HL 18: Quantum dots and wires I

Time: Monday 15:00–18:15 Location: POT 151

Invited Talk HL 18.1 Mon 15:00 POT 151

Highly efficient sources of single indistinguishable photons — •Niels Gregersen — DTU Fotonik, Technical University of Denmark, Kongens Lyngby, Denmark

Single-photon sources (SPSs) capable of emitting single indistinguishable photons are key components in optical quantum information processing. The SPS figures of merit include the efficiency ϵ of the photon collection and the indistinguishability η of the emitted photons, and scalable optical quantum information processing requires that the product $\epsilon\eta$ is increased very close to unity. In this presentation, I will review present SPS design strategies including the micropillar design and the photonic nanowire design, and I will discuss the potential for increasing $\epsilon\eta$ towards unity.

HL 18.2 Mon 15:30 POT 151

Real-time optical detection of every individual Auger process in a quantum dot — •Hendrik Mannel[1], Jens Kerski[1], Pia Lochner[1], Annika Kurzmann[1], Philipp Stegmann[1], Jürgen König[1], Arne Ludwig[2], Andreas D. Wieck[2], Axel Lorke[1], and Martin Geller[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

Auger recombination is a non-radiative process, where the recombination energy of an electron-hole pair is transferred to a third charge carrier. In nanostructured materials, it is a common effect especially in colloidal quantum dots, where it quenches the radiative emission with an Auger recombination time below nanoseconds. In self-assembled QDs, the Auger recombination has only been observed recently [1]. We use two-color resonant laser excitation of the exciton and trion transition on a single self-assembled quantum dot with magnetic fields from 4 to 10 Tesla to monitor every quantum event of the Auger process in real-time. With full counting statistics we observe that the Auger process can be used to tune optically the charge carrier occupation of the dot by the incident laser intensity. Independently we can change the charge carrier occupation of the dot with the electron tunneling from the reservoir by the gate voltage. This demonstrates the potential of the Auger effect for controlling precisely the charge state in a quantum system by optical means. [1] A. Kurzmann et al., Nano Lett. 16, 3367 (2016).

HL 18.3 Mon 15:45 POT 151

Non-Markovianity in quantum optical signals: Wigner time delay and anomalous population trapping — •Alexander Carmele[1,3], Stephan Reitzenstein[2], and Scott Parkins[3] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin — [2]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin — [3]Department of Physics, University of Auckland, Private Bag 92019, Auckland, New Zealand

In comparison to fundamental atom-photon interfaces, a key factor to the understanding of observed phenomena in semiconductor quantum electrodynamics is the presence of a structured environment. This system-reservoir interaction induces intrinsically non-Markovian dynamics [1]. For example, the Wigner delay of QD light emission is limited not only by twice the radiative lifetime as in the case for isolated atoms but also by the phonon-scattering induced decoherence time to approximately the lifetime of the exciton [2]. Another example is anomalous population trapping in multiple-emitter and multiple-excitation waveguide-QED systems. We show that the Markovian treatment does not capture population trapping dynamics even if local phase differences in the light-matter coupling elements are allowed [3].

[1] A. Carmele and S. Reitzenstein, Nanophotonics **8**, 655 (2019).
[2] M. Strauß et al, Phys. Rev. Lett **122**, 107401 (2019).
[3] A. Carmele et al, arXiv:1910.13414 (2019).

HL 18.4 Mon 16:00 POT 151

A deterministically fabricated spectrally-tunable quantum dot based single-photon source — •Marco Schmidt, Martin v. Helversen, Sarah Fischbach, Arsenty Kaganskiy, Ronny Schmidt, Andrei Schliwa, Tobias Heindel, Sven Rodt, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

Spectrally-tunable quantum light sources are key building blocks of future quantum information networks. Semiconductor-based quantum dots are among the most promising candidates to fulfill this task. On the one hand, this is because of their excellent properties to generate single, indistinguishable and polarization entangled photons and on the other hand, it is explained by their compatibility with advanced device concepts. We demonstrate a tunable single-photon source based on a deterministically fabricated QD microlens which is positioned on top of a piezoactuator via a gold thermocompression bonding procedure [1]. The combination of deterministic fabrication, spectral-tunability and high photon-extraction efficiency makes the QD-microlens single-photon source an interesting building block for the realization of quantum communication networks. The functionality of the strain tunable system and spectroscopic investigations including PID controlled frequency stabilization will be presented.

