HL 33: Quantum Dots: Optical Properties I

Time: Tuesday 9:30–13:00 Location: POT 81

Invited Talk HL 33.1 Tue 9:30 POT 81

Deterministic Single Quantum Dot Devices: Building Blocks for Photonic Quantum Networks — •Stephan Reitzenstein — Institute of Solid State Physics, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

The emerging field of photonic quantum technologies relies crucially on the availability of practical quantum light sources. Prime candidates to realize such sources are self-assembled semiconductor quantum dots (QDs). This is explained by their superb optical properties in terms of the quantum efficiency, the single photon purity and the high photon indistinguishability. Moreover, QDs allow for the generation of entangled photon pairs and more complex photon states. Still, it is a great challenge to further develop these key building blocks beyond proof-of-principle demonstrations towards scalable quantum devices enabling advanced systems such as multi-partite quantum networks.

In this talk, I will review exciting progress in the field of QD based devices with a focus on the development of practical and efficient quantum light sources for future photonic quantum networks. This includes important aspects such efficient light extraction strategies, deterministic nanoprocessing technologies and the quantum optical evaluation of the photon sources. In particular, I will introduce in-situ electron beam lithography, which allows for the realization of QD based quantum devices with high process yield. The talk will conclude with an outlook on upcoming challenges such as entanglement swapping using QD based quantum light sources.

HL 33.2 Tue 10:00 POT 81

Non-linear two-photon resonance fluorescence of a single artificial atom — •Jonathan Müller, Lukas Hanschke, Per-Lennart Ardelt, Manuel Koller, Tobias Simmet, Alexander Bechtold, Kai Müller, and Jonathan Finley — Walter Schottky Institut, TU-München, 85748 Garching, Germany

Resonance fluorescence that arises from the interaction of a coherent light field with a two level system, has led to the development of numerous physical breakthroughs in atomic quantum optics. Increasing the complexity of the physical systems, first predictions for a non-linear counterpart of resonance fluorescence were made theoretically already 30 years ago.

We present non-linear resonance fluorescence studies for the two-photon excitation of individual semiconductor quantum dots. Monitoring the population evolution for increasing Rabi frequencies we observe an s-shaped behavior as a clear signature of the non-linear excitation process. Quantum optical simulations based on a 4-level system provide excellent agreement with the measurements and reveal the crucial role of the environmental coupling to LA-phonons which leads to a redistribution of the population between the levels. Finally, we directly measure the formation of dressed states in the non-linearly driven system that emerge from the resonant two-photon interaction between the coherent light field and the 4-level artificial atom. Our results open the route for investigating a range of optical phenomena from entangled photon pairs to photon bundles resulting from the coherent non-linear interaction in two-photon resonance fluorescence.

HL 33.3 Tue 10:15 POT 81

Solid-state ensemble of highly entangled photon sources at rubidium atomic transitions — •Michael Zopf[1], Robert Keil[1], Yan Chen[1], Bianca Höfer[1], Jiaxiang Zhang[1], Fei Ding[1,2], and Oliver G. Schmidt[1,3] — [1]Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstraße 20, 01069 Dresden, Germany — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [3]Merge Technologies for Multifunctional Lightweight Structures, Technische Universität Chemnitz, Germany

Semiconductor InAs/GaAs quantum dots grown by the Stranski-Krastanov method are among the leading candidates for the deterministic generation of polarization entangled photon pairs. Despite remarkable progress in the last twenty years, many challenges remain for this material, such as extremely low yield (<1% quantum dots can emit entangled photons), low degree of entanglement, and large wavelength distribution. Here we show that, with an emerging family of GaAs/AlGaAs quantum dots grown by droplet etching and nanohole infilling, it is possible to obtain a large ensemble (close to 100%) of polarization-entangled photon emitters on a wafer without any post-growth tuning. Under pulsed resonant two-photon excitation, all measured quantum dots emit single pairs of entangled photons with ultra-high purity, high degree of entanglement (fidelity up to F = 0.91, with a record high concurrence C = 0.90), and ultra-narrow wavelength distribution at rubidium transitions. Therefore, a solid-state quantum repeater can be practically implemented with this new material.

HL 33.4 Tue 10:30 POT 81

Resonantly excited quantum dots: from quantum beats in temporal domain to two-photon interference of remote sources — •J. H. Weber[1], H. Vural[1], M. Müller[1], C. Schneider[2], S. L. Portalupi[1], S. Höfling[2,3], and P. Michler[1] — [1]IHFG, IQ^{ST} Center and SCoPE, Universität Stuttgart — [2]Physikalisches Institut, Universität Würzburg — [3]School of Physics and Astronomy, University of St. Andrews, UK

Two-photon interference is a crucial building block for photonic quantum information technology such as linear optical quantum computation and quantum-enhanced phase determination. For such applications, highly indistinguishable single photons are essential. Single semiconductor quantum dots are promising emitters because of their high brightness, indistinguishability and on-demand single photon emission. Resonant excitation is proven to strongly reduce dephasing mechanisms. In the present study, we carry out coherent and on-demand initialization of the two-level system: in contrast to the commonly observed Rabi oscillations, here we prove this coherent initialization by the observation of strongly pronounced quantum beats in the temporal dynamics of the spontaneous emission. Furthermore, high indistinguishability of the subsequently emitted photons could be shown by exploiting the Hong-Ou-Mandel effect. To scale photonic quantum information processing with quantum dots, two-photon interference of distinct sources is crucial. Therefore, two remote quantum dots were tuned into resonance, accomplishing two-photon interference of the on-demand generated resonance fluorescence.

