HL 29: Quantum dots: Optical properties II

Time: Wednesday 9:30–13:00 Location: BEY 154

HL 29.1 Wed 9:30 BEY 154

Multiparticle Calculations for Single GaN/AlN Quantum Dots - Results and Comparison — •Gerald Hönig, Momme Winkelnkemper, Andrei Schliwa, and Dieter Bimberg — Institut für Festkörperphysik, Technische Universität Berlin, D-10623 Berlin, Germany

Despite tremendous advances in single quantum dot (QD) spectroscopy of GaN/AlN QDs, many of their properties, especially the Coulomb-interactions in multiparticle-systems, are only poorly understood. In this theoretical work we investigate different calculation methods for such interactions based on 8-band-kp theory.

Configuration-interaction (CI) calculations for this QD-system fail due to an insufficient basis size, which is limited by the computational expense. Self-consistent calculations within the Hartree-approximation have been performed, neglecting exchange- and correlation-effects. Different approaches (e.g. local density based approximations) are used to include these effects, correcting the Hartree-energies of excitons, trions, biexcitons confined in QDs with different structural properties and giving more realistic results for recombination energies. We will report our results and compare the different methods.

HL 29.2 Wed 9:45 BEY 154

Demonstration of strong coupling via electro-optical tuning in high quality QD-micropillar systems — •Caroline Kistner, Tobias Heindel, Christian Schneider, Arash Rahimi-Iman, Stephan Reitzenstein, Sven Höfling, and Alfred Forchel — Technische Physik, Physikalisches Institut, Universität Würzburg, Am Hubland, D-97074 Würzburg

The investigation of cavity quantum electrodynamics effects such as strong coupling in optically pumped QD-microcavity systems has become an active area of research in recent years. Up to now, most of the experiments employed a temperature change of the sample in order to tune a QD exciton line through resonance with the cavity mode. This limits the tuning speed to the range from kHz to MHz due to the thermal relaxation time of the structures. Recent progress in the fabrication of electrically contacted micropillar cavities enabled us to develop a reversible and fast electro-optical resonance tuning technique. Electro-optical tuning exploits the quantum confined Stark effect (QCSE) and paves the way for fast optical switches operating in the GHz range. Making use of the QCSE we tuned a QD emission line through resonance with a high quality (Q) cavity mode (Q=14,000) by applying a reverse bias to the p-i-n structure and observed of strong coupling associated with a vacuum Rabi-Splitting of 63 μeV.

HL 29.3 Wed 10:00 BEY 154

Phonon-assisted tunneling in two-electron quantum dot molecules — •Anna Grodecka[1], Paweł Machnikowski[2], and Jens Förstner[1] — [1]Computational Nanophotonics Group, Theoretical Physics, University Paderborn, Paderborn, Germany — [2]Institute of Physics, Wrocław University of Technology, Wrocław, Poland

Spin states of two-electron doped quantum dot molecules (QDMs) have been employed in many quantum logical gates proposals where tunneling processes play a crucial role. Therefore, their timescales and efficiency are of primary importance. In this work, phonon-assisted tunneling in a lateral two-electron QDM is studied theoretically [1]. The phonon and Coulomb interactions are simultaneously incorporated. We take into account interaction with acoustic phonons via deformation potential and piezoelectric coupling and show that the latter can be even the dominant contribution. The phonon-assisted tunneling rates calculated for GaAs QDMs reach values (up to 160/ns) many orders of magnitude higher than the other decoherence processes resulting from spin-orbit or hyperfine interaction, thus can play a dominant role in QDM-based quantum gates.

1. A. Grodecka, P. Machnikowski, and J. Förstner, Phys. Rev. B 78, 085302 (2008).

HL 29.4 Wed 10:15 BEY 154

The Influence of Fröhlich-Coupling on Rabi-Oscillations in Semiconductor Quantum Dots — •Kolja Schuh, Jan Seebeck, Paul Gartner, and Frank Jahnke — Institute for Theoretical Physics, University of Bremen, Germany

Rabi-oscillations can be used to switch occupations in a well-defined way and therefore are considered for application in optical switches. Particularly quantum dots have been regarded as possible candidates. The influence of dephasing due to electron-LA-phonon interaction in semiconductor quantum dots was shown in Ref. [1]. In addition to dephasing, this contribution focuses on the influence of scattering processes due to electron-LO-phonon-interaction.

We use a quantum-kinetic many-body theory, where carriers are described as polarons [2]. For quantum-dot states the effective coupling is enhanced, so that there are strong dephasing as well as fast carrier scattering processes even for semiconductors with weak polar coupling. We find that the particle scattering is of particular importance for the switching behaviour as the carrier distribution changes even in the absence of an optical pulse.

[1] J. Förstner et al., Phys. Rev. Lett. 91, 127401 (2003).
[2] J. Seebeck et al., Phys. Rev. B 71, 125327 (2005).

