HL 24: Quantum dots: Optics

Time: Wednesday 9:30–13:15 Location: POT 151

HL 24.1 Wed 9:30 POT 151

Raman spectroscopic structure analysis of colloidal semiconductor core-shell quantum dots for the achievement of near-unity quantum efficiency — •Sandra Zech[1,2], Sonja Krohn[2], Hannes Van Avermaet[3], Zeger Hens[3], Jan Steffen Niehaus[4], Janina Maultzsch[1], and Holger Lange[2] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Institute of Physical Chemistry, University of Hamburg, Hamburg, Germany — [3]Physics and Chemistry of Nanostructures, Ghent University, Ghent, Belgium — [4]Fraunhofer IPA Center for Applied Nano-Technology CAN, Hamburg, Germany

State of the art applications of quantum dots (QDs) require near-unity photoluminescence quantum yield (PLQY). This demand is rarely achieved and therefore the synthesis process is under constant optimization and nanocrystals consisting of a core with one or more shells of different materials are paving the way to achieve high PLQY. As those components have diverse lattice parameters, the induction of strain within the QDs is inevitable. Recently, we applied Raman spectroscopy for in depth structure characterization and a strain minimization approach to optimize the synthesis of InP/ZnSe/ZnS QDs towards near-unity PLQY. A similar effect plays a role in CdSe/CdS QDs when aiming for high PLQY. In these QDs, the formation of an alloyed interface between the CdSe core and CdS shell is assumed. By Raman spectroscopy, we are able to monitor the formation of these alloyed domains for different QD parameters and correlate it with the PLQY.

HL 24.2 Wed 9:45 POT 151

Collective Excitation of Spatio-Spectrally Distinct Quantum Dots Enabled by Chirped Pulses — •Florian Kappe[1], Yusuf Karli[1], Thomas Bracht[2], Saimon Covre da Silva[3], Tim Seidelmann[4], Vollrath Martin Axt[4], Armando Rastelli[3], Gregor Weihs[1], Doris Reiter[2,5], and Vikas Remesh[1] — [1]Institute für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [2]Institut für Festkörpertheorie, WWU Münster, Münster, Germany — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Linz, Austria — [4]Theoretische Physik III, Universität Bayreuth, Bayreuth, Germany — [5]Condensed Matter Theory, TU Dortmund, Dortmund, Germany

To boost the communication rate in quantum communication devices, it is desirable to have an ensemble of single photon sources that can be collectively excited, despite their spectral variability. Rabi rotation, the most popular method for resonant excitation of the quantum dot, cannot assure a highly efficient state preparation, due to its sensitivity to the excitation parameters. Here, we demonstrate the robustness of Adiabatic Rapid Passage, using chirped laser pulses and collectively excite biexciton states [1] in energetically and spatially distinct quantum dots. We also demonstrate a regime of phonon contribution that widens the detuning range. Being able to generate high-purity photons from spatially multiplexed quantum dot sources with high efficiency is a big step towards the implementation of high photon rate quantum key distribution protocols. [1] Kappe et al, https://arxiv.org/abs/2209.08972 (in peer review)

HL 24.3 Wed 10:00 POT 151

Prospects of atomic vapor-based storage of single photons emitted by a deterministically fabricated quantum dot device — •Avijit Barua[1], Benjamin Maass[2], Norman Vincenz Ewald[2], Suk-in Park[3], Sung-yul Park[3], Jin-Dong Song[3], Janik Wolters[2], and Stephan Reitzenstein[1] — [1]Technische Universität Berlin, Berlin, Germany — [2]German Aerospace Center (DLR), Berlin, Germany — [3]Korea Institute of Science and Technology, Seoul, Republic of Korea

Semiconductor quantum dots (QDs) are extensively investigated as single-photon sources for applications in photonic quantum technology. Here, we develop bright and strain-tunable QD single-photon sources at the Cs D1 transition wavelength and explore the storage ability of semiconductor QD in atomic quantum memories. The devices are designed and numerically optimized to maximize extraction efficiency using the finite element method. By considering circular Bragg resonators with integrated QDs and Au-backside mirror, we numerically demonstrate a photon extraction efficiency of 65% and a Purcell factor of 0.72. In the experimental development, we implement in-situ electron-beam lithography to precisely integrate selected single QDs at 894 nm in such structures to create bright single-photon sources. The emission from the developed quantum devices is studied by means of photon autocorrelation measurements. Furthermore, we explore the prospects of interfacing the QD single photons with a vapor-based quantum memory by employing a ladder-type EIT configuration that allows for low-noise storage and retrieval at high repetition rates.

