In particular, Hartree-Fock renormalizations can lead to over two orders of magnitude reduction in the predicted pump-intensity requirement for group-velocity slowdown. Results are presented for the slow-down factor and slow-down-bandwidth product in a pulsed InGaAs-GaAs quantum-dot lambda scheme, and the influence of light propagation effects is also briefly discussed.

HL 12.11 Mon 17:30 H17

Exciton Aharonov-Bohm Effect and Emission Kinetics in Non-circular Nanorings — •Michal Grochol, Frank Grosse, and Roland Zimmermann — Institut für Physik der Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany

The exciton Aharonov-Bohm effect (X-ABE), an oscillatory component in the energy with magnetic field, has been studied recently in semiconductor quantum dots [1] and nanorings of type I and II [2]. The close relation between X-ABE and exciton persistent current induced by the optical excitation has been revealed. Moreover, the exciton emission kinetics, even though within a simplified model [3], has been investigated and limitations for the observability of X-ABE in circular nanorings have been found. Here we present calculations of the absorption and photoluminesce spectra, and wave functions for a non-circular nanoring having only one symmetry axis. It is shown that lowering the circular symmetry weakens X-ABE in general. However, if the asymmetry is small the observability of the X-ABE can be improved substantially accompanied by a change of the oscillation period compared to the circular case. This model represents a further step towards more realistic description of nanorings.

[1] M. Grochol, F. Grosse, and R. Zimmermann, Phys. Stat. Sol. (C) **3**, 2518 (2006)

[2] M. Grochol, F. Grosse, and R. Zimmermann, Phys. Rev. B, **74**, 115416 (2006).

[3] M. Grochol, F. Grosse, and R. Zimmermann, Phys. Stat. Sol (B) **243**, 3834 (2006)

HL 12.12 Mon 17:45 H17

Phonons in semiconductor nanostructures — •Andreas Knittel and Frank Grosse — Institut für Physik der Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany

Phonons in semiconductor nanostructures like quantum dots affect the dephasing of optical excitations decisively. In our presented work, the inhomogeneous, atomistic nature of the problem is simulated by employing a valence-force field description. The parameters are taken either directly from experiment or are calculated by density functional theory. The investigated structures include quantum dots of different shapes and alloy compositions. They consist of compounds with either zincblende or wurtzite crystal structure, therefore capturing the equilibrium structures of III-V and group III-nitrides. The phonon density of states is determined by calculating the velocity correlation function in a molecular dynamics simulation. We present also a comparison to continuum elasticity solutions of the wave equation for acoustical phonons.