HL 39: Quantum dots and wires: Optical properties I

Time: Thursday 9:30–12:45 Location: H34

HL 39.1 Thu 9:30 H34

Full photon statistics for superradiant quantum-dot-microcavity lasers via the Monte Carlo wave-function method — •Sergej Neumeier and Jan Wiersig — Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Postfach 4120, D-39016 Magdeburg, Germany

Superradiance, the enhancement of spontaneous emission, appears due to radiative coupling between emitters. Using this effect highly efficient quantum-dot nanolasers can be build [1]. It has been experimentally observed that this coupling also leads to an enhanced photon bunching [2]. These inter-emitter coupling effects have been described by simulating open systems in quantum optics [3,4] using the Monte Carlo wave-function method [5,6,7]. The method gives access to the full photon statistics. Experimentally the full photon statistics, e.g. auto-correlation functions ($g^{(2)}(0)$ etc.) and the photon-number distribution p_n, can be measured using a transition edge sensor [8].

We use the Monte Carlo wave-function method to study a continuously driven (cw) quantum-dot ensemble interacting with a single-mode light field in a microcavity.

[1] H. A. M. Leymann et al., Phys. Rev. Appl. 4, 044018 (2015). [2] F. Jahnke et al., Nat. Comm. 7, 11540 (2016). [3] V. V. Temnov et al., Phys. Rev. Lett. 95, 243602 (2005). [4] V. V. Temnov et al., Opt. Express 17, 5774 (2009). [5] K. Mølmer et al., J. Opt. Soc. Am. B 10, 524 (1993). [6] J. Dalibard et al., Phys. Rev. Lett. 68, 580 (1992). [7] N. Gisin, Helvetica Physica Acta 62, 363 (1989). [8] E. Schlottmann et al., Phys. Rev. Appl. 9, 064030 (2018).

HL 39.2 Thu 9:45 H34

An information theoretical approach to the many-particle hierarchy problem: application to quantum dot microcavity lasers — •Boris Melcher, Boris Gulyak, and Jan Wiersig — Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Postfach 4120, D-39016 Magdeburg, Germany

Using the maximum entropy principle [E. T. Jaynes, Phys. Rev. 106, 620 (1957), Phys. Rev. 108, 171 (1957)], we develop a stand-alone approach to numerically determine the full density matrix of open quantum systems. By doing so, the many-particle hierarchy problem that arises in conventional equation of motion techniques and makes it necessary to utilize factorization and truncation schemes such as the cluster expansion method [H. A. M. Leymann et al., Phys. Rev. B 89, 085308 (2014)], is completely avoided. Instead, a finite set of input information is used to calculate the least biased density matrix self-consistently, and thus making all relevant expectation values and correlation functions as well as the full statistics directly accessible.

As a benchmark, we compare the maximum entropy method results for a four-level single quantum dot microcavity laser where the full density matrix is still available by numerically solving the von Neumann-Lindblad equation and demonstrate excellent agreement in terms of entropy, mean photon number, autocorrelation function, and photon statistics. Finally, we show that our approach can be used as a tool for learning about the relevant processes of quantum systems.

HL 39.3 Thu 10:00 H34

Carrier dynamics and modulation properties in tunnel-injection based quantum-dot structures — •Michael Lorke[1], Stephan Michael[1], Igor Khanonkin[2], Gadi Eisenstein[2], and Frank Jahnke[1] — [1]Institute for Theoretical Physics, University of Bremen, Germany — [2]Andrew and Erna Viterbi Department of Electrical Engineering, Technion, Haifa, Israel

For tunnel-injection (TI) quantum-dot (QD) lasers record high small signal modulation bandwidth and improved performance of 1.55μm InAs QDs on InP-based hetero-structures (1) were reported, which underscores their application potential for high-speed optical communication networks. However, large signal modulation, which really is the fingerprint of applicability in optical communication, is much less investigated. We present a theoretical analysis of TI laser and amplifier devices by combining material realistic electronic structure calculations with a detailed description of the carrier dynamics. Based on these investigations, we can give design guidelines to optimize the modulation bandwidth and turn-on delay.

HL 39.4 Thu 10:15 H34

Exploring excited electronic states in QDs by spatially structured laser beams - a theoretical investigation — •Matthias Holtkemper, Doris E. Reiter, and Tilmann Kuhn — Institut für Festkörpertheorie, Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster

In many experiments an optically driven self-assembled quantum dot (QD) is excited at some high energy. The created "hot" exciton relaxes via short-living intermediate levels into the exciton ground state which then decays radiatively. A detailed knowledge of the intermediate single and multiexciton levels is crucial to understand different relaxation channels as well as time-resolved nonlinear optical signals. However, many of the intermediate excitons are not optically accessible by standard Gaussian beams and, thus, difficult to study.

