HL 57: Quantum Dots and Wires: Optics II

Time: Friday 9:30–13:00 Location: H13

HL 57.1 Fri 9:30 H13

Deterministic Generation of Linear Photonic Cluster States with Semiconductor Quantum Dots: A Detailed Comparison of Different Schemes — •Nikolas Köcher, David Bauch, Nils Heinisch, and Stefan Schumacher — Physics Department, CeOPP, and PhoQS, Paderborn University, Germany

Graph and cluster states are types of multipartite entangled states with applications in quantum communication [1] and measurement-based quantum computation [2]. We theoretically investigate and compare different schemes for the deterministic generation of linear photonic cluster states using spins and trions in charged semiconductor quantum dots under strong Purcell enhancement. The schemes differ in the method used for spin control and whether the emitted photonic qubits are polarization or time-bin encoded. We efficiently track the fidelity and the usable length of the cluster states by calculating the expectation values of their stabilizer generators, assessing their fidelity beyond the calculation of gate fidelities [3]. We find that the performance of the different schemes and which scheme is optimal strongly depend on the cavity environment and the coherence time of the spin qubit.

[1] K. Azuma, K. Tamaki, H.-K. Lo, Nat. Commun. 6, 6785 (2015).
[2] R. Raussendorf, H. Briegel, Phys. Rev. Lett. 86, 5188 (2001).
[3] D. Bauch, N. Köcher, N. Heinisch, S. Schumacher, APL Quantum 1, 036110 (2024).

HL 57.2 Fri 9:45 H13

Scalable integration of site-controlled quantum dots into circular Bragg grating resonators — •Kartik Gaur, Avijit Barua, Sarthak Tripathi, Sam Baraz, Lukas Dworaczek, Neha Nitin, Imad Limame, Aris Koulas-Simos, Priyabrata Mudi, Sven Rodt, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, D-10623 Berlin

The buried-stressor approach [1] is one of the pivotal methods for the growth of site-controlled quantum dots (SCQDs). This growth technique makes use of the strain from a partially oxidized AlAs layer to induce site-selective nucleation of InGaAs quantum dots. Here, we report on growth, fabrication, and surface and optical characterizations of such SCQDs. A systematic investigation of the effects of variation of SCQD growth parameters on QDs density, surface morphology, and optical properties is done using atomic force microscopy (AFM), cathodoluminescence (CL), and microphotoluminescence (μPL) spectroscopy. Moreover, these SCQDs are integrated into circular Bragg gratings (CBGs) in a scalable manner highlighting the advantage of our advanced growth approach. Quantum optical characterizations are also performed on these SCQD-CBGs. The comprehensive understanding of the intricacies involved in the growth and characterization of SCQDs and their scalability in device integration offers a roadmap for the advancement of nanophotonic technologies and quantum information.

[1] A. Strittmatter, et. al., Applied Physics Letters, 100(9):093111, 03 2012.

HL 57.3 Fri 10:00 H13

Spectral correlations of dynamical resonance fluorescence — •Santiago Bermúdez Feijóo[1], Eduardo Zubizarreta Casalengua[2], Kai Müller[2], and Klaus D. Jöns[1] — [1]PhoQS Institute, CeOPP, and Department of Physics, Paderborn University, Paderborn, Germany — [2]Walter Schottky Institute, School of Computation, Information and Technology and MCQST, Technische Universität München, Garching, Germany

In this work, we explore the time-dependent, frequency-filtered [1] photon statistics of a two-level system under pulsed excitation, whose dynamical emission spectrum [2] has been recently experimentally measured using semiconductor QDs [3]. Our results show that photon statistics are not fixed [4] but vary between bunching and antibunching, depending on the applied frequency filters. This reveals an intricate interplay between pulse area, photon frequencies, and correlations, extending insights from the CW case [5]. Notably, frequency-filtering enhances time-bin applications: for odd pulses, it suppresses two-photon events by up to two orders of magnitude, while for even pulses, it restores single-photon purity. This approach simplifies entanglement generation by enabling photon-number control [6] via frequency selection, eliminating the need for complex excitation schemes. [1] E. del Valle et al. PRL 109(18):183601 (2012). [2] Moelbjerg, A. et al. PRL.108, 017401 (2012). [3] Boos, K. et al. PRL.132, 053602 (2024). [4] Fischer, K. et al. Nature Phys 13, 649*654 (2017). [5] J.C. Lopez Carreno et al. Laser & Photonics Reviews, 11(5):1700090 (2019). [6] Wein, S.C et al. Nat. Photon. 16, 374*379 (2022).

