HL 52 Quantum dots and wires: Optical properties IV

Time: Friday 11:00–14:00 Room: POT 151

HL 52.1 Fri 11:00 POT 151

Optical absorption and gain of Quantum Dots - Influence of Coulomb and carrier-phonon correlations — •Michael Lorke, Jan Seebeck, Torben R. Nielsen, Paul Gartner, and Frank Jahnke — Institute for Theoretical Physics, University of Bremen

In recent years, semiconductor quantum dots have been studied extensively due to possible applications in optoelectronic devices like LEDs or lasers. An important ingredient for the modeling of these devices as well as for practical applications is the knowledge of dephasing processes. They determine the homogeneous linewidth of the quantum dot resonances and limit the coherence properties of quantum dot lasers.

We use a microscopic theory to to study the optical absorption and gain properties of semiconductor quantum dot systems. The excitation-induced dephasing and the line-shifts of the quantum dot resonances are determined from a quantum kinetic treatment of correlation processes which includes non-Markovian effects due to Coulomb and carrier-phonon interaction. A special focus of these investigations is the clarification of the importance of various scattering channels due to the Coulomb interaction.

We observe a pronounced damping of the quantum dot resonances accompanied by strong line-shifts with increasing carrier density. Our results are compared to recent photoluminescence spectroscopy measurements of single QDs in which linewidths of several meV at room temperature are found.

HL 52.2 Fri 11:15 POT 151

Co-dependence of electron and nuclear spin systems and ultra-long spin lifetimes in self-assembled QDs — •Ruth Oulton[1], A. Greilich[1], S. Verbin[1,2], R.V Cherbunin[1,2], I.V. Ignatiev[1,2], D.R. Yakovlev[1], M. Bayer[1], I. Merkulov[3], V. Stavarache[4], D. Reuter[4], and A. Wieck[4] — [1]Experimentelle Physik II, Universität Dortmund, 44221 Dortmund, Germany — [2]Institute of Physics, St.Petersburg State University, St.Petersburg, Russia — [3]A.F. Ioffe Physico-Technical Institute, RAS, St.Petersburg, 194021, Russia — [4]Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

The hyperfine interaction between electrons and randomly orientated nuclei in QDs is predicted to lead to fast electron spin decoherence over a timescale of nanoseconds. An aligned nuclear and electron spin system, however, is predicted to be ultra-stable, with spin lifetimes much larger than that of either the electron or the nuclei in isolation. We demonstrate an accumulation of PL polarization and subsequent preservation of spin memory in n-doped QDs over a millisecond timescale, indicative of a strong co-dependence of the resident electron and nuclear spins. Application of small (10 -100microT) external fields demonstrate that the weak effective electronic magnetic field on the nuclei is the key to achieving and maintaining the co-aligned system.

HL 52.3 Fri 11:30 POT 151

Direct Observation of Inter-level Phonon Relaxation in Individual Quantum Dot Molecules — •T. Nakaoka[1,2], H. J. Krenner[1], E. C. Clark[1], M. Sabathil[1], M. Bichler[1], Y. Arakawa[2], G. Abstreiter[1], and J. J. Finley[1] — [1]Walter Schottky Institut and Physik Department, Technische Universität München, Am Coulombwall 3, D-85748 Garching, Germany — [2]RCAST, University of Tokyo, 4-6-1, Komaba, Meguro-ku, Tokyo, 153-8505, Japan

We present an optical study of relaxation between tunnel coupled excitonic states in individual self-assembled InGaAs/GaAs QD-molecules embedded in Schottky photodiodes. Radiative lifetimes and temperature evolution of the emission intensities of the coupled states are probed close to the point of maximum coupling. The interdot coupling ($2E$) is tuned by detuning (Δ) away from the anticrossing [$E_{direct} - E_{indirect} = (\Delta^2 + (2E)^2)^{1/2}$] using static electric field perturbations. The results obtained clearly demonstrate that the radiative lifetimes of the coupled excitonic states can be tuned from $\tau = 0.3$ ns to 1.3 ns, as the fraction of direct character of the exciton wavefunction is varied. Furthermore, close to the anticrossing ($\Delta \sim 0$) where the electron component of the wavefunction hybridizes into symmetric and antisymmetric orbitals, the lifetimes of both transitions tend to the same value confirming the fully mixed nature of the states. Temperature dependent measurements demonstrate that relaxation from the antibonding to bonding state can occur during the radiative lifetime. Analysis of the temperature dependent data indicates that such inter-level relaxation proceeds over timescales faster than ~ 100 ps for $2E = 3.1$ meV mediated by acoustic phonon scattering.

