Q 20: QuanTour II – Multi-photon Effects & Entanglement

Inspired by QuanTour, the traveling quantum-dot light source, the sessions QuanTour I-V focus on the physics of quantum light generation in solid-state systems and applications in quantum networks.

Time: Tuesday 11:00–13:00 Location: P 7

Invited Talk Q 20.1 Tue 11:00 P 7

Entangled photons from GaAs quantum dots in tunable circular Bragg resonators — •Armando Rastelli — Institute of Semiconductor and Solid State Physics, Johannes Kepler University, Linz, Austria

Entanglement is one of the most fascinating phenomena in quantum physics and a key resource for quantum technologies. Different from probabilistic sources, Quantum Dots (QDs) can emit polarization entangled photon pairs with negligible probability of multi-pair emission using the biexciton-exciton radiative cascade.

To make such sources practical, it is important to maximize the degree of entanglement, brightness, maximum emission rate, photon indistinguishably, and to be able to fine-tune the wavelength of the emitted photons. Ideally, the source should fulfill these requirements even when operated at temperatures of 30-40 K, that are reachable with compact cryocoolers. Meeting this list of requirements on a single QD device is a formidable challenge.

In this presentation, we will present our contribution to the field by focusing on GaAs QDs embedded in strain- and electrically-tunable circular Bragg resonators (CBRs). By making use of the intrinsically short lifetimes of GaAs QDs, the Purcell enhancement in the CBRs, as well as coherent excitation schemes, we will discuss the feasiblity of practical and scalable sources of entangled photons based on QDs.

Q 20.2 Tue 11:30 P 7

Indistinguishable photons from a two-photon cascade — •Timon L. Baltisberger[1], Francesco Salusti[2], Mark R. Hogg[1], Malwina A. Marczak[1], Nils Heinisch[2], Sascha R. Valentin[3], Arne Ludwig[3], Stefan Schumacher[2], Klaus D. Jöns[2], and Richard J. Warburton[1] — [1]Department of Physics, University of Basel, Switzerland — [2]Department of Physics and Center for Optoelectronics and Photonics Paderborn (CeOPP), Paderborn University, Germany — [3]Lehrstuhl für angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

Two crucial aspects of photon-based quantum technologies are indistinguishability and entanglement, both giving rise to a wide range of non-classical effects. The biexciton → exciton → ground state (XX → X → GS) cascade in self-assembled semiconductor quantum dots can produce polarization-entangled photon pairs [1]. However, the cascaded emission of this ladder system leads to timing jitter in photon emission, translating to a reduced indistinguishability of photons from both transitions [2]. Using the Purcell-effect in an open microcavity [3] to accelerate one transition of the two-step-cascade, we manipulate the timing jitter of the emitted photons in-situ. Our results show excellent agreement between theory and experiments over a wide range of parameters, and the generation of photons with very high indistinguishabilities of 94±2% (XX) and 82±6% (X).

[1] N. Akopian *et al.* Phys. Rev. Lett. **96**, 130501 (2006)
[2] E. Schöll *et al.* Phys. Rev. Lett. **125**, 233605 (2020)
[3] N. Tomm *et al.* Nat. Nanotechnol. **16**, 399 (2021)

Q 20.3 Tue 11:45 P 7

Photon Number Coherence in Two Photon Excitation — •Yusuf Karli[1,2], Florian Kappe[2], René Schwarz[2], Doris Reiter[3], Vikas Remesh[2], and Gregor Weihs[2] — [1]University of Cambridge, UK — [2]Universität Innsbruck, Austria — [3]TU Dortmund, Germany

Semiconductor quantum dots are prime candidates for single-photon sources in quantum communication, yet the security of protocols such as Quantum Key Distribution (QKD) depends critically on the Photon Number Coherence (PNC) of the emitted state. We investigate the generation and control of PNC in GaAs quantum dots under resonant two-photon excitation regimes, comparing standard biexciton-exciton cascading with stimulated two-photon excitation. While standard TPE yields negligible PNC due to incoherent relaxation processes, we demonstrate that the stimulated scheme effectively preserves electronic coherence, enabling on-demand tuning of PNC from zero to maximum values simply by varying the excitation pulse area. This stimulated approach simultaneously enhances photon indistinguishability to 95% while maintaining high purity [1]. Furthermore, addressing the sensitivity of TPE to environmental fluctuations, we introduce a robust stimulated adiabatic rapid passage (sARP) scheme[2]. We show that sARP maintains stable, vanishing PNC even in the presence of power drifts, for tailoring photon statistics to the specific security requirements of advanced quantum network protocols[1, 2].

[1] Karli, Y. et al. npj Quantum Inf. 10, 17. [2] Karli, Y. et al. Appl. Phys. Lett. 125 (25)

Q 20.4 Tue 12:00 P 7

Challenges and Advances Toward Maximal Entanglement in Quantum Dot Emitters — •Francesco Basso Basset for the QD-E-QKD photon source-Collaboration — Department of Physics, Politecnico di Milano, Milan, Italy

Quantum dots have become established sources of highly polarization-entangled photons, aiming to overcome trade-offs between brightness and entanglement. Despite evidence of nearly dephasing-free operation, open questions remain on the practical limits. This talk recaps experiments identifying mechanisms that must be controlled to reach near-unity entanglement, including multipair emission from re-excitation, spin noise from hyperfine interactions, and challenges in cavity-integrated devices operated at high brightness and GHz rates.

