HL 19: Quantum Dots and Wires: Optics I

Time: Tuesday 9:30–13:00 Location: EW 202

HL 19.1 Tue 9:30 EW 202

Dynamics of Robust Photonic Cluster-State Generation from Quantum-Dot Molecules — •David Bauch, Nikolas Köcher, Nils Heinisch, and Stefan Schumacher — Physics Department, CeOPP, and PhoQS, Paderborn University, Germany

Quantum Dot Molecules (QDMs) have garnered significant attention for their role in measurement-based quantum computation and communication, specifically due to their ability to generate indistinguishable and temporally strongly entangled photon states [1]. Recent theoretical strides have advanced methods for generating these states across various physical systems. Within the intrinsically emerging lambda systems in QDMs, rotations and excitations between the ground states facilitate photon generation, contributing to the formation of cluster states, photonic graph states, and beyond [1,2]. Our research focusses on the generation of simple linear cluster states from QDMs. We demonstrate temporal dynamics, strong correlations, time-bin entanglement through stabilizer generator expectation values and indistinguishability among emitted photons. Our numerical exploration provides detailed insights into the efficiency and viability of the emission protocol for the deterministic generation of highly entangled photonic cluster states. This serves as a crucial steppingstone for advancing the generation of more intricate states such as higher dimensional photonic cluster and graph states, marking a noteworthy step towards the utilization of photonic quantum states in practical applications.

[1] Vezvaee et al., Phys. Rev. Appl. 18.L061003 (2022). [2] Raissi et al., arXiv preprint 2211.13242 (2022)

HL 19.2 Tue 9:45 EW 202

Magneto-optical generation and characterization of dark exciton state in a quantum dot — •René Schwarz[1], Florian Kappe[1], Yusuf Karli[1], Thomas Bracht[2], Saimon Covre da Silva[3], Armando Rastelli[3], Vikas Remesh[1], Doris Reiter[2], and Gregor Weihs[1] — [1]Institute für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [2]Condensed Matter Theory, Department of Physics, TU Dortmund, Dortmund, Germany — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Linz, Austria

Semiconductor quantum dots are arguably the most promising platform for future quantum technologies. Due to the confinement of charge carriers, a variety of photon states can be generated, making them a highly adaptable quantum platform. While the most common optical excitation methods target the so-called bright excitons or biexcitons for the generation of single or entangled photon states, quantum dots also accommodate optically dark excitons, which are not directly accessible via optical excitation methods. The dark exciton states exhibit significantly slower decay rates compared to their bright counterparts, making them potential candidates for application in quantum information protocols that demand the control of quantum coherence over long time scales [1]. In this work, we generate the dark exciton states in a single GaAs/AlGaAs quantum dot emitting ~ 800 nm under a magneto-optical excitation (in-plane magnetic field ~ 3.2 T), and characterize the emission energy splitting, lifetime variation and polarization response. [1] Phys. Rev. Lett. 94, 030502 (2005)

HL 19.3 Tue 10:00 EW 202

Stimulated excitation and coherent control of dark exciton state population in a quantum dot — •Florian Kappe[1], René Schwarz[1], Yusuf Karli[1], Thomas Bracht[2], Saimon Covre da Silva[3], Armando Rastelli[3], Vikas Remesh[1], Doris Reiter[2], and Gregor Weihs[1] — [1]Institute für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [2]Condensed Matter Theory, Department of Physics, TU Dortmund, Dortmund, Germany — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Linz, Austria

Semiconductor quantum dots, with their capability of confining charge carriers and various spin configurations resulting from it, can be regarded as a highly versatile platform for generating non-classical light. While the generation of single photons or entangled photon pairs from quantum dots utilizes the so-called bright excitons and biexcitons respectively, quantum dots can also host optically dark excitons. Such states are optically inactive due to the spin-selection rules. Due to their longer coherence times, a direct and coherent optical excitation and control of dark states are of great interest in modern quantum information protocols [1]. In this work we demonstrate a stimulated excitation and coherent control of the dark exciton population via the biexciton state in a GaAs/AlGaAs quantum dot in presence of an in-plane magnetic field. The versatility of our scheme allows not only a deterministic preparation, but storage and a temporal retrieval of the dark state population, giving rise to a programmed single photon/photon pair emission.