[1] M. Schmidt et al., A deterministically fabricated spectrally-tunable quantum dot based single-photon source, Opt. Mat. Express, in press (2019)

HL 18.5 Mon 16:15 POT 151

Preparation of the dark exciton in a semiconductor quantum dot using spatially structured light — •Doris E. Reiter[1], Matthias Holtkemper[1], Guillermo F. Quinteiro[2], and Tilmann Kuhn[1] — [1]Institut für Festkörpertheorie, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]IMIT and Departamento de Física, FaCENA, Universidad Nacional del Nordeste, Corrientes, Argentina

The ground state manifold of a semiconductor quantum dot hosts optically bright excitons which can be used for single photon generation. However, there are also two optically dark excitons in the ground state manifold, which are potentially interesting for storage. To access these dark excitons, we here propose the excitation of the quantum dot with the longitudinal component of a spatially structured light field. This light field component excites a light hole exciton in an excited state, also called a hot exciton state. In typical quantum dots, the hot exciton states are strongly mixed. We calculate the electronic structure of the quantum dot using a configuration interaction method accounting for Coulomb interaction and valence band mixing. We find a strong mixing between the excited light hole exciton and a hot dark heavy hole exciton. The latter is composed of an electron in the s-shell and a hole in the d-shell, which can relax quickly to its ground state (i.e., the s-shell). In this way we can prepare the dark exciton in the ground state manifold, which due to its optically inactivity exhibits a very long lifetime.

30 min. break.

HL 18.6 Mon 17:00 POT 151

Fiber coupling of quantum dot based entangled photon sources — •Weijie Nie[1], Robert Keil[1], Nand Lal Sharma[1], Caspar Hopfmann[1], Fei Ding[2], and Oliver Schmidt[1,3] — [1]Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstrasse 2, 30167 Hannover, Germany — [3]Chemnitz University of Technology, Reichenhainer Strasse 70, 09107 Chemnitz, Germany

Fiber-based highly efficient entangled photon sources are an essential ingredient for quantum photonic networks. While the realization of fiber-coupled single photon sources has been attempted by various methods, direct fiber coupling of quantum dot based entangled photon sources has not been reported. In our work, we employ quantum dot nanomembranes directly attached to single mode fiber end-faces for efficient photon extraction. A key ingredient of efficient photon collection into fibers is the careful design and implementation of an air gap between fiber end face and quantum dot nanomembrane.

HL 18.7 Mon 17:15 POT 151

Radiative coupling between quantum-dot emitters in bimodal microcavity lasers — •Isa Hedda Grothe and Jan Wiersig — Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Germany

In bimodal micropillar lasers with two orthogonally polarized modes the interaction with the common quantum-dot gain medium leads to gain competition between the two modes. This results in superthermal values of the autocorrelation function for the weak, non-lasing mode. [1] For standard nanolasers with a single cavity mode, on the other hand, a strong influence of inter-emitter correlations on the input-output characteristics as well as on the statistics of the emitted light has been described. Sub- and superradiant effects can cause an underestimation of the β-factor here and lead to the occurrence of superthermal bunching below threshold. [2]

In light of these findings we make use of a theoretical semiconductor laser model that includes correlations between the emitters in the description of bimodal microcavity lasers to investigate whether an influence of sub- and superradiant effects on the emission behavior can be observed in these systems as well.

[1] H. A. M. Leymann et al., Phys. Rev. A 87, 053819 (2013).
[2] H. A. M. Leymann et al., Phys. Rev. Appl. 4(4), 044018 (2015).

