HL 8: Quantum Dots and Wires 2: Optics 1

Time: Monday 15:00–18:15 Location: H32

Invited Talk HL 8.1 Mon 15:00 H32

Crux of Using the Cascaded Emission of a Three-Level Quantum Ladder System to Generate Indistinguishable Photons — •Eva Schöll[1,2], Lucas Schweickert[2], Lukas Hanschke[1,3], Katharina D. Zeuner[2], Friedrich Sbresny[3], Thomas Lettner[2], Rahul Trivedi[4], Marcus Reindl[5], Saimon Filipe Covre da Silva[5], Rinaldo Trotta[6], Jonathan Finley[3], Jelena Vučković[4], Kai Müller[3], Armando Rastelli[5], Val Zwiller[2], and Klaus D. Jöns[1,2] — [1]PhoQS, CeOPP, and Department of Physics, Paderborn University, Germany — [2]KTH Stockholm, Sweden — [3]WSI, MCQST and TUM Munich, Germany — [4]Stanford University, California, USA — [5]JKU Linz, Austria — [6]Sapienza University Rome, Italy

Single and indistinguishable photons are basic building blocks for many quantum technology applications. Here (PRL, **125**, 233605 (2020)), we investigate the degree of indistinguishability of cascaded photons emitted from a three-level quantum ladder system; in our case the biexciton-exciton cascade of semiconductor quantum dots. Despite unprecedented single-photon purity, we theoretically show that the indistinguishability for both emitted photons is inherently limited by the ratio of the lifetimes of the excited and intermediate states. We confirm this finding both experimentally and with quantum optical simulations by comparing the quantum interference visibility of cascaded and non-cascaded exciton emission of the same quantum dot. Based on our model, we propose photonic structures or stimulated emission (PRL, **128**, 093603, (2022)) from the excited to the intermediate state to increase the lifetime ratio and overcome the limited indistinguishability.

HL 8.2 Mon 15:30 H32

Carrier dynamics in quantum-dot tunnel- injection structures: microscopic theory and experiment — •Michael Lorke[1], Igor Khanonkin[2], Stephan Michael[1], Johann Peter Reithmaier[3], Gadi Eisenstein[2], and Frank Jahnke[1] — [1]Institute for Theoretical Physics, University of Bremen, Otto-Hahn-Allee 1, Bremen, 28359, Germany — [2]Electrical Engineering Department and Russel Berrie Nanotechnology Institute, Technion, Haifa, 32000, Israel — [3]Technische Physik, Institute of Nanostructure Technologies and Analytics, Center of Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Kassel, 34132, Germany

Among the challenges for the next generation of semiconductor lasers is the enhancement of their modulation speed to satisfy the need for higher data transfer rates. For this purpose, tunnel injection lasers are an appealing concept, as they promise improved modulation rates and better temperature stability. Moreover, they eliminate a major detrimental effect of quantum dot lasers, which is the gain nonlinearity caused by hot carriers. It is shown in this work how the aforementioned improvements depend on the design of tunnel-injection devices. We perform a theory-experiment comparison on scattering times in tunnel injection devices to highlight the importance of alignment between the injector well and the quantum dot ensemble. It is shown how differences in the coupling to the injector quantum well caused by the alignment lead to scattering times into the quantum dot ensemble that vary by an order of magnitude.

HL 8.3 Mon 15:45 H32

Statistical limits for entanglement swapping with independent semiconductor quantum dots — •Jingzhong Yang[1], Michael Zopf[1], Pengji Li[1], Nand Lal Sharma[2], Weijie Nie[2], Frederik Benthin[1], Tom Fandrich[1], Eddy Patric Rugeramigabo[1], Caspar Hopfmann[2], Robert Keil[2], Oliver. G. Schmidt[2,3,4], and Fei Ding[1,5] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Institute for Integrative Nanosciences, Leibniz IFW Dresden, Helmholtzstraße 20, 01069 Dresden, Germany — [3]Material Systems for Nanoelectronics, Technische Universität Chemnitz, 09107 Chemnitz, Germany — [4]Nanophysics, Faculty of Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden, Germany — [5]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Schneiderberg 39, 30167 Hannover, Germany

Semiconductor quantum dots are promising constituents for future quantum communication. Here we explore the limits for sources of polarization-entangled photons from biexciton-exciton cascade of the quantum dots. We stress the necessity of tuning the exciton fine structure, and explain why the time evolution of photonic entanglement in quantum dots is not applicable for large quantum networks. We identify the critical device parameters and present a numerical model for benchmarking the device scalability in order to bring the realization of distributed semiconductor-based quantum networks one step closer to reality.