HL 52.4 Fri 11:45 POT 151

Optical control of spin coherence in singly charged (In,Ga)As/GaAs quantum dots — •Alex Greilich[1], R. Oulton[1], E.A. Zhukov[1], I.A. Yugova[1], D.R. Yakovlev[1,2], M. Bayer[1], A. Shabaev[3], Al.L. Efros[3], I.A. Merkulov[2], V. Stavarache[4], D. Reuter[4], and A. Wieck[4] — [1]Experimentelle Physik II, Universität Dortmund, D-44221, Germany — [2]A.F. Ioffe Physico-Technical Institute, RAS, St. Petersburg, 194021, Russia — [3]Naval Research Laboratory, Washington, DC 20375, USA — [4]Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany

Electron spin coherence has been studied in n-type modulation doped (In,Ga)As/GaAs quantum dots (QDs) which contain on average a single electron per dot. The coherence arises from resonant excitation of the QDs by circularly polarized picosecond laser pulses, creating a coherent superposition of an electron and a trion state. Time dependent Faraday rotation is used to probe the spin precession of the optically oriented electrons about a transverse magnetic field. Spin coherence generation can be controlled by the pulse intensity, being most efficient for $(2n+1)\pi$ pulses.

HL 52.5 Fri 12:00 POT 151

Tailored quantum dots for entangled photon pair creation — •Thorsten Berstermann[1], Alex Greilich[1], Matthias Schwaab[1], Thomas Auer[1], Ruth Oulton[1], Dimitri Yakovlev[1], Manfred Bayer[1], Victorina Stavarache[2], Dirk Reuter[2], and Andreas Wieck[2] — [1]Experimentelle Physik 2, Universität Dortmund, D-44221 Dortmund, Germany — [2]Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany

Entangled photon pairs from quantum dots (QD) are the key requirement for quantum-cryptography and quantum teleportation [1]. Lowering the symmetry of a QD leads to an asymmetry-induced exchange splitting δ between the two bright exciton energy levels. In order to obtain polarization entangled photon pairs from the biexciton radiative decay cascade, this splitting should be smaller than the homogeneous linewidth γ of each level. In this talk we compare the asymmetry-induced exchange splitting δ of the bright-exciton ground-state doublet in self-assembled (In,Ga)As/GaAs quantum dots, determined by Faraday rotation with its homogeneous linewidth γ, obtained from the radiative decay in time-resolved photoluminescence and differential transmission. Post-growth thermal annealing of the dot structures leads to a considerable increase of the homogeneous linewidth, while a strong reduction of the exchange splitting is simultaneously observed. The annealing can be tailored such that the asymmetry-induced exchange splitting becomes even smaller than the homogeneous linewidth.

[1]D.Bouwmeester, A.Ekert, A.Zeilinger, The Physics of Quantum Information, Springer, Berlin(2000)

HL 52.6 Fri 12:15 POT 151

Systematic size-dependence of anisotropic exchange interaction in InAs/GaAs quantum dots — •Robert Seguin, Sven Rodt, Andrei Schliwa, Konstantin Pötschke, Udo W. Pohl, and Dieter Bimberg — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

A comprehensive study of the exchange interaction of charge carriers in self-organized InAs/GaAs quantum dots (QDs) is presented. Single QDs are examined by means of cathodoluminescence applying metallic shadow masks. The spectra reveal a systematic dependence of the anisotropic exchange interaction on QD size.

The exchange interaction in nanostructures has been subject of a lively debate in recent years. Its anisotropic part governs the excitonic fine-structure splitting (fss), the key parameter determining the suitability of QDs for quantum cryptography, and the degree of polarization of excited charged excitons (trions) in QDs. While the number of participating particles varies between two (excitons) and three (trions), the underlying physical effect is the same. We show that the magnitude of the excitonic fss and the degree of polarization of excited trions are indeed correlated.