HL 19.4 Tue 10:15 EW 202

Coherent Preparation of High Quality Single Photon States — •Yusuf Karli[1], Florian Kappe[1], Ria G. Krämer[2], René Schwarz[1], Thomas K. Bracht[3], Daniel Richter[2], Doris E. Reiter[3], Stefan Nolte[2], Gregor Weihs[1], and Vikas Remesh[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, 6020, Innsbruck, Austria — [2]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Center of Excellence in Photonics, 07745 Jena, Germany — [3]Condensed Matter Theory, Department of Physics, TU Dortmund, 44221 Dortmund, Germany

Traditional Two-Photon Excitation (TPE) methods not only face challenges related to indistinguishability and photon number coherence but also exhibit sensitivities to the excitation laser pulse parameters. In response, we introduce a Stimulated Two-Photon Excitation (sTPE) within Adiabatic Rapid Passage(ARP) process , where a second laser pulse resonant with the biexciton-to-exciton transition significantly reduces time jitter, enhancing both indistinguishability and photon number coherence. Experimental results demonstrate the effectiveness of sTPE within Adiabatic Rapid Passage (ARP) schemes, offering a promising avenue for robust single-photon generation to advance quantum communication technologies.

HL 19.5 Tue 10:30 EW 202

Electron capture dynamics into self-assembled quantum dots far from equilibrium with their environment — •Lukas Berg[1], Laurin Schnorr[1], Thomas Heinzel[1], Arne Ludwig[2], and Andreas Dirk Wieck[2] — [1]Heinrich-Heine Universität, Düsseldorf, Germany — [2]Ruhr-Universität, Bochum, Germany

The electron capture process in self-assembled quantum dots at large distance from the reservoirs is studied by deep level transient spectroscopy. Capture rates are obtained as a function of temperature, applied bias voltage and quantum dot occupancy. The observed activated character of the capture suggests that the back contact is the dominant electron source. A model is developed where electrons diffuse from the reservoir across the barrier onset from the space charge region to be captured by the self-assembled quantum dots.

HL 19.6 Tue 10:45 EW 202

Entanglement in Resonance Fluorescence — •Santiago Bermúdez Feijóo[1], Juan Camilo Lopez Carreño[2], and Magdalena Stobinska[3] — [1]Departamento de Fisica, Universidad Nacional de Colombia, Ciudad Universitaria, K. 45 No. 26 85, Bogota D.C., Colombia — [2]Institute of Theoretical Physics, University of Warsaw, ul. Pasteura 5, 02-093, Warsaw, Poland — [3]Faculty of Mathematics, Informatics and Mechanics, University of Warsaw, ul. Banacha 2, 02-097 Warsaw, Poland

Particle entanglement is a fundamental resource upon which are based many quantum technologies. In this Article, we introduce a new source of entangled photons based on resonance fluorescence delivering photon pairs as a superposition of vacuum and the Bell state $|\Phi-\rangle$. Our proposal relies on the emission from the satellite peaks of a two-level system driven by a strong off-resonant laser, whose intensity controls the frequencies of the entangled photons. Notably, the frequency of the entangled photons can be tuned without decreasing their degree of entanglement and, unlike current technologies, the intensity of our source can be increased without the risk of spoiling the signal by involving high-order processes into the emission. Finally, we illustrate the power of our novel source by exciting an ubiquitous condensed-matter system, namely polaritons, and showing that they are left in a maximally entangled steady state.

30 min. break

HL 19.7 Tue 11:30 EW 202

Temperature-independent photon entanglement from quantum dots — •Thomas Bracht[1,2], Moritz Cygorek[3], Tim Seidelmann[4], Vollrath Martin Axt[4], and Doris E. Reiter[2] — [1]Institut für Festkörpertheorie, Uni Münster, DE — [2]Condensed Matter Theory, TU Dortmund, DE — [3]Heriot-Watt University, Edinburgh, UK — [4]Theoretische Physik III, Universität Bayreuth, DE

High levels of entanglement are essential for reliable quantum communication. In this context, quantum dots have emerged as a promising platform, offering excellent photon properties and controllability.

