HL 25: Focussed Session: Quantum Nanophotonics in Solid State Systems: Status, Challenges and Perspectives II (joint session HL/TT)

Organizers: Alexander Szameit(U Rostock), Ruth Oulton (U Bristol), and Stephan Reitzenstein (TU Berlin)

Time: Wednesday 9:30–13:15 Location: EW 201

Invited Talk HL 25.1 Wed 9:30 EW 201

The quantum knitting machine: a quantum dot as device for deterministic production of cluster states of many entangled photons — •David Gershoni — The Physics Department and The Solid State Institute, Technion, Haifa, 32000, Israel

Photonic cluster states are a resource for quantum computation based solely on single-photon measurements [1]. We use semiconductor quantum dots to deterministically generate long strings of polarization-entangled photons in a cluster state by periodic timed excitation of a precessing matter qubit [1-2]. In each period, an entangled photon is added to the cluster state formed by the matter qubit and the previously emitted photons. In our prototype device, the qubit is the confined dark exciton [3,4], and it produces strings of hundreds of photons in which the entanglement persists over five sequential photons [5]

[1] H. J. Briegel, "Versatile cluster entangled light", Science 354, 416 (2016)

[2] N. H. Lindner and T. Rudolph, "Proposal for pulsed on-demand sources of photonic cluster state strings", Phys. Rev. Lett. 103, 113602 (2009)

[3] E.Poem, et al, "Accessing the dark exciton with light", Nature Physics 6, 993, (2010)

[4] I. Schwartz, et al, "Deterministic writing and control of the dark exciton spin using short single optical pulses", Phys. Rev. X 5, 011009 (2015)

[5] I. Schwartz, et al, "Deterministic generation of a cluster state of entangled photons", Science 354, 434, (2016)

HL 25.2 Wed 10:00 EW 201

Time reordering of paired photons through two-photon strong coupling and generation of maximally entangled states in quantum dots — •Samir Bounouar[1], Christoph De La Haye[1], Max Strauss[1], Peter Schnauber[1], Alexander Thoma[1], Manuel Gschrey[1], Jan-Hindrik Schulze[1], Andre Strittmatter[2], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Abteilung für Halbleiterepitaxie, Otto-von-Guericke, Universität, 39106 Magdeburg, Germany

We show that strong coupling of a continuous laser field to the exciton-biexciton radiative cascade of a semiconductor quantum dot (QD) allows for the observation of the dressed states and the manipulation of the paired photons time ordering [1]. Moreover, two-photon Rabi oscillations of the dressed states population, due to the non-linear coherent driving of the radiative cascade, confirm the coherent nature of the two-photon driving. We also show that maximally entangled states can be efficiently generated from microlens-QD with non-zero fine structure splitting and that their fidelity to the Bell states remains unaffected by the decoherence over the full wave-packet [2].

[1] S. Bounouar et al., Phys. Rev. Lett. 118, 233601 (2017). [2] S. Bounouar et al., (in preparation).

HL 25.3 Wed 10:15 EW 201

Quantum-optical spectroscopy of a two-level system using an electrically driven micropillar laser as resonant excitation source — •Sören Kreinberg[1], Tomislav Grbešic[1], Max Strauss[1], Alexander Carmele[2], Monika Emmerling[3], Christian Schneider[3], Sven Höfling[3], Xavier Porte[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Institut für Theoretische Physik, Technische Universität Berlin, Germany — [3]Technische Physik, Julius-Maximilians-Universität Würzburg, Germany

Two-level emitters constitute the core elements of photonic quantum systems and exploring their physics is at the heart of quantum optics. Of special interest is the strict-resonant optical excitation of such emitters to generate quantum light with close to ideal properties. Up till now related experiments have been performed exclusively using bulky lasers. This hinders the application of resonantly driven two-level emitters in quantum technology, which relies on the availability of compact sources of indistinguishable photons. Here we propose and demonstrate quantum-optical spectroscopy of a single QD embedded in a planar microcavity resonantly excited by an electrically driven high-β quantum dot micropillar laser. We obtain single photons with strong multi-photon suppression $g^{(2)}(0)$=0.02 and high photon indistinguishably V=0.57(9) under pulsed excitation with a repetition rate of 156 MHz. Our results demonstrate the exquisite potential of high-β microlasers as coherent excitation sources in quantum nanophotonics and pave the way to compact, resonantly driven quantum light sources.