HL 8.4 Mon 16:00 H32

Maximally entangled and GHz-clocked on-demand photon pair source — •Caspar Hopfmann[1], Weijie Nie[1], Nand Lal Sharma[1], Carmen Weigelt[1], Fei Ding[2], and Oliver G. Schmidt[1,3,4] — [1]Institute for Integrative Nanosciences, Leibniz IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover, Germany — [3]Material Systems for Nanoelectronics, Technische Universität Chemnitz, 09107 Chemnitz, Germany — [4]Nanophysics, Faculty of Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden, Germany

We present a 1 GHz-clocked, maximally entangled and on-demand photon pair source based on droplet etched GaAs quantum dots using two-photon excitation. By employing these GaP microlens-enhanced devices in conjunction with their substantial brightness, raw entanglement fidelities of up to 0.95 and post-selected photon indistinguishabilities of up to 0.93, the suitability for quantum repeater based long range quantum entanglement distribution schemes is shown. Comprehensive investigations of a complete set of polarization selective two-photon correlations facilitate an innovative method to determine the extraction and excitation efficiencies directly - opposed to commonly employed indirect techniques. Additionally, time-resolved analysis of Hong-Ou-Mandel interference traces reveal an alternative approach to the investigation of pure photon dephasing.

HL 8.5 Mon 16:15 H32

Photoneutralization of charges in GaAs quantum dot based entangled photon emitters — Jingzhong Yang[1], Tom Fandrich[1], •Frederik Benthin[1], Robert Keil[2], Nand Lal Sharma[2], Weijie Nie[2], Caspar Hopfmann[2], Oliver G. Schmidt[2,3,4], Michael Zopf[1], and Fei Ding[1,5] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]Institute for Integrative Nanosciences, Leibniz IFW Dresden, Germany — [3]Material Systems for Nanoelectronics, Technische Universität Chemnitz, Germany — [4]Nanophysics, Faculty of Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, Germany — [5]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Germany

Semiconductor-based quantum dot emitters are an attractive source for generating pairwise photonic entanglement and a promising constituent of photonic quantum technologies. However, quantum dots typically suffer from luminescence blinking, lowering the efficiency of the source and hampering their scalable application in quantum networks. We investigate the spectral and quantum optical response of the quantum dot emission by introducing an additional wavelength tunable gate laser. Under two-photon resonant excitation of the neutral biexciton in a GaAs/AlGaAs quantum dot, the blinking of the neutral exciton emission was observed. Our finding demonstrates that the emission blinking can be actively suppressed by controlling the balance of free electrons and holes in the vicinity of the quantum dot thereby significantly increasing the quantum efficiency by 30%.

30 min. break

HL 8.6 Mon 17:00 H32

Franson interference on a resonantly driven biexciton cascade — •Marcel Hohn[1], Kisa Barkemeyer[2], Matthias Kunz[1], Arsenty Kaganskiy[1], Samir Bounouar[1], Alexander Carmele[2], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörper Physik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Institut für Theoretische Physik, Technische Unviersität Berlin, 10623 Berlin, Germany

The deterministic generation of entangled photon pairs is of special interest for applications in quantum communication and computation. As many experiments focus on entanglement in the polarization base, energy-time entangled photons used for Franson interference offer the advantage of high robustness in long-distance fiber transmission. We report on Franson measurements performed in cw mode on the resonantly driven biexciton cascade of a deterministically fabricated quantum dot device. The two-photon visibility of such a three-level system crucially dependents on the decay rates of the ideally long upper- and short living intermediate state [1]. A relation hard to achieve for the biexciton cascade, where the lifetime of the biexciton state is usually short compared to the exciton state. Nevertheless, our measurements yield a high two-photon visibility up to (73 ± 2)%, surpassing the CHSH inequality of 70.7% [2]. This result demonstrates the high potential of generating energy time entangled photons in a resonantly driven biexciton cascade.

[1] K. Barkemeyer, et al., Phys. Rev. A, 103, 62423 (2021)
[2] J. F. Clauser, et al., Phys. Rev. Lett. 23, 880 (1969)

HL 8.7 Mon 17:15 H32

Red Detuned Excitation of a Quantum Dot — •Yusuf Karli[1], Florian Kappe[1], Thomas Bracht[2], Julian Münzberg[1], Tim Seidelmann[3], Vollrath Martin Axt[3], Saimon Covre da Silva[4], Armando Rastelli[4], Vikas Remesh[1], Doris Reiter[5], and Gregor Weihs[1] — [1]Institute für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [2]Institut für Festkörpertheorie, Universität Münster, Münster, Germany — [3]Theoretische Physik III, Universität Bayreuth, Bayreuth, Germany — [4]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Linz, Austria — [5]Condensed Matter Theory, Department of Physics, TU Dortmund, Dortmund, Germany