HL 57.4 Fri 10:15 H13

Resonance fluorescence measurements on rapid thermally annealed self-assembled quantum dots — H. Mannel[1], •F. Rimek[1], M. Zöllner[1], N. Schwarz[1], N. Bart[2], A. Ludwig[2], A. D. Wieck[2], A. Lorke[1], and and M. Geller[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

A single self-assembled quantum dots (QD) is one of the promising candidate as a bright (high photon rate) and stable (fourier-limited) linewidth single photon source [1]. They are typically grown by molecular beam epitaxy (MBE) and have photon emission energies in the near-infrared spectrum. There are several techniques to control the size, which shift the emission wavelength. The so-called indium flush is often used, where the tip of the dot is thermally flushed away [2]. Alternatively, the confinement can be altered by rapid thermal annealing (RTA) [3], which lets indium and gallium diffuse. Here, we investigate the optical properties of rapidly thermally annealed quantum dots. In particular, we study the effects of RTA on the resonance fluorescence line width. This is done by three different measurements. First, we scan over the applied gate voltage and calculate the linewidth using the Stark shift of the exciton. Second, we scan the linewidth directly with a tunable laser. In addition, we study the lifetime in pulsed resonant measurements. The change in the confinement potential might also change dephasing processes such as photoemission or the Auger effect.
[1] N. Tomm et al., Nat. N. **16**, 399-403 (2021). [2] H. Sasakura et al., JAP **102**, 013515 (2007). [3] N. Perret et al., PRB **62**, 5092 (2000).

HL 57.5 Fri 10:30 H13

Exploring the limits of absolute position accuracy in single emitter localization microscopy — •Maximilian Heller, Chenxi Ma, Timon Handrup, Yiteng Zhang, Xian Zheng, Micheal Zopf, and Fei Ding — Leibniz Universität Hannover, Institut für Festkörperphysik, Appelstraße 2, 30167 Hannover

Solid-state single photon emitters (SPEs) integrated in photonic nanostructures provide highly efficient light-matter interfaces for quantum information applications. Wide-field optical positioning has shown the potential to be an inexpensive method with high troughput to achieve the desired spatial matching of SPEs to the nanostructure. However, the accuracy of optical positioning setups has been overlooked so far and mainly the fitting uncertainty has been used as figure of merit. Here, we use arrays of gold nanodisks with pre-defined positions to systematically quantify the main sources of error in fabrication and imaging. From this, we develop a comprehensive calibration model to render the systematic errors insignificant compared to the uncertainties. We demonstrate that the careful calibration of the optical positioning process leads to an increased yield of quantum photonic devices by fabricating and characterizing a large number of circular Bragg gratings around epitaxial quantum dots.

HL 57.6 Fri 10:45 H13

On-demand storage and retrieval of single photons from a semiconductor quantum dot in a room-temperature atomic vapor memory — •Avijit Barua[1], Benjamin Maass[1,2], Norman Vincenz Ewald[1,2], Elizabeth Robertson[2], Kartik Gaur[1], Suk In Park[3], Sven Rodt[1], Jin-Dong Song[3], Stephan Reitzenstein[1], and Janik Wolters[2] — [1]Technische Universität Berlin (TUB), Berlin, Germany — [2]German Aerospace Center (DLR), Berlin, Germany — [3]Korea Institute of Science and Technology (KIST), Seoul, Republic of Korea

Interfacing light from solid-state single-photon sources with scalable and robust room-temperature quantum memories has been a long-standing challenge in photonic quantum information technologies due to inherent noise processes and time-scale mismatches between the operating conditions of solid-state and atomic systems. Here, we demonstrate on-demand storage and retrieval of single photons from a semiconductor QD device in a room-temperature atomic vapor memory. A deterministically fabricated InGaAs QD light source emits single photons at the wavelength of the cesium D1 line at 895 nm which exhibit an inhomogeneously broadened linewidth of 5.1(7) GHz and are subsequently stored in a low-noise ladder-type cesium vapor memory. We show control over the interaction between the single photons and the atomic vapor, allowing for variable retrieval times of up to 19.8(3) ns at an internal efficiency of 0.6(1)%. Our results significantly expand the application space of both room-temperature vapor memories and semiconductor QDs in future quantum network architectures.

15 min. break

HL 57.7 Fri 11:15 H13

Effects of atomistic fluctuations on the excitonic fine-structure in alloyed colloidal quantum Dots — •Anne Nadine Tewonoue Djota, Surender Kumar, and Gabriel Bester — Institute of physical chemistry and physics, University of Hamburg

The electron-hole exchange interaction in the presence of spin-orbit coupling leads for an atomistic calculation to a small energy splitting of the excitonic state known in this context as the fine structure splitting (FSS). Although this splitting is typically small, it has large consequences for the optical properties. For instance, the photoluminescence originates from these few states and is governed by the splitting (giving rise to temperature dependence) and polarization of these low energy excitonic states. So far most of the theoretical modeling has assumed that high symmetry structures lead to a simple dark-bright splitting with a large degeneracy of the excitonic states. In this work, we show based on atomistic calculations, that even globally perfectly symmetric structures (i.e., as far as an atomistic construction permits a "spherical" quantum dot) show a qualitatively different FSS as soon as alloying is introduced. The alloying effect is significantly stronger than any global shape anisotropy where the symmetry is broken for instance by geometrical elongation of the quantum dot. On the other hand, alloying a quantum dot through processes such as cation exchange is inherently random. As a result, different random alloy configurations with the same size and composition can exhibit significantly different FSS.