HL 25.4 Wed 10:30 EW 201

Ultrafast electric phase control of a quantum dot exciton — •Alex Widhalm[1], Amlan Mukherjee[1,2], Sebastian Krehs[1], Björn Jonas[1], Nandlal Sharma[1], Peter Kölling[1,2], Andreas Thiede[2], Jens Förstner[1,2], Dirk Reuter[1], and Artur Zrenner[1] — [1]Physics Department, University of Paderborn — [2]Department of Electrical Engineering, University of Paderborn, Paderborn 33098, Germany

The coherent control of QD excitons can be performed in Ramsey type experiments, where the QD is excited with two phase locked optical $\frac{\pi}{2}$ pulses seperated by a time delay. Here we present an experiment, where the first pulse defines the phase of the exciton, which is subsequently manipulated by ultrafast Stark tuning of the exciton energy. The resulting phase shift is measured by quantum interference using the second $\frac{\pi}{2}$ pulse. We have already shown, that the coherent phase of a QD exciton can be manipulated electrically by phase-locked RF signals[1]. Here we have designed SiGe:C BiCMOS chips for the generation of ultrafast electric pulses (rise times <20 ps @ cryogenic operationality) and ultrafast photodiodes with embedded high quality InGaAs QDs. Electric connections have been established by short distance wire bonding. This hybrid approach enables us to perform electric control synchroneous to double pulse ps laser excitation. We are able to demonstrate electrically controlled phase manipulations with magnitudes up to 3π and the electric control of the QD occupancy on time scales below the dephasing time of QD exciton.

Ref: [1] S. de Vasconcellos et al., Nature Photonics 4, 545 (2010).

HL 25.5 Wed 10:45 EW 201

Telecom-wavelength GaAs-based quantum dots for practical single-photon sources — •A Musiał[1], Ł Dusanowski[1,2], P Holewa[1], P Mrowiński[1], A Maryński[1], K Gawarecki[1], N Srocka[3], T Heuser[3], D Quandt[3], A Strittmatter[3,4], S Rodt[3], S Reitzenstein[3], and G Sek[1] — [1]Faculty of Fundamental Problems of Technology, Wrocław Uni of Science and Technology, Wrocław, Poland — [2]Technical Physics, Uni of Würzburg, Würzburg, Germany — [3]Institute of Solid State Physics, Technical Uni of Berlin, Berlin, Germany — [4]Institute of Experimental Physics, Otto von Guericke Uni Magdeburg, Magdeburg, Germany

Quantum communication applications require stand-alone, high-purity on-demand single-photon sources (SPS) operating at telecom wavelengths, preferably fiber-coupled for easy integration with existing optical networks. In this regard, we evaluated the potential of GaAs-based quantum dots (QDs) grown by high-throughput and mature MOCVD technology. The emission wavelength was shifted to telecom wavelengths utilizing an InGaAs strain reducing layer. The electronic structure of the QDs was optimized for well-separated ground state exciton emission to allow for high single-photon purity and good thermal stability. Single QDs have been placed deterministically in nanophotonic structures for increased light extraction. The influence of temperature and excitation energy on single-photon generation was studied resulting in triggered high-purity single-photon emission under p-shell resonant excitation at 30K suitable for commercializing fiber-coupled single-photon sources based on cryogenic-free Stirling cryocoolers.

HL 25.6 Wed 11:00 EW 201

Quantum emitter coupled to photonic modes: superradiant to subradiant phasetransition generates a dark state cascade — Michael Gegg, Alexander Carmele, Andreas Knorr, and

•Marten Richter — Institut für Theoretische Physik, Technische Universität Berlin, Germany

If an ensemble of quantum emitter like quantum dots, NV centers or atom are coupled to photonic or plasmonic modes, collective effects can lead to collective super- or subradiance. Here, we discuss a type of phase transition, that describes the transition from predominantly superradiant states to subradiant states with applications to quantum information storage. The simulation for a large number of two level systems is made possible by a method exploiting the permutation symmetry for identical system [1,2] available through the library PsiQuaSP [3]. In the described situation the important quantity for the generation of the subradiant states is the cavity decay and not the individual quantum emitter decay. Experimental signatures as well as entanglement properties are discussed.