They both increase with decreasing exciton recombination energy and thus increasing with quantum dot size.

HL 52.7 Fri 12:30 POT 151

Demonstration of intrinsic non-exponential quantum dot emission dynamics due to reduced electron-hole correlation — •Thomas Auer[1], Matthias Schwab[1], Manfred Bayer[1], Thorsten Berstermann[1], Jan Wiersig[2], Norman Baer[2], Christopher Gies[2], Frank Jahnke[2], Viktorina Stavarache[3], Dirk Reuter[3], and Andreas Wieck[3] — [1]Experimentelle Physik II, Universität Dortmund, 44221 Dortmund — [2]Institut für Theoretische Physik, Universität Bremen, 28334 Bremen — [3]Angewandte Festkörperphysik, Ruhr-Universität Bochum, 44780 Bochum

The emission dynamics of self-assembled quantum dots has been studied using time-resolved photoluminescence (TRPL) spectroscopy. Quantum dot emission dynamics are normally described using the picture of quantum dots as two-level systems, where electron-hole-pairs are fully correlated, resulting in a predicted exponential decrease of the emission. Non-exponential decay of the TRPL has been reported in the literature, but is normally attributed to various factors, such as dark excitons or ensemble variations. However our calculations show that reduction of e-h pair correlation leads to intrinsically non-exponential dynamics. In agreement with these calculations, our measurements of the radiative exciton decay clearly show a non-exponential behaviour with non-resonant excitation. A study of the temperature dependence of the decay and comparison with measurements on n-doped quantum dots reveal the intrinsic nature of the non-exponentiality. By exciting resonantly, a fully correlated two-level system may be prepared which displays an exponential decay as expected.

HL 52.8 Fri 12:45 POT 151

Quantum light emission of two lateral tunnel-coupled InGaAs/GaAs quantum dots controlled by a tunable static electric field — •Claus Hermannstädter[1], Gareth J. Beirne[1], Lijuan Wang[2], Armando Rastelli[2], Oliver G. Schmidt[2], and Peter Michler[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Max-Planck Institut für Festkörperforschung, Heisenbergstr. 1, 70569 Stuttgart, Germany

We present the observation of lateral quantum coupling between two self-assembled InGaAs/GaAs quantum dots (QDs). Each single lateral quantum dot molecule (QDM) exhibits a distinctive photoluminescence spectrum consisting of neutral and charged excitonic, as well as biexcitonic emission. Photon statistics measurements between the dominant emission lines display strong antibunching, confirming the presence of quantum coupling within the QDM, and cascaded emission between corresponding biexcitonic and excitonic emission. We also show that the coupling can be controlled using a static electric field, and that the relative intensities of the two neutral excitonic transitions can be reversibly switched between the two emission energies. Subsequently, the QDM can be used as a tunable single-photon emitter simply by applying a small electric field.

HL 52.9 Fri 13:00 POT 151

Optically Probing Hole Spin Dynamics in InGaAs Quantum Dots — •Stefan Schaeck, Dominik Heiss, Miro Kroutvar, Max Bichler, Dieter Schuh, Gerhard Abstreiter, and Jonathan J. Finley — Walter Schottky Institut, Am Coulombwall 3, 85748 Garching, Germany

Recently, we presented an optically driven spin memory device that enables selective generation, storage and readout of single electron spins in InGaAs self assembled quantum dots (QDs). This device operates via optical charging of a sub ensemble of dots via polarized optical excitation and selective exciton ionisation using an internal electric field. Using such techniques we studied the electron spin lifetime (T_1) as a function of Zeeman energy and lattice temperature and deduced the dominant relaxation mechanisms for self assembled QDs.

Lately, we have extended our investigations to a modified device design that enables investigation of the dynamics of optically generated *holes*. In strong contrast to electron storage experiments, hole storage samples reveal no optical polarization memory effect for storage times of $0.5\mu s$ and magnetic fields up to $\sim 12T$. These findings contrast strongly with our findings for electrons, indicating that the hole spin decays over much faster timescales. The hole (T_1) time in QDs has been controversially discussed in the literature; some theories indicating that it can be comparable to electrons whilst others predict orders of magnitude faster relaxation. Our results provide, much needed, experimental data for comparison with theory.