We theoretically explore the possibilities that arise by excitations with spatially structured light fields, such as higher modes in optical cavities or freely propagating Bessel or Hermite-Gaussian beams. We show that many of the intermediate states become accessible by such light fields. Furthermore, we show that the spatial degree of freedom of these laser fields can be used to excite different excitonic levels selectively. With this we propose a generalized polarization measurement, where not just the orientation of the dipole moments, but also the spatial orientation of the excitonic states can be measured.

HL 39.5 Thu 10:30 H34

Influence of lattice mismatch on direct and indirect electronic states in $In_{1-x}Ga_xAs_ySb_{1-y}$ quantum dots grown on GaP or GaAs — •Petr Klenovsky[1,2], Andrei Schliwa[3], and Dieter Bimberg[3,4] — [1]Masaryk University, Department of Condensed Matter Physics, Brno, Czech Republic — [2]Czech Metrology Institute, Brno, Czech Republic — [3]Technical University Berlin, Inst Solid State Physics, Berlin, Germany — [4]Chinese Acad Sci, Chinese German Ctr Green Photon, Changchun, Jilin, Peoples R China

We study the electronic structure of $In_{1-x}Ga_xAs_ySb_{1-y}$/GaAs/GaP quantum dots as an example of system exhibiting concurrently direct and indirect transitions both in real and momentum space. We show that this system provides a unique combination of physical properties currently studied in the physics of low-dimensional systems and potentially provides much easier access to applications in quantum information technology than the currently studied (In,Ga)As/GaAs dots. We inspect the confinement potentials for $\mathbf{k} \neq 0$ and $\mathbf{k} = 0$ conduction and $\mathbf{k} = 0$ valence bands, formulate the method of $\mathbf{k} \cdot \mathbf{p}$ calculations for $\mathbf{k}$-indirect transitions, and we discuss the excitonic structure of Γ-transitions in this system. Throughout this process we compare the results obtained for dots on both GaP and GaAs substrates revealing the influence of the large hydrostatic stress for the former and, moreover, enabling us to make a direct comparison with the (In,Ga)As/GaAs quantum dot system.

HL 39.6 Thu 10:45 H34

Interpreting ensemble photoluminescence of InAs quantum dots coupled to a Fermi reservoir — •Alexander Rolf Korsch[1], Giang Nam Nguyen[1], Marcel Schmidt[1], Carsten Ebler[1], Sascha René Valentin[1], Pia Lochner[1,2], Charlotte Rothfuchs[1], Andreas Dirk Wieck[1], and Arne Ludwig[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany — [2]Fakultät für Physik and CENIDE, Universität Duisburg-Essen, Germany

Self-assembled InAs quantum dots in semiconductor heterostructures enabled the realization of new technologies such as quantum dot lasers or single photon sources. For many applications, temperature stability of the emission properties is desired and tunability of energy levels by an applied voltage is required [1].

We present anomalous behavior of temperature-dependent photoluminescence (PL) measurements on InAs quantum dot ensembles coupled to an electron reservoir. When negative gate voltages are applied to the sample, an anomalous initial increase of the integrated PL signal intensity with rising temperature is observed for the ground state and first excited state emission peaks. The anomalous temperature-dependence is caused by electrons tunneling from the electron reservoir to the quantum dots enhancing the PL signal. This effect can be accounted for by a modified Arrhenius model. PL measurements at 77 K are further compared to capacitance-voltage spectroscopy measurements on the same sample supporting the proposed interpretation.

[1] Ediger et al., Nature Physics 3, 774 (2007).

15 min. break

HL 39.7 Thu 11:15 H34

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[1] Ediger et al., Nature Physics 3, 774 (2007).

HL 39.8 Thu 11:30 H34

Ultrasensitive, high spectral resolution photocurrent detection of QDs excitons — •Sebastian Krehs, Alex Widhalm, Björn Jonas, Nand Lal Sharma, Dirk Reuter, and Artur Zrenner — Physics Department, University of Paderborn, Warburger Str. 100, Paderborn

In optical experiments on single quantum dots the exciton ground state transition appears as a two-level system with a lifetime limited linewidth of a few μeV. In contrast to resonance fluorescence, photocurrent (PC) spectroscopy is a quantitative method to read out the occupancy of the QD. In the past PC detection was limited to a regime with high tunneling rates and elevated excitation powers, which results in PC in the pA-range. Therefore the linewidth of QD excitons, as observed in the PC measurements suffered from lifetime and power broadening. Refined PC detection enabled us to improve its sensitivity down to the fA-range. This allows us to investigate the linewidth of QDs at exceptionally low tunneling rates and at very low excitation powers.