HL 57.8 Fri 11:30 H13

How Surface Defects Shape the Excitons and Photoluminescence of Ultrasmall CdSe Quantum Dots — •Torben Steenbock[1], Emilia Drescher[1], Tobias Dittmann[1], and Gabriel Bester[2,3] — [1]Department of Chemistry, University of Hamburg, HARBOR, Hamburg 22761, Germany. — [2]Department of Chemistry and Physics, University of Hamburg, HARBOR, Hamburg 22761, Germany. — [3]The Hamburg Centre for Ultrafast Imaging, Hamburg 22761, Germany.

Ultrasmall CdSe quantum dots (QDs) with diameters up to 2 nm show broad photoluminescence (PL) spectra presumably due to emission from band-edge excitons and defect states. However, the origin of the defect emission and the effect of defects on the band-edge excitons is not fully understood. Based on spin-orbit density functional theory and screened configuration interaction singles, we show that Cd-dimer and Se defects form in-gap defect states. In comparison with experiment, we discuss the role of deep and shallow defect states for the PL and cover the dependence of their contributions to the PL with respect to the QD size. Further, we observe that these defects lead to a localization of the molecular orbitals (MOs) involved in the band-edge excitons creating large electric dipoles in the MOs. In the excitonic states, these dipoles cause multiexponential PL decay from the band-edge states with a highly anisotropic polarization of the emission. The polarization is found to be very sensitive with respect to the exact composition of the surface.

HL 57.9 Fri 11:45 H13

Room-temperature single photon emitters in hexagonal boron nitrite coupled to an open optical cavitiy — •Anthony Ernzerhof, Lukas Lackner, Martin Esmann, Ivan Solovev, and Christian Schneider — Carl von Ossietzky Universität Oldenburg, Germany

Single photon emitters (SPEs) are a key component in photonic quantum technologies. Potential applications include secure communications and quantum metrology. Here, we present SPEs at room temperature (RT) based on hexagonal boron nitride (hBN) nano crystallites, which exhibit remarkable optical properties[1]. Our work focuses on the integration of these SPEs in an optical cavity with open access and full tunability. The cavity device allows to enhance the emitter performance via the Purcell effect, which significantly improves the emitter emission rate and source collection efficiency[2]. We discuss our technological approach towards engineering the open cavity yielding a flexible, transportable, compact and userfriendly opto-mechanically tunable emitter-cavity device, which, in principle, is of universal use beyond hBN based single photon sources. We further discuss challenges associated to the implementation of hBN nano-crystallites in such a cavity.

[1] Tran, T.et al. Quantum emission from hexagonal boron nitride monolayers. Nature Nanotech 11, 37-41 (2016). [2] Tobias Vogl et al. Compact Cavity-Enhanced Single-Photon Generation with Hexagonal Boron Nitride, ACS Photonics 6 (8), 1955-1962 (2019).

HL 57.10 Fri 12:00 H13

Silicon nitride-based photonic integrated circuit interfaced via photonic wire bonds with InGaAs-QDs emitting at telecom wavelength — •Ulrich Pfister[1], Daniel Wendland[2,3], Florian Hornung[1], Lena Engel[1], Hendrik Hüging[2], Elias Herzog[1], Ponraj Vijayan[1], Raphael Joos[1], Erik Jung[3], Michael Jetter[1], Simone L. Portalupi[1], Wolfram H. P. Pernice[2,3], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen (IHFG), Center for Integrated Quantum Science and Technology (IQ^{ST}) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [2]Institute of Physics and Center for Nanotechnology, University of Münster, 48149 Münster, Germany — [3]Kirchhoff-Institute for Physics, University of Heidelberg, 69120 Heidelberg, Germany

Photonic integrated circuits (PICs) play a crucial role for realizing several quantum technologies in a small footprint. In this regard, hybrid approaches are beneficial for combining the highly developed silicon platform with the on-demand single-photon emission of III-V semiconductor quantum dots (QDs). We employed 3D laser writing technology to realize photonic wire bonds (PWBs) for funnelling single-photons from the III-V-based chip, containing the QDs emitting at 1550nm, into a Si_3N_4-based PIC [1]. An on-chip beamsplitter was used to measure a $g^{(2)}(0) = 0.11 \pm 0.02$, demonstrating the functionality of the hybrid approach on a single-photon level. Additionally, the average efficiency of the PWBs was precisely quantified.
[1] Ulrich Pfister, *et al.*, arXiv:2411.05647