[1] Phys. Rev. B 91, 035306 (2015)
[2] New J. Phys. 18, 043037 (2016)
[3] Sci. Rep. 7, 16304 (2017)
[4] New J. Phys. (in press), (2017), https://doi.org/10.1088/1367-2630/aa9cdd, arXiv:1705.02889

15 min. break.

Invited Talk HL 25.7 Wed 11:30 EW 201

Exploiting the Bright and the Dark Side of Deterministic Solid-State Quantum-Light Sources — •Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

Quantum-light sources are key building blocks for future photonic technologies with applications in the fields of quantum communication, quantum computation and quantum metrology.
Here, we will review recent experiments exploiting quantum-light sources based on photonic microlenses deterministically fabricated above pre-selected semiconductor quantum dots (QDs). The first part of the talk will focus on experiments demonstrating the efficient, triggered generation of photon twins - a light state comprised of two temporally correlated photons degenerate in energy and polarization [1]. For this purpose, we select QDs whose exciton finestructure splitting equals the biexciton binding energy $\Delta E_{\mathrm{FSS}}=|E^{\mathrm{XX}}_{\mathrm{bin}}|$. In the second part, we demonstrate that we can exploit photonic QD microlenses to all-optically access the dark exciton (DE) state [2]. By clearly observing the quantum beats of the DE spin-eigenstates $|\Uparrow\Uparrow \pm \Downarrow\Downarrow\rangle$, we provide evidence for the robustness of the DE as a long-lived coherent spin-qubit and pave the way towards its wider application. Finally, we briefly discuss prospects of QD-based quantum-light sources for the realization of quantum-secured communication networks.

[1] T. Heindel et al., Nature Communications 8, 14870 (2017)
[2] T. Heindel et al., APL Photonics 2, 121303 (2017)

HL 25.8 Wed 12:00 EW 201

Two-photon interference with remote quantum dots at 1550 nm after quantum frequency conversion — •J. H. Weber[1], B. Kambs[2], J. Kettler[1], S. Kern[1], H. Vural[1], J. Maisch[1], S. L. Portalupi[1], M. Jetter[1], C. Becher[2], and P. Michler[1] — [1]IHFG, IQ$^{\mathrm{ST}}$ Center and SCoPE, Universität Stuttgart — [2]Fachrichtung Physik, Universität des Saarlandes

Two-photon interference (TPI) with telecom photons from remote quantum emitters is of key importance for future long-distance quantum networking. Here, quantum frequency conversion (QFC) is exploited to transfer single near-infrared photons from semiconductor quantum dots to the telecom C-band. We demonstrate that the presented technology opens the path for on-demand generation of highly bright single-photon emission at 1550 nm without the need for special sample design or intrinsic tuning mechanisms. Standing prove for the feasibility of this hybrid technology, we report on TPI with remote quantum dots, being only limited to spectral wandering due to the charge environment of the bulk material. The feasibility of this technology is further strengthened by unprecedented overlap of measured TPI contrast and theoretical prediction which is only possible due to the convenient and highly stable tuning mechanism delivered by QFC. With this respect, the theoretical derivations consider both off-resonant TPI as well as inhomogeneous broadening and blinking of the emitters. Finally, we simulate wave propagation in optical fibers to study the effect of dispersion and experimentally demonstrate that 2 km of fiber delay does not affect the remote TPI visibility.

HL 25.9 Wed 12:15 EW 201

Photon-Number-Resolving Transition Edge Sensors for the Metrology of Quantum-Light Sources — •Marco Schmidt[1,2], Martin von Helversen[1], Fabian Gericke[1], Elisabeth Schlottmann[1], Manuel Gschrey[1], Peter Schnauber[1], Jan-Hindrik Schulze[1], André Strittmatter[1], Jörn Beyer[2], Sven Rodt[1], Tobias Heindel[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Physikalisch-Technische Bundesanstalt, Abbestraße 2-12, 10587 Berlin, Germany

Photon-number-resolving detectors (PNR) allow for direct access to the photon number distribution of nanophotonic light sources and can thus be exploited to explore the photon statistics of semiconductor-based non-classical light sources. In this work, we report on the realization of a stand-alone measurement system with two fiber-coupled transiton edge sensors (TESs) integrated within a compact adiabatic demagnetization refrigerator. The performance of the detector system is analyzed in terms of its detection efficiency, which is determined to be larger than 87 % (850 - 950 nm). As an exemplary application in QD-metrology, we employ this detector to evaluate the photon number distribution of QD-based single- and twin- photon sources [1] based on deterministically fabricated QD microlenses.