First, we report evidence of a recently proposed limitation in the standard on-demand scheme, resonant two-photon excitation of the biexciton-exciton cascade. The effect, linked to the optical Stark shift, strengthens as emission overlaps the excitation pulse, calling for dedicated mitigation. Second, we examine an often overlooked degree of freedom: emission angle. Photon momentum and polarization are correlated, especially in microcavities, introducing which-path information that reduces polarization entanglement. A simple dipole-emission model captures the behavior and guides the design of structures that maximize extraction efficiency without compromising fidelity.

These results show that key aspects of quantum-emitter behavior remain unresolved, and it is still too early to set limits on the future role of this technology in quantum networks.

Q 20.5 Tue 12:15 P 7

Scalable quantum interference of photons from multiple quantum dots. — •Sheena Shaji[1], Suraj Goel[1], Julian Weircinski[1], Frederik Brooke Barnes[1], Moritz Cygorek[2], Antoine Borel[1], Natalia Herrera Valencia[1], Erik M. Gauger[1], Mehul Malik[1], and Brian D. Gerardot[1] — [1]Institute of Photonics and Quantum Sciences, Heriot-Watt University, Edinburgh EH14 4AS, United Kingdom — [2]Condensed Matter Theory, Technical University of Dortmund, 44227 Dortmund, Germany

Scaling semiconductor quantum dots as platform to provide many mutually indistinguishable emitters remain has been a challenge due to their random spatial distribution and spectral inhomogeneity. In this talk, I will present a method to overcome these challenges using spatial light modulators to deterministically excite multiple emitters on the same chip, and to route their emission into a desired collection mode by programming phase grating holograms on them. We investigate cooperative emission arising from path erasure between distant, indistinguishable emitters. The primary signature of multi-emitter quantum interference, the emergence of bunching at zero delay in an intensity correlation experiment, is used to characterize the inter-emitter indistinguishability and the degree of correlation. We demonstrate scalability of this interference from two to five spectrally degenerate quantum dots and further confirm inter-emitter indistinguishability through Hong-Ou-Mandel interference between two emitters. These results provide a pathway towards rapid characterization of multiple emitters and realization of programmable, photonic quantum circuits.

Q 20.6 Tue 12:30 P 7

Entanglement generation through multi-photon interference with deterministic single photons in the telecom C-Band — •Nico Hauser[1], Matthias Bayerbach[1], Jochen Kaupp[2], Yorick Reum[2], Giora Peniakov[2], Johannes Michl[2], Martin Kamp[2], Tobias Huber-Loyola[2], Andreas T. Pfenning[2], Sven Höfling[2], and Stefanie Barz[2] — [1]Universität Stuttgart, 70569 Stuttgart, Germany — [2]Julius-Maximilians-Universität, 97074 Würzburg, Germany

Multi-photon interference of highly indistinguishable single photons in the telecom C-band is a critical requirement for many quantum communication and quantum computation protocols. While quantum dot-based single-photon sources have been demonstrated to be a prime candidate for deterministic single-photon generation in the telecom C-band, the generation of entangled multi-photon states from C-band quantum dots remains an active area of research. Here, we present multi-photon interference experiments using symmetric N-port beam splitters for multi-partite entanglement generation. We combine a quantum dot emitting in the telecom C-band with an active demultiplexing scheme to deterministically separate consecutively emitted single photons and show the generation of genuine multi-photon entangled states using compact, fiber-based multiport interferometers.

Q 20.7 Tue 12:45 P 7

High-fidelity entangled photon pairs from a quantum-dot-based single-photon source — •Malwina A. Marczak[1], Timon L. Baltisberger[1], Mark R. Hogg[1], Spencer Johnson[2], Nathan Arnold[2], Benjamin Nussbaum[2], Sascha R. Valentin[3], Arne Ludwig[3], Paul Kwiat[2], and Richard J. Warburton[1] — [1]University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland — [2]University of Illinois, 337 Loomis Laboratory, 1110 W. Green Street, Urbana IL 61801, USA — [3]Ruhr-Universität Bochum, Universitätsstrasse 150, 44780 Bochum, Germany

Entangled photon pairs are a ubiquitous resource in quantum technologies, used in quantum key distribution and quantum networking. For scalable quantum networks, pairs that are indistinguishable in all degrees of freedom are essential, as they enable high-fidelity entanglement swapping across network nodes. We demonstrate a high-fidelity source of "swappable" entangled photon pairs using a semiconductor quantum dot (QD) coupled to a tunable microcavity. By actively modulating the QD emission between orthogonal polarization states, delaying one path in a low-loss Herriott cell, and recombining the two on a balanced beam splitter, we generate entangled photon pairs with a fidelity of 96%. The photons are mutually indistinguishable, enabling efficient entanglement swapping, a crucial requirement for quantum repeaters. We identify and mitigate fidelity-limiting factors, achieving a maximum fidelity of 98.9% through time-resolved post-selection that suppresses residual multi-photon events concentrated near the excitation pulse.