HL 57.11 Fri 12:15 H13

Quantum Communication Protocols Using Polarization-Entangled Photon Emitters — Michele Rota[1], Francesco Basso Basset[1], •Francesco Salusti[2], Alessandro Laneve[1], Mattia Beccaceci[1], Giuseppe Ronco[1], Nicolas Claro Rodriguez[2], Thobias Krieger[3], Quirin Buchinger[4], Saimon Filipe Covre Da Silva[3], Sandra Stroj[5], Sven Höfling[4], Tobias Huber-Loyola[4], Armando Rastelli[3], Klaus Jöns[2], and Rinaldo Trotta[1] — [1]Department of Physics, Sapienza University of Rome, 00185 Rome, Italy — [2]PhoQS, CeOPP and Department of Physics, Paderborn University, 33098 Paderborn, Germany — [3]Institute of Semiconductor and Solid State Physics, JKU University, 4040 Linz, Austria — [4]Julius-Maximilians-Universität Würzburg, Physikalisches Institut, 97074 Würzburg, Germany — [5]Forschungszentrum Mikrotechnik, FH Vorarlberg, 6850 Dornbirn, Austria

We demonstrate entanglement swapping using [1] a quantum dot in a novel cavity with piezoelectric actuators [2]. We use these entan- gled photons after the swapping operation for quantum key distribu- tion with a modified Ekert91 protocol [3], highlighting temporal post- selection*s impact on photon indistinguishability and protocol metrics.
References: [1] J.-W. Pan, et al., Phys. Rev. Lett. 80, 3891 (1998) [2] M. B. Rota, et al., eLight 4, 13 (2024), ISSN 2662-8643 [3] F. B. Basset, et al., Science Advances 7, eabe6379 (2021)

HL 57.12 Fri 12:30 H13

Efficient fiber coupling of telecom single photons from circular Bragg gratings — •Nam Tran[1], Pavel Ruchka[2], Sara Jakovljevic[2], Benjamin Breiholz[1], Peter Gierss[1], Ponraj Vijayan[1], Carlos Eduardo Jimenez[3], Alois Herkommer[3], Michael Jetter[1], Simone Luca Portalupi[1], Harald Giessen[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQ^{ST}) and SCoPE, University of Stuttgart — [2]4. Physikalisches Institut, Center for Integrated Quantum Science and Technology (IQ^{ST}) and SCoPE, University of Stuttgart — [3]Institut für Technische Optik, Research Center of Photonic Engineering, SCoPE, University of Stuttgart

This work aims at quantitatively investigating the spatial stability and coupling efficiency of telecom C-band photons, generated by an epitaxial quantum dot embedded in a circular Bragg grating, into single mode optical fibers. These results are then compared to a bare single mode fiber without the 3D printed lens and a collection via a microscope objective. In terms of the total fiber coupling efficiency, the lensed and bare fiber outperform the microscope objective by up to a factor of 2.9 corresponding to a measured count rate at the detectors of 0.44MHz and 1.11MHz, respectively. The lateral (vertical) displacement showed that within a few (a few tenths) of microns the coupling degrades less than a factor of two.

HL 57.13 Fri 12:45 H13

Development of Stark-tuned InGaAs quantum dots emitting in the telecom O-band on silicon substrate — •Sarthak Tripathi, Kartik Gaur, Imad Limame, Priyabrata Mudi, Sven Rodt, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, D-10623 Berlin

Quantum dots (QDs) are promising for single-photon emission, essen tial for quantum technologies like secure communication and quantum key distribution (QKD). In particular, InGaAs QDs that emit photons in the telecom O-band are especially valuable due to their compatibility with current metropolitan fiber-based QKD systems. Additionally, it is interesting to develop Si-compatible device concepts. Achieving High quality QDs on silicon are challenging due to lattice mismatch with III-V materials, leading to defects and performance degradation. To overcome this, we use a GaP buffer layer to reduce strain, improve lat tice matching, enabling high-quality QD growth with low defect den sities.By integrating epitaxial n- and p-doped GaAs layers with ohmic contacts, we apply an electric field to modify the QD energy levels via Stark effect, allowing controlled tuning of the emission wavelength. This tunability is crucial for aligning the QD emission with telecom standards or compensating for fabrication-induced variations. Optical and quantum optical characterizations confirm the effectiveness of this approach, demonstrating excellent quantum optical properties. These results highlight the potential of electrically tunable InGaAs QDs on Si as a scalable platform for quantum communication, compatible with Si-based technologies and fiber-based telecom networks.