HL 52.10 Fri 13:15 POT 151

Wavelength- and spin-selective addressing of self-organized InAs/GaAs quantum dots by means of spectral hole burning — •Till Warming[1], Witlef Wieczorek[1], Martin Geller[1], Victor Ustinov[2], Alexey Zhukov[2], and Dieter Bimberg[1] — [1]Institut für Festkörperphysik, TU Berlin — [2]A.F. Ioffe Physico-Technical Institute RAS, St. Petersburg, Russia

Semiconductor quantum dots (QDs) with their possibility to confine one single carrier only, representing one quantum bit of information, are potential candidates for future memory devices. Here, spectral hole burning is used for wavelength-selective addressing of a subensemble of QDs from the large inhomogeneously broadened QD ensemble. Resonant laser excitation and controlled tunneling leads to QDs charged with single carriers. Such charging manifest itself in photocurrent spectra as increased absorption due to the formation of negatively charged trions. Spin-selective addressing by polarized excitation is demonstrated at low temperatures and sufficiently high magnetic fields when pure spin states prevail. The formation of trion depends on the polarization of the primary and secondary pump wi9th respect to each other, in order to take account of Pauli blocking. Spin-selective readout of the carriers is realized. Parts of this work are funded by the European SANDiE NoE, contr. no. NMP4-CT-2004-500101 and SFB296 of DFG.

HL 52.11 Fri 13:30 POT 151

Lasing effects in high quality AlAs/GaAs micropillar cavities — •Carolin Hofmann[1], Stephan Reitzenstein[1], Steffen Münch[1], Anatolly Bazhenov[1,2], Alexander Gorbunov[1,2], Andreas Löffler[1], Johann Peter Reithmaier[1,3], Martin Kamp[1], Leonid Keldysh[1,4], Vladimir Kulakovskii[1,2], and Alfred Forchel[1] — [1]Technische Physik, Universität Würzburg, Germany — [2]Institute for Solid State Physics, Russian Academy of Science, Chernogolovka, Russia — [3]Physik, Universität Kassel, Germany — [4]Lebedev Physical Institute, Russian Academy of Science, Moscow, Russia

We report on studies performed on optically pumped high quality micropillar laser-structures. The pillars are based on planar microcavity structures grown by molecular beam epitaxy. The planar structures consist of a GaAs λ-cavity sandwiched between DBR with up to 27 quarter-wavelength layer pairs of AlAs and GaAs. In the center of the cavity a low density layer of InGaAs quantum dots is embedded. Micropillars with diameters as low as a few hundred nanometers were patterned. By microphotoluminecence measurements at low temperatures we have studied the transition from spontaneous emission to laser operation for pillars of different diameter and quality factors of up to 35000. Lasing was observed for pillars which contain less than 100 quantum dots. Laser operation is identified by a nonlinear increase of the output intensity versus excitation power. We will discuss the influence of the pillar diameter and the quality factor on the lasing characteristics of the micropillar laser-structures and give an estimation of the influence of single quantum dots on the lasing behaviour.

HL 52.12 Fri 13:45 POT 151

Lifetime of localized excitons in InGaN quantum dots — •M. Dworzak, M. Winkelnkemper, A. Hoffmann, and D. Bimberg — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin

At low temperature indium-rich fluctuation islands in a 2 nm thick InGaN layer form a quantum dot (QD) ensemble of ultra-high density. Regarding the recombination dynamic of localized excitons these QDs differ extremely from other QD systems. Spatially resolved investigations on single InGaN QDs by means of time-resolved photoluminescence (TRPL) showed a broad distribution of the exciton lifetimes, even for QDs with similar transition energy. [1]

On one hand this behavior is causes by different electron/hole wavefunction overlaps due to the disordered distribution of QD size, shape and indium content inside the QD ensemble. This is modeled by 8-band kp theory. On the other hand TRPL studies showed redistribution of carriers between the QDs. Thus, also different transfer probabilities inside the QD ensemble lead to different time constants.

[1] Bartel et al., Appl. Phys. Lett. 85, 1946 (2004)