[1] T. Heindel et al., Nat. Commun. 8, 14870, (2017)

HL 25.10 Wed 12:30 EW 201

Hong-Ou-Mandel Experiment using Single-Photon Fock-States and Photon-Number Resolving Detectors — •Martin von Helversen[1], Jonas Böhm[1], Marco Schmidt[1,2], Jan-Hindrik Schulze[1], André Strittmatter[1], Sven Rodt[1], Jörn Beyer[2], Tobias Heindel[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Physikalisch-Technische Bundesanstalt, Abbestraße 2-12, 10587 Berlin, Germany

Quantum light sources based on semiconductor quantum dots (QDs) are promising candidates for many applications in the research fields of quantum metrology and quantum communication. Important characteristics of such emitters, e.g. the degree of single-photon purity and photon indistinguishability, are typically assessed via time-correlated measurements using silicon-based click detectors in Hanbury-Brown and Twiss (HBT-) and Hong-Ou-Mandel (HOM-) type configuration. Here, we employ a state of the art photon-number-resolving detection system based on two transition edge sensors (TES) to analyze the emission of a deterministically fabricated QD-based single-photon source and quantitatively compare our results with experimental data obtained for standard click detectors. Our results demonstrate that photon-number resolving detectors are very attractive tools for the metrology of quantum light sources.

HL 25.11 Wed 12:45 EW 201

Effect of second order piezoelectricity on exciton dipole, finestructure and binding energies of multi-excitons in strain-tuned InGaAs/GaAs quantum dots — •Petr Klenovský[1,2], Petr Steindl[1,2], Johannes Aberl[3], Eugenio Zallo[4,5], Thomas Fromherz[3], Armando Rastelli[3], and Rinaldo Trotta[3] — [1]Department of Condensed Matter Physics, Faculty of Science, Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic — [2]Central European Institute of Technology, Masaryk University, Kamenice 753/5, 62500 Brno, Czech Republic — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Altenbergerstraße 69, A-4040 Linz, Austria — [4]Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstraße 20, D-01069 Dresden, Germany — [5]Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

We study the effects of nonlinear piezoelectricity on the exciton electric dipole moment, fine-structure, and binding energies of multi-exciton complexes in strain-tuned InGaAs/GaAs quantum dots and investigate the influence of various elements of the expansion of electrical polarization in terms of applied elastic stress. We find that a presence of a large built-in stressor (like quantum dot) is necessary for the dipole inversion to occur. Furthermore, the analysis provides a simple relation to estimate the influence of applied stress on the electrical polarization in zincblende nanostructures.

HL 25.12 Wed 13:00 EW 201

Strain tuning of deterministically fabricated quantum dot microlenses for advanced quantum communication — •Sarah Fischbach, Marco Schmidt, Ronny Schmidt, Arsenty Kaganskiy, André Strittmatter, Tobias Heindel, Sven Rodt, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, Germany

Long distance quantum communication requires networks of quantum repeaters, which are based on the generation of indistinguishable pairs of entangled photons. Quantum dots (QDs) can generate entangled photons from their exciton-biexciton cascade and methods of semiconductor nanofabrication allow one to realize efficienct sources emitting highly indistinguishable photons.
Due to the random nature of the self-assembled growth process, QDs vary over a wide range in their emission wavelength. Deterministic nanoprocessing needs to be applied to integrate QDs matching a target wavelength. Additionally, to enable entaglement distribution, two QD-based sources need to be tuned into resonance by spectral fine-tuning. Strain tuning is a very accurate tuning method which maintains the high optical quality of the QD emission.
We demonstrate a tunable single-photon source based on a deterministically fabricated QD microlens which is positioned on top of a piezoactuator by a flip-chip goldbonding technique. QD microlenses can act as efficient single-photon sources with low $g^{(2)}(0)$-values and a high photon indistinguishability, which are now equipped with the feature of strain tunability.