15 min. break

HL 29.5 Wed 10:45 BEY 154

Influence of phonon confinement on optical and current spectra in nanowire-based quantum dots — •Carsten Weber and Andreas Wacker — Mathematical Physics, Lund University, Box 118, 221 00 Lund, Sweden

Recent progress in the growth of nanowire heterostructures allows the study of quantum dots embedded in semiconductor nanowires. Here, we investigate the influence of the reduced dimensionality of the quantized phonon modes on the electron-phonon coupling and compare it to the interaction with bulk phonons. In the optical spectrum, this is reflected in the form of discrete side peaks of the excitonic transition and a zero-phonon line broadening, where both the deformation potential and the piezoelectric coupling are important for different types of phonon modes. In transport signals, discrete characteristics found in the current spectra through double dot systems may be explained by the one-dimensional density of states of the phonons. We present theoretical results of electron-phonon coupling in nanowire-based quantum dots in optical and current spectra.

HL 29.6 Wed 11:00 BEY 154

Time-resolved μ-photoluminesence investigations of group-III-nitride quantum dots — •Thomas Switaiski, Stefan Werner, Erik Stock, Momme Winkelnkemper, Axel Hoffmann, and Dieter Bimberg — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstrasse 36, 10623 Berlin

Small fluctuations in size, shape and composition of self-organized quantum dots (QDs) strongly effect the decay times of localized excitonic transitions. Here, we present time and spatially resolved photoluminesence measurements of single InGaN/GaN QDs. The sample is excited with the second harmonic of a modelocked and tuneable Ti:Sapphire laser through a metallic shadow mask, which improves the lateral resolution and allowing spectroscopy of single QDs. Using eight-band $\boldsymbol{k}\cdot\boldsymbol{p}$ modelling, we show that the built-in piezo- and pyroelectric fields within the QDs cause a sensitive dependence of the radiative lifetimes of the exact QD geometry and composition. Moreover, the radiative lifetimes also depend strongly on the composition of the direct surrounding of the QDs.

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Resonant Raman and resonant photoluminescence spectroscopy on quantum-dot helium — •Tim Köppen[1], Dennis Franz[1], Andreas Schramm[2], Christian Heyn[1], Detlef Heitmann[1], and Tobias Kipp[1] — [1]Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg, Germany — [2]Optoelectronics Research Center, Tampere University of Technology, Finland

We investigate electronic excitations in InGaAs quantum dots containing two electrons, also called artificial quantum-dot helium, by resonant optical spectroscopy in magnetic fields. In order to match the quantum dot ground state transition energy to both the sensitivity range of our detector and the emission energy range of our laser we rapidly thermally annealed the samples. The occupation of the quantum dots with electrons can be precisely controlled and monitored by applying a voltage between a back contact and a gate of our sample and by measuring the capacitance. The quantum-dot helium is the most fundamental system to investigate many-particle effects induced by Coulomb interaction. We observe optical transitions in the quantum dots provoked by resonant Raman and resonant photoluminescence spectroscopy.

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HL 29.8 Wed 11:30 BEY 154

Low threshold lasing in electrically pumped high-Q quantum dot-micropillar cavities — •Tobias Heindel, Caroline Kistner, Arash Rahimi-Iman, Christian Schneider, Sven Höfling, Stephan Reitzenstein, and Alfred Forchel — Technische Physik, Physikalisches Institut, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

High-Q semiconductor microcavities are very attractive structures for the study of low threshold lasing with quantum dot (QD) gain media. Exploiting cavity quantum electrodynamics (cQED) effects these structures are good candidates for a thresholdless laser as they feature a large fraction β of spontaneous emission coupled into the lasing mode. So far, most of the studies on microcavity lasers have focussed on lasing in optically pumped QD-microcavity systems. However, in light of an ultimate thresholdless microcavity laser, it is crucial to combine pronounced cQED effects with the possibility of electrically pumping the active medium.

We report on low threshold lasing in high-Q electrically pumped QD-micropillar cavities. Lasing action associated with threshold currents as low as 8 μA at 10 K is observed for micropillar lasers with quality factors exceeding 10.000. An optimized contact scheme allows us to observe lasing for pillar structures with diameters as small as 1.5 μm, containing on average less than 100 quantum dots as gain medium. Photon autocorrelation studies reveal pronounced photon bunching near threshold as a clear signature for the transition from spontaneous to stimulated emission.