For this work we have fabricated Schottky photodiodes with embedded high quality MBE grown QDs. We have been able to demonstrate exciton ground state linewidths as low as 1.62 μeV in the low tunneling regime. Our results are close to the Fourier transform limit of InAs/GaAs QD systems, as shown by Kuhlmann et al. using resonance fluorescence [1].

[1] A.V. Kuhlmann et al. Nature Physics 9, 570-575 (2013).

HL 39.9 Thu 11:45 H34

Hot carrier cooling dynamics in PbS quantum dots - The influence of surface termination — •Emanuele Minutella[1,2], Nuri Yazdani[3], Vanessa Wood[3], and Holger Lange[1,2] — [1]Institute for Physical Chemistry, University of Hamburg — [2]The Hamburg Centre For Ultrafast Imaging, CUI — [3]Labratory for Nanoelectronics, Department of Information Technology and Electrical Engineering, ETH Zurich

Carrier multiplication (CM) in PbS quantum dots (QD) is an intriguing phenomenon with promises towards applications such as field-effect transistors, light-emitting diodes or solar cells due to their optical properties.(1) CM occurs in direct competition with carrier cooling via phonon emission or other relaxation channels.(2)In an experimental study, it was shown that halide-terminated PbS QDs feature an improved performance in solar energy conversion.(3) Our recent theoretical work showed that electron-phonon interactions are strongly suppressed in halide-terminated QDs due to reduction of the thermal displacement of the surface atoms.(4)

In our contribution we present an experimental study of the surface-termination impact. We observe the cooling of photo-induced hot carriers by femtosecond transient absorption spectroscopy in PbS QDs capped with different ligands. Our experimental results agree with the theoretical predictions and enable a tuning of the electron-phonon coupling in colloidal QDs.

(1) Adv. Mater. 2018, 30, 1800082 (2) ACS Nano 2017, 11, 6286-6294 (3) Nat. Mater. 2017, 16, 258-263 (4) Nano Lett. 2018, 18, 2233-2242

HL 39.10 Thu 12:00 H34

Capacitance-Voltage spectroscopy on Quantum Dots as sensor for trap charge density — •Giang Nam Nguyen[1], Alexander Rolf Korsch[1], Carsten Ebler[1], Marcel Schmidt[1], Pia Lochner[1,2], Fabian Brinks[1,2], Andreas Dirk Wieck[1], and Arne Ludwig[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany — [2]Fakultät für Physik and CENIDE, Universität Duisburg-Essen, Germany

Self assembled quantum dots (QDs) act as major candidates for many future quantum devices for which much higher material quality are needed. While disadvantages of non-radiative recombination centers are obvious for optoelectronic devices, fluctuating charges in the environment of QDs lead to spectral wandering or blinking, as the electric field varies randomly and changes the emitter's energy levels by quantum confined Stark effect [1].

A trap charge density sensor using capacitance-voltage (C-V) spectroscopy on QDs embedded in a diode structure is demonstrated. After optically exciting our device at different biases and wavelengths, we find a strongly electric field and photon energy dependent persistent shift of the QDs' charging resonances. We propose a Franz-Keldysh or k-space indirect type of excitation of trap states within the diode. To quantify the according charge trap density, we model the band bending by 1D band structure simulation. For low trap densities we find an excellent agreement with a simple linear dependence, making our device an efficient charge trap density monitor.

[1] J. Houel et al, Phys. Rev. Lett. 108, 107401 (2012)

HL 39.11 Thu 12:15 H34

Interpreting ensemble photoluminescence of InAs quantum dots coupled to a Fermi reservoir — •Alexander Rolf Korsch[1], Giang Nam Nguyen[1], Marcel Schmidt[1], Carsten Ebler[1], Sascha René Valentin[1], Pia Lochner[1,2], Charlotte Rothfuchs[1], Andreas Dirk Wieck[1], and Arne Ludwig[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany — [2]Fakultät für Physik and CENIDE, Universität Duisburg-Essen, Germany

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[1] Ediger et al., Nature Physics 3, 774 (2007).

HL 39.12 Thu 12:30 H34

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