HL 24.4 Wed 10:15 POT 151

Double pulse excitation schemes for enhanced multiphoton interference — •Yusuf Karli[1], Florian Kappe[1], Julian Munzberg[1], Thomas Bracht[2], Saimon Covre da Silva[3], Armando Rastelli[3], Doris Reiter[2,4], Robert Keil[1], Vikas Remesh[1], and Gregor Weihs[1] — [1]Institute für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [2]Institut für Festkörpertheorie, WWU Münster, Münster, Germany — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Linz, Austria — [4]Condensed Matter Theory, TU Dortmund, Dortmund, Germany

High-efficiency generation multiphoton states is an important prerequisite for linear quantum computing applications. Semiconductor quantum dots are high-brightness sources of highly indistinguishable single photons, which can then be used to generate multiphoton states via active temporal-to-spatial demultiplexing. Resonant s-shell excitation is the most popular method to generate high-indistinguishability single photons from a quantum dot [1], however, at the cost of brightness from cross-polarization filtering. Here, we advocate the versatility of novel double-pulse excitation schemes by demonstrating an 8-fold enhancement in four-photon coincidence rates. [1] APL Photonics 7.7 (2022)

HL 24.5 Wed 10:30 POT 151

Towards deterministic generation of time-bin entangled photons from GaAs quantum dots — •Florian Kappe[1], Yusuf Karli[1], Thomas Bracht[2], Saimon Covre da Silva[3], Armando Rastelli[3], Vikas Remesh[1], Doris Reiter[2,4], and Florian Kappe[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [2]Institut für Festkörpertheorie, WWU Münster, Münster, Germany — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Linz, Austria — [4]Condensed Matter Theory, TU Dortmund, Dortmund, Germany

Semiconductor quantum dots are bright, on-demand single photon sources suitable for realising quantum communication devices. Here, we present our first results towards the deterministic generation of time-bin entangled photon states via dark exciton states from GaAs/AlGaAs quantum dots. Our schemes employ chirped laser pulses and an external magnetic field that enables the coupling of bright and dark exciton states in the quantum dot [1,2]. Based on numerical methods we analyze the quantum dot dynamics and state preparation fidelity and identify that the preparation schemes are quite robust against the phonon influence.

[1] Phys. Rev. B. 92(20), (2015). [2] Phys. Rev. B 104.7 (2021).

HL 24.6 Wed 10:45 POT 151

Generation of indistinguishable and entangled photons at telecom frequencies using tailored cavity designs — •David Bauch, Dustin Siebert, Jens Förstner, Klaus D. Jöns, and Stefan Schumacher — Department of Physics, Electrical Engineering and CeOPP, Paderborn University, Germany

The commonly utilized biexciton-exciton cascade yields photons with intrinsically limited indistinguishability [1]. By tuning the biexciton-exciton lifetime ratio, large increases in single photon indistinguishability can be achieved [1,2]. Using the cavity-induced Purcell enhancement is a simple method for radiative lifetime tuning. Employing a circular Bragg reflector at telecom wavelengths for suitable quantum dots allows for a Purcell enhanced biexciton-exciton transition, while still maintaining high extraction efficiency for the exciton-ground state transition. The decreased lifetime of the biexciton results in a faster emission of then indistinguishable single photons. Here, we demonstrate this effect numerically and determine the theoretically required parameters for the biexciton-exciton transition to yield highly indistinguishable single photons, which are also entangled with their exciton-

ground state emission counterpart. We guide our calculations using Maxwell simulations for the cavity design, allowing for close-to real-life system predictions. Our simulation demonstrates the robust increase of the indistinguishability of the emitted photons even when accounting for electron-phonon coupling at low temperatures.

[1] E. Schöll, et al., Physical Review Letters 125, 233605 (2020) [2] F. Sbresny, et al., Physical Review Letters 128, 093603 (2022)

HL 24.7 Wed 11:00 POT 151

Exciton diffusion in a quantum dot ensemble — •Karol Kawa and Paweł Machnikowski — Wrocław University of Science and Technology, 50-370 Wrocław, Poland

We study theoretically Förster transfer [1] of an exciton in an ensemble of quantum dots (QDs) randomly distributed on a circular mesa. In such a system energy transfer was observed experimentally within a spatially resolved photoluminescene sprectroscopy [2]. The analytical form of Förster coupling in the general ensemble of quantum dipole emitters is known [3–5]. It is a sum of three power-law terms diminishing with distance, each multiplied by an oscillating factor. The fundamental transition energy in each QD is randomized. We solve the equation of motion for the density matrix using the stochastic simulation method with a given exciton decay rate. Then, we present the evolution of the exciton mean square displacement (MSD) from the initially excited QD. It runs in three time stages. First, a ballistic motion, followed by a standard diffusion, which ends at saturation. Using an approximate analytical approach [6], we provide formulas that qualitatively reproduce all stages of the MSD.