HL 18.8 Mon 17:30 POT 151

Efficient electronic structure calculations for extended systems of coupled quantum dots for Quantum Cascade Lasers Based on a Quantum Dot Superlattice — •Alexander Mittelstädt and Andrei Schliwa — Institut für Festkörperphysik, Technische Universität Berlin

We present a 'linear combination of atomic orbitals'–type of approximation, enabling accurate electronic structure calculations for systems of up to 20 or more electronically coupled quantum dots. Using realistic single quantum dot wavefunctions as basis to expand the eigenstates of the heterostructure, our method shows excellent agreement with full 8-band $\boldsymbol{k} \cdot \boldsymbol{p}$ calculations, exemplarily chosen for our benchmarking comparison, with an orders of magnitude reduction in computational time. We show that, in order to correctly predict the electronic properties of such stacks of coupled quantum dots, it is necessary to consider the strain distribution in the whole heterostructure. Edge effects determine the electronic structure for stacks of $\lesssim 10$ QDs, after which a homogeneous confinement region develops in the center. The overarching goal of our investigations is to design a stack of vertically coupled quantum dots with an intra-band staircase potential suitable as active material for a quantum-dot-based quantum cascade laser.

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Exploring the Full Photon Statistics of Bimodal-Micropillar Lasers with a Two-Channel Photon-Number-Resolving Transition-Edge-Sensor — •Ching-Wen Shih[1], Marco Schmidt[1], Wenera Zent[1], Christian Schneider[2], Sven Höfling[2], Jörn Beyer[3], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany — [2]Technische Physik, Universität Würzburg, Germany — [3]Physikalisch-Technische Bundesanstalt, Berlin, Germany

Photon statistics is no doubt one of the key characteristics of photons in quantum light sources. In this regard, a transition-edge-sensor (TES) is an extremely sensitive calorimeter which can resolve the photon numbers and provide the full photon statistics in one shot. Besides, in the case of quantum-dot micropillar lasers, it has been found out that a slight structural asymmetry in the cross-section of micropillars can lift the degeneracy of two fundamental mode components with perpendicular polarizations. In this work, we report on the joint photon number distribution of both modes in such bimodal-micropillar lasers measured by a two-channel photon-number-resolving TES detector system. While both modes share the common quantum dot gain, photon distributions mixed of thermal and Poissonian characteristics were observed above the lasing threshold, indicating interesting mode switching and gain competition effects. We then further reveal the higher-order correlation functions $g^{(k)}(0)$ with $k \geq 2$ and the cross-correlation functions of both modes as a further confirmation of their behaviors.

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GaAs based quantum dot structures for VECSEL and MIXSEL applications — •Tanja Finke[1], Vitalii Sichkovskyi[1], Jacob Nürnberg[2], Matthias Golling[2], Ursula Keller[2], and Johann Peter Reithmaier[1] — [1]Institute of Nanostructure Technologies and Analytics (INA), Technische Physik, CINSaT, University of Kassel, Germany — [2]Institute for Quantum Electronics, Ultrafast Laser Physics Laboratory, ETH Zürich, Switzerland

By integration of a semiconductor saturable absorber mirror (SESAM) into a vertical external cavity surface emitting laser (VECSEL), one can form a mode-locked integrated external-cavity surface emitting laser (MIXSEL). InGaAs quantum dots (QDs) were used for the gain and absorber regions and optimized by MBE towards high dot density and narrow photoluminescence (PL) emission. The influence of the growth parameters as well as a post-growth rapid thermal annealing (RTA) on the optical and morphological properties of QDs was studied. Furthermore, distributed Bragg mirrors (DBR) were grown and maximum reflectivity values of 99.8 % could be achieved. All the sections were integrated into a single VECSEL structure. To improve the absorption and fast recovery dynamics of high-quality QD-SESAMs, p-type doping recombination centers close to the QD layers were introduced. The effect of the beryllium δ-doping level and post-growth RTA on the optical properties of the QDs was studied and QD-SESAMs with different designs were characterized by nonlinear reflectivity and pump-probe experiments. A fast recovery time of 2 ps and saturation parameters comparable to QW based SESAMs were achieved.