Here, I propose a novel approach to achieve maximal entanglement, overcoming previous shortcoming for example in two-photon excitation. Building upon the Swing-Up of Quantum Emitter (SUPER) scheme, I demonstrate its efficiency in generating entangled photon pairs from quantum dot systems in optical cavities [1]. An important aspect of this approach is the decoupling of the preparation process from the subsequent photon emission, enabling an effective initial-value problem, previously inaccessible in two-photon absorption settings. By leveraging this decoupling, an entanglement with unprecedentedly high fidelity is achieved, even when accounting for phonon interaction at elevated temperatures up to 80K. This makes the approach interesting for the use in real-world quantum communication scenarios.

[1] T. K. Bracht et al., Optica Quantum (accepted, 2024)

HL 19.8 Tue 11:45 EW 202

Development and deterministic fabrication of electrically controlled quantum dot bullseye resonators — •Setthanat Wijitpatima[1], Priyabrata Mudi[1], Avijit Barua[1], Normen Auler[2], Binamra Shrestha[2], Sven Rodt[1], Dirk Reuter[2], and Stephan Reitzenstein[1] — [1]Institute of Solid-State Physics, Technische Universität Berlin, D-10623 Berlin, Germany — [2]Center of Optoelectronics and Photonics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany

Quantum repeaters hold the potential to contribute to long-distance quantum communication significantly. They can be made of such quantum light sources with high photon extraction efficiency (PEE), high single-photon purity, high indistinguishability, and precise control over spectral features. We present a new device design enabling the electrical control of quantum dots (QDs) by deterministically integrating them into electrically connected bullseye resonators. Numerical simulations are conducted to optimize both the epitaxial layer structure and the nanophotonic device design achieving a high PEE of 74% at a numerical aperture of 0.8. Marker-based cathodoluminescence scans are performed to pre-select suitable QDs, which are then pre-characterized via electric-field-dependent micro-photoluminescence measurements before electron beam lithography is performed to fabricate QD-bullseye resonators. After the integration, the post-characterizations are carried out on the same QDs to study the effect of device fabrication on their electro-optical properties.

HL 19.9 Tue 12:00 EW 202

Swing-Up Dynamics in Quantum Emitter Cavity Systems: Near Ideal Single Photons and Entangled Photon Pairs — •Nils Heinisch, Nikolas Köcher, David Bauch, and Stefan Schumacher — Physics Department, CeOPP, and PhoQS, Paderborn University, Germany

In the SUPER scheme (Swing-UP of the quantum EmitteR population) excitation of a quantum emitter is achieved with two off-resonant, red-detuned laser pulses, as theoretically [1] and experimentally demonstrated [2,3]. In particular, this approach promises generation of high-quality single photons without the need of complex laser stray light suppression or careful spectral filtering. In the present work we extend this method to quantum emitters, specifically semiconductor quantum dots (QDs), inside a resonant optical cavity [4-6]. A significant advantage of the SUPER scheme is identified in that it eliminates re-excitation of the quantum emitter by suppressing photon emission during the excitation cycle via the AC-Stark effect. This, in turn, leads to almost ideal single photon purity, overcoming a major factor typically limiting the quality of photons generated with quantum emitters in high quality cavities. We further find that for cavity-mediated degenerate photon-pair generation from the QD biexciton the SUPER excitation does not spoil the polarization entanglement. [1] T. K. Bracht et al., PRX Quantum 2, 040354 (2021). [2] Y. Karli et al., Nano Letters 22, 6567 (2022). [3] K. Boos et al., arXiv:2211.14289 (2022). [4] N. Heinisch et al., arXiv:2303.12604 (2023). [5] L. Vannucci et al., PRB 107, 195306 (2023). [6] T. K. Bracht et al., arXiv:2307.00304 (2023).