[1] T. Förster, Ann. Phys., 437, 55 (1948)
[2] F.V. de Sales et al., Phys. Rev. B 70, 235318 (2004)
[3] M.J. Stephen, J. Chem. Phys. 40, 669 (1964)
[4] R.H. Lehmberg, Phys. Rev. A 2, 883 (1970)
[5] F. Miftasani and P. Machnikowski, Phys. Rev. B 93, 075311 (2016)
[6] K. Kawa and P. Machnikowski, Phys. Rev. B 102, 174203 (2020)

30 min. break

HL 24.8 Wed 11:45 POT 151

Preparation of spin qubits in droplet-etched GaAs quantum dots using quasi-resonant excitation — •Caspar Hopfmann[1], Nand Lal Sharma[1], Weijie Nie[1], Robert Keil[1], Fei Ding[2], and Oliver G. Schmidt[1,3,4] — [1]Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstr. 20, 01069 Dresden — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover — [3]Material Systems for Nanoelectronics, Technische Universität Chemnitz, 09107 Chemnitz — [4]Nanophysics, Faculty of Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden

Optically accessible quantum memories are fundamental for implementations of quantum networks as they facilitate the synchronization required for schemes of long-distance quantum information exchange. In order to use GaAs quantum dots, which so far has proven to be bright on-demand sources of entangled photon pairs, deterministic preparation of specific spin states is necessary. We present a comprehensive study on heralded spin preparation employing excited state resonances of droplet etched GaAs quantum dots. By observation of excitation spectra for a range of fundamental excitonic transitions the properties of different quantum dot energy levels, i.e. shells, are revealed. The innovative use of polarization-resolved excitation and detection in the context of quasi-resonant excitation spectroscopy of quantum dots greatly simplifies the determination of the spin preparation fidelities. By employing this method, spin preparation fidelities of quantum dot ground states of up to 85 % are found.

HL 24.9 Wed 12:00 POT 151

Effect of tunnel barrier thickness on optical properties of GaAs quantum dots embedded in Schottky diode structures — •Nand Lal Sharma[1], Moritz Langer[1], Ankita Choudhary[1], Oliver G. Schmidt[2], and Caspar Hopfmann[1] — [1]Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [2]Material Systems for Nanoelectronics, Technical University Chemnitz, 09107 Chemnitz, Germany

GaAs quantum dots (QDs) are promising candidates for on demand generation of single and entangled photon pair sources for quantum communication applications. In these QDs, the charge stability and optical linewidth depend on the solid-state environment, which can be controlled by embedding them in a diode structure [1]. In this work we investigate the effect of tunnel barrier thickness on the optical properties of droplet etched GaAs/AlGaAs QDs [2], embedded in Schottky diode structures. The QD photoluminescence from different charge states is controlled by application of an external bias. The effects of quantum dot charging, quantum confined Stark effect and photon coherence are investigated as a function of tunnel barrier thickness.

HL 24.10 Wed 12:15 POT 151

Size-dependence of the Auger process in self-assembled quantum dots — •Hendrik Mannel[1], Marcel Zöllner[1], Fabio Rimek[1], Arne Ludwig[2], Andreas Wieck[2], Martin Geller[1], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Duisburg, 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 (QD), where short Auger recombination times $\tau_{Au} < 1\,ns$ quench the radiative recombination. In self-assembled QDs, an Auger recombination rate of $\tau_{Au} \approx 1\,ms$ has been observed [1].

We use resonance fluorescence to measure the Auger rate of differently sized self-assembled QDs having exciton recombination energies in the range of 920 to 980 nm [2]. The dots are charged with one electron before driving the trion transition to observe the quenching of this transition time-resolved on the investigated sample structure without a wetting layer.

Independently we can change the charge carrier occupation of the dot by gate voltage-dependent electron tunneling from the reservoir. This is a step to further understand the Auger effect and hopefully supress this unwanted effect in future application of quantum information processing.