15 min. break

HL 29.9 Wed 12:00 BEY 154

Electric field tunable polarization and enhanced single-photon emission from lateral quantum dot molecules embedded in a planar microcavity — •Marcus Witzany[1], Claus Hermannstädter[1], Matthias Heldmaier[1], Gareth J. Beirne[1,4], Wolfgang-Michael Schulz[1], Marcus Eichfelder[1], Robert Rossbach[1], Michael Jetter[1], Lijuan Wang[2], Armando Rastelli[3], Oliver G. Schmidt[3], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Allmadring 3, 70569 Stuttgart — [2]Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, 70569 Stuttgart — [3]Institut für Integrative Nanowissenschaften, IFW Dresden, Helmholtzstr. 20, 01069 Dresden — [4]now: Cavendish Laboratories, University of Cambridge, J.J. Thomson Ave., Cambridge, CB3 0HE, UK

The photoluminescence (PL) from single InGaAs quantum dot molecules (QDMs) embedded in a planar micro-cavity grown using a combination of metal-organic vapor phase and molecular beam epitaxy has been examined. We demonstrate that embedding the QDM in a planar micro-cavity increases the single-photon extraction efficiency by a factor of 30. The molecules consist of two quantum dots coupled along the [1-10] crystal direction via electron tunneling [PRL 96, 137401, 2006]. The QDM PL is found to be linearly polarized along [1-10] with different polarization anisotropy values between 0 - 40% depending on the QDM geometry and coupling. Applying an electric field along the coupling axis can enhance the linear polarization of the PL due to electron wave function elongation.

HL 29.10 Wed 12:15 BEY 154

Nanocrystal Quantum Dots as Emitters in DBR Microcavities — •Johannes Haase[1], Tobias Otto[2], Maik Langner[1], Dirk Dorfs[2], Hartmut Fröb[1], Alexander Eychmüller[2], and Karl Leo[1] — [1]TU Dresden, Institut für Angewandte Photophysik, George-Bähr-Str. 1, 01069 Dresden — [2]TU Dresden, Physikalische Chemie und Elektrochemie, Bergstr. 66b, 01062 Dresden

Semiconductor nanocrystal quantum dots (NQD) have the outstanding property to emit photons of a wavelength depending on their physical size as a result of the quantum confinement. They are therefore spectral tunable emitters and furthermore exhibit very high quantum yields. For organic microcavity lasers or organic photonic boxes they can be used as alternative emitters or secondary emitters being coupled to the emission of the organic molecules. In our experiments, we use colloidal synthesized CdSe(core)/CdS(shell) rods, where the absorption edge is more blue shifted, with respect to the emission line, than for particles without shell. We incorporate these particles into transparent, thermally stable matrices with a high concentration of the NQDs. By varying the film thickness and changing the refractive index of the material by the amount of NQDs in the matrix material, we can modify the resonance conditions of the cavity to match the peak emission of the NQDs. We present emission spectra from micro-photoluminescence measurements.

HL 29.11 Wed 12:30 BEY 154

All optical spin storage and readout in a single quantum dot — Dominik Heiss, Vase Jovanov, Florian Klotz, •Daniel Rudolph, Max Bichler, Martin S. Brandt, Gerhard Abstreiter, and Jonathan J. Finley — Walter Schottky Institut, Am Coulombwall 3, 85748 Garching, Germany

We propose an all optical spin readout method for single quantum dots (QDs) and demonstrate its feasibility. Our method involves using a voltage switchable QD spin memory structure that can be switched between two modes of operation: (i) charging, where optically generated holes are removed from the dot whilst electrons remain stored and (ii) readout, where optically generated carriers recombine to produce luminescence. The spin projection of a electron prepared using circularly polarized light during the charging phase of the measurement can be tested via a polarization conditional absorption of a second laser pulse tuned to the X- transition. This readout pulse converts the spin information of the resident electron into a charge occupancy (1e or 2e), which can then be repeatedly sampled during the readout phase of the measurement. The charging and discharging dynamics are probed using time dependent measurements to measure the tunneling escape time of the electron and hole. Furthermore, first measurements in magnetic fields (B=10 T) show indications of spin blockade during attempts to charge the dot with the second electron. This blockade can be lifted by delaying the 2e charging pulse by times longer than the electron spin relaxation time (T1~40 us).

HL 29.12 Wed 12:45 BEY 154

Optical spin control in charged quantum dots with a single Mn atom — •Giselmar Hemmert[1], Doris E. Reiter[1], Vollrath Martin Axt[2], and Tilmann Kuhn[1] — [1]Institut für Festkörpertheorie, WWU Münster, Wilhelm-Klemm-Str. 10, 48149 Münster — [2]Institut für Theoretische Physik III, Universität Bayreuth, 95440 Bayreuth

In semiconductor quantum dots spins bear good prospects as basic elements for new quantum hardware such as quantum bits. In a single quantum dot containing a single Mn atom charged by an electron (hole) the excitation by laser light causes the formation of a trion complex, i.e. a positively or negatively charged exciton. The trion spin, like the carrier spin in the non-excited state, is coupled to the Mn spin via the exchange interaction. This coupling allows for the manipulation of the optically not directly accessible Mn spin via spin flip processes of either the electron (hole) or the trion and thus ultimately for the manipulation of the Mn spin by laser light. We consider a charged CdTe quantum dot doped with a single Mn atom and focus on electron and light hole processes as heavy holes do not induce spin flips. Starting from a well defined initial state we show that the six Mn spin states can be set by a series of ultrashort laser pulses. Thus besides the electron (hole)/trion spin also the Mn spin may be used as a basis for controlled operations in the field of spintronics.