HL 19.10 Tue 12:15 EW 202

Deterministic nanofabrication of Purcell-enhanced single-photon sources based GaAs quantum dots — •Dinara Basharova[1], Nand Lal Sharma[2], Ching-Wen Shih[1], Chirag Palekar[1], Alexander Kosarev[1], Sven Rodt[1], Sai Abhishikth Dhurjati[2], Caspar Hopfmann[2], and Stephan Reitzenstein[1] — [1]Institute of Solid State Physics, Technische Universität Berlin, D-10623 Berlin, Germany — [2]Leibniz Institute for Solid State and Materials Research Dresden, 01069 Dresden, Germany

On-demand single-photon and entangled photon pair sources based on semiconductor quantum dots (QDs) have drawn a great attention in the applications of quantum technologies, including quantum networks and computation. In quantum communication networks, quantum repeaters with QDs are necessary to extend the range of communication distance. In our work, we deterministically integrate semiconductor heterostructures with high-quality GaAs quantum dots emitting at 780 nm into circular Bragg grating (CBG) resonators with a gold mirror. Our design exhibits a theoretical photon extraction efficiency above 70% and a Purcell factor exceeding 14. In addition, in combination with reflectance measurement, we optimize the fabrication process to achieve excellent cavity performance. We use marker based electron beam lithography (EBL) as precise deterministic nanofabrication technique. The fabricated quantum light sources are characterized by high-resolution cathodoluminescence, micro-photoluminescence, and quantum optical spectroscopy, showing multi-photon emission suppression with g(2)(0) = 93%.

HL 19.11 Tue 12:30 EW 202

Quantum optical properties of resonantly excited semiconductor quantum dots embedded in hybrid circular Bragg Gratings — •Martin von Helversen[1], Lucas Rickert[1], Daniel Vajner[1], Johannes Schall[1], Shulun Li[1,2], Sven Rodt[1], Zhichuan Niu[2], Stephan Reitzenstein[1], and Tobias Heindel[1] — [1]Institute of Solid State Physics, Technical University Berlin, Berlin, Germany — [2]Institute of Semiconductors, Chinese Academy of Sciences, Beijing, China

Aiming at the efficient on-demand generation of indistinguishable and highly pure single-photons, semiconductor quantum dots have proven excellent candidates - to large extend also due to the vast progress in their integration into photonic cavities. Amongst these, hybrid circular Bragg Gratings (hCBGs) have quickly become a well established choice, due to their broad outcoupling enhancement combined with high Purcell factors. Owed to the possible generation of polarization entangled photons, much research focuses on two-photon-resonant excitation.

In this work, we take advantage of a deterministically integrated QD in a hybrid CBG with a T_1-time below 50 ps to study its quantum optical properties under quasi-resonant p-shell as well as resonant s-shell excitation, the latter in continuous wave as well as in the pulsed regime under varying optical pulse-lengths. While purities exceeding 98% are achieved even under p-shell, we observe indistinguishable photons with a non-postselected visibility of over 88% under resonant excitation.

HL 19.12 Tue 12:45 EW 202

Highly coherent GaAs-based microcavity polaritons dots at 200 K — •Ismael dePedro-Embid, Alexander Kuznetsov, Klaus Biermann, and Paulo Santos — Paul-Drude-Institut für Festkörperelektronik, Berlin, Deutschland

Microcavity (MC) polaritons, serve as an exceptional bridge between condensed matter and photonic systems. Achieving precise control over their spatial distribution, stability, and coherence is crucial for unlocking their full potential in practical applications. This can be achieved by creating zero-dimensional polariton dots by lateral confinement within the MC spacer. In this study, we investigate the effects of lateral confinement on the energy and temporal coherence of MC polaritons in (Al, Ga) As intracavity dots at temperatures up to 200 K, which are much higher than the usually studied temperatures of around 10 K for this material system. Our experimental results show that the spectral linewidths of the confined polariton states are substantially narrower than their unconfined counterparts, demonstrating that confinement significantly enhances the temporal coherence across a broad range of dot dimensions. A comprehensive analysis of the temperature dependence of the resonances points to protection from low-energy acoustic phonon scattering as the primary mechanism for linewidth narrowing. The latter underscores the effectiveness of lateral confinement as a method for engineering polariton-phonon interaction at high temperatures. This work thus establishes the feasibility of GaAs-based polariton structures with long temporal coherence at high temperatures.