[1]*A. Kurzmann et al., Nano Lett. 16, 3367 (2016). [2]*M. Löbl et al., Commun. Phys. 2, 93 (2019).

HL 24.11 Wed 12:30 POT 151

Single Mode Coupled Emission of Resonant Excited GaAs Quantum Dots — •Martin Kernbach[1,2], Julian Siller[1], Sophia Fuchs[1], and Andreas W. Schell[1,2] — [1]Leibniz Universität Hannover, Deutschland — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland

Quantum technologies like computing, QKD, or sensing demand for deterministic bright sources of single indistinguishable photons. In order to provide quantum light of isolated systems properly usable for quantum information science, an efficient excitation and extensive collection in a single mode is required. Single molecules and cavity confined quantum dots are convenient sources. The coupling to the excited state is maximized on resonance, but challenges the usability of the emitter due to the costs for the separation of the optical excitation mode from the mode of emission. A temporal, spacial, spectral, or combined method for separation is typically used. Here we present a realization of a single emitter under resonant excitation in a confocal setup coupled into a single mode fiber with the emission mode filtered by polarization. So far, a free beam is directed on the objective mounted with the scanning stages on a 1 m long stick in a liquid helium reservoir. For resonant cw excitation of GaAs semiconductor quantum dots a SNR of polarization suppression up to 100 and count rates of 280 kcps are archived by using a collecting lens with NA 0.68 only. Under this scheme further investigations regarding the blinking behavior are possible as well as probing alternative emitters like single molecules.

HL 24.12 Wed 12:45 POT 151

The role of charge transfer for light emission from excitonic complexes in a single quantum emitter — •Marcel Zöllner[1], Fabio Rimek[1], Hendrik Mannel[1], Andreas D. Wieck[2], Arne Ludwig[2], Martin Geller[1], and Axel Lorke[1] — [1]University of Duisburg-Essen, Germany — [2]Ruhr-University Bochum, Germany

Due to the non-radiative Auger recombination in self-assembled quantum dots [1], the light emission of the trion X^- is reduced. However, for devices and statistical analyses, such as random telegraph signals, the amount of quantum dot photons is of great importance.

With time-resolved resonance fluorescence (RF) measurements, we investigate a comparatively small quantum dot, where we can tune the rate of the electron tunneling from the back contact into the quantum dot by increasing the gate voltage. This results in an up to two orders of magnitude higher trion intensity. Due to the large gate voltages (i.e. energetically strongly tilted conduction band) the electrons can easily

overcome the tunnel barrier. Thus, the electron tunneling becomes the dominant effect and charges the quantum dot significantly faster than the Auger effect can discharge it.
Our results indicate that thin tunneling barriers, which can quickly equilibrate states in a quantum dot, make its radiative recombination more resilient against spurious charge transfer (Auger, electron capture, internal photoemission). However, this improvement goes along with a short coherence time.
[1] P. Lochner et al., Phys. Rev. B 103, 075426 (2021).

HL 24.13 Wed 13:00 POT 151

Single photon source in a topological cavity — Jonathan Jurkat[1], Sebastian Klembt[1], Marco De Gregorio[1], •Moritz Meinecke[1], Quirin Buchinger[1], Tristan Hader[1], Johannes Beierlein[1], Oleg Egorov[3], Monika Emmerling[1], Constantin Krause[1], Christian Schneider[2], Tobias Huber-Loyola[1], and Sven Höfling[1] — [1]Technische Physik, Physikalisches Institut and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, 97074 Würzburg, Germany — [2]Lehrstuhl für Physik, Universität Oldenburg, 26129 Oldenburg, Germany — [3]Lehrstuhl für Kondensierte Materietheorie und Optik, Friedrich-Schiller-Universität Jena, 07743 Jena, Germany

The introduction of topological physics into the field of photonics has led to the development of photonic devices endowed with robustness against structural and photonic disorder. While a range of platforms have been successfully implemented demonstrating topological protection of light in the classical domain, the implementation of quantum light sources in photonic devices harnessing topologically non-trivial resonances is largely unexplored. Here, we demonstrate a single photon source based on a single semiconductor quantum dot coupled to a topologically non-trivial Su-Schrieffer-Heeger (SSH) cavity mode. We provide an in-depth study of Purcell enhancement for this topological quantum light source and demonstrate its emission of non-classical light on demand. Our approach is a promising step towards the application of topological cavities in quantum photonics.