Semiconductor quantum dots have emerged as promising sources of highly indistinguishable single photons. To operate as an on-demand photon source, a quantum dot must be prepared in its exciton state, for which, several protocols exist. A recent remarkable theoretical discovery, also presented at this conference, showed that the exciton state in a quantum dot can be efficiently populated by two red-detuned pulses in a swing-up mechanism. We demonstrate the experimental implementation of this mechanism relying on amplitude-shaping of a broadband laser pulse in a 4f shaper including a spatial light modulator. The decisive advantage of our scheme is that both pulses are red-detuned and therefore, no higher-lying states of the quantum dot will be directly addressed. Our results contribute towards an effortless method for generating high-purity single photons, yet most importantly, removing the need for stringent polarization filtering.

HL 8.8 Mon 17:30 H32

Dephasing mechanisms revealed by two-photon coincidence measurements — •Julian Wiercinski, Moritz Cygorek, and Erik M. Gauger — SUPA, Institute of Photonics and Quantum Sciences, Heriot-Watt University, Edinburgh, UK

Cooperative effects of entangled quantum emitters play a key role in quantum technologies like, e.g., quantum computing and are known to influence their light emission as well as absorption - a key ingredient for highly efficient quantum batteries and light harvesting complexes. Only recently, cooperative emission of two quantum dots has been observed experimentally.

Inspired by these results we use numerically complete methods to theoretically investigate the impact of different dephasing mechanisms on the cooperative emission of two quantum dots. We show that different dephasing mechanisms lead to severe qualitative differences in the two-photon coincidence signals. These can be explained by the influence of dephasing on the dynamics of the inter-emitter entanglement. Therefore, we argue, two-photon coincidence measurements make dephasing visible in the experiment acting as a probe for underlying dephasing mechanisms.

HL 8.9 Mon 17:45 H32

Bandwidth Limit in Optically Detected Single Electron Tunneling Events — •Jens Kerski[1], Hendrik Mannel[1], Pia Lochner[1], Eric Kleinherbers[1], Annika Kurzmann[2], Arne Ludwig[3], Andreas D. Wieck[3], Jürgen König[1], Axel Lorke[1], and Martin Geller[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Germany — [2]2nd Institute of Physics, RWTH Aachen University, Germany — [3]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

Measurements of single quantum processes have recently attracted increasing attention. One example is the counting of single electron tunnel events in quantum dots. These individual quantum jumps are usually measured electrostatically. However, new optical detection methods have been developed that promise higher time resolution, although their potential has not yet been fully investigated. Here, we study the resonance fluorescence of the excitonic transition from a self-assembled quantum dot embedded in a tailored diode structure.

We detect the optical signal with single photon resolution and use a post-processing procedure to identify the optimal bandwidth for the analysis of our data. We demonstrate that we can evaluate our data with up to 175 kHz bandwidth and show how the chosen bandwidth affects the determined tunneling rates and the evaluation by full counting statistics. Using a simple model, we discuss how the Poisson distribution of the photons limits the time resolution even in ideal measurements and propose how a time resolution of more than 1 MHz could be achieved.

HL 8.10 Mon 18:00 H32

The Origin of Antibunching in Resonance Fluorescence — •Lukas Hanschke[1,2], Lucas Schweickert[3], Juan Camilo López Carreño[4], Eva Schöll[1,3], Katharina D. Zeuner[3], Thomas Lettner[3], Eduardo Zubizarreta Casalengua[4], Marcus Reindl[5], Saimon Filipe Covre da Silva[5], Rinaldo Trotta[6], Jonathan J. Finley[2], Armando Rastelli[5], Elena del Valle[4,7], Fabrice P. Laussy[4,8], Val Zwiller[3], Kai Müller[2], and Klaus D. Jöns[1] — [1]PhoQS, CeOPP, and Department of Physics, Paderborn University, Germany — [2]WSI, MCQST and TU Munich, Germany — [3]KTH Stockholm, Sweden — [4]University of Wolverhampton, UK — [5]JKU Linz, Austria — [6]Sapienza University Rome, Italy — [7]Universidad Autónoma de Madrid, Spain — [8]Moscow, Russia

We present measurements that prove that the simultaneous observation of sub-natural linewidth and antibunching of resonance fluorescence is not possible. High-resolution spectroscopy reveals the sharp spectral feature of the weak driving regime with a vanishing component of incoherently scattered light. Filtering the emission in the order of the Fourier limited linewidth leads to the loss of antibunching in the correlation measurement. Our theoretical model identifies two-photon interference between the coherent and incoherently scattered light as the origin of antibunching. This prefigures schemes to achieve a source of single photons with sub-natural linewidth [PRL 123, 170402 (2020)].