HL 33.5 Tue 10:45 POT 81

Photoelectron generation and capture in the resonance fluorescence of a quantum dot — Annika Kurzmann[1], Arne Ludwig[2], Andreas D. Wieck[2], Axel Lorke[1], and •Martin Geller[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Germany. — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany.

The ultimate goal for self-assembled quantum dots (QDs) as single photon sources is a transform-limited photon stream. This goal has not yet been reached, as spectral wandering of the center frequency of the QD transition is still observed. The major sources of this spectral jitter are charge and nuclear spin noise. Charge noise can arise from charging/discharging of trap states that are filled by photoexcited free charge carriers. Furthermore, these photoexcited electrons can relax into the QD, quenching the transitions in a resonant measurement.

Time-resolved resonance fluorescence on a single self-assembled quantum dot (QD) is used to analyze the generation and capture of photoinduced free charge carriers [1]. We directly observe the capture of electrons into the QD as an intensity reduction of the exciton transition and in the appearence of a non-equilibrium trion resonance. The exciton transition is quenched until the captured electron tunnels out of the dot again in the order of milliseconds. Our results demonstrate that even under resonant excitation, excited free electrons are generated and can negatively influence the optical properties of a QD.

[1] A. Kurzmann et al., Appl. Phys. Lett. **108**, 263108 (2016).

Coffee Break

HL 33.6 Tue 11:30 POT 81

Ultrafast electric control of a quantum dot exciton — •Amlan Mukherjee[1,2,3], Alex Widhalm[1,3], Nandlal Sharma[1,3], Andreas Thiede[2,3], Dirk Reuter[1,3], and Artur Zrenner[1,3] — [1]Department Physik, Universität Paderborn, Paderborn, Germany — [2]Höchstfrequenzelektronik, Universität Paderborn, Paderborn, Germany — [3]Center for Optoelectronics and Photonics Paderborn (CeOPP), Universität Paderborn, Paderborn, Germany

The excellent optical properties of single InGaAs QDs combined with ultrafast electric control allow for the realisation of new coherent opto-electronic functionalities. Universal coherent control can be achieved by combining the control of occupancy using optical pulses with phase control using electric pulses within the dephasing time of the ground state QD exciton. To implement fast electric phase control, we have designed a SiGe:C hetero-bipolar electronic circuit for the generation of ultrafast electric signals, which act as phase gates for a single QD. Our current circuit design generates rise times below 15 ps and it is fully operational at liquid Helium temperatures. In Ramsey experiments we demonstrate a coherent electric phase manipulation over up to 20π and the realisation of a π phase change within 35 ps. Also, such ultrafast electrical pulses can be used in combination with cw excitaion to perform an adiabatic rapid passage for robust exciton generation. We report results from our attempts to perform the electrically chirped excitation of an exciton.

HL 33.7 Tue 11:45 POT 81

Highly indistinguishable and strongly entangled photons from symmetric GaAs quantum dots — •Daniel Huber[1], Marcus Reindl[1], Yongheng Huo[2,1], Huiying Huang[1], Johannes S. Wildmann[1], Oliver G. Schmidt[2], Armando Rastelli[1], and Rinaldo Trotta[1] — [1]Institute of Semiconductor and Solid State Physics, Johannes Kepler University, Linz, Altenbergerstr. 69, 4040, Austria — [2]Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstr. 20, 01069 Germany

The development of scalable sources of non-classical light is fundamental to unlock the technological potential of quantum photonics. Among the systems under investigation, semiconductor quantum dots (QDs) are currently emerging as near-optimal sources of indistinguishable single photons. However, experiments on conventional Stranski-Krastanow InGaAs QDs have reported non-optimal levels of entanglement and indistinguishability of the emitted photons. For applications such as entanglement teleportation and quantum repeaters, these criteria have to be met simultaneously. In this talk, I will present a material system that has received limited attention so far: GaAs QDs grown via droplet etching. I will demonstrate that under resonant excitation these highly symmetric QDs deliver photon pairs with high degree of indistinguishability and with an unprecedented degree of entanglement fidelity. The results suggest that if QD entanglement resources will be used for future quantum technologies, GaAs might be the material system of choice
[arXiv:1610.06889] .

HL 33.8 Tue 12:00 POT 81

Deterministically fabricated bright single-photon sources with a backside gold mirror — •Sarah Fischbach[1], Alexander Thoma[1], Esra Burcu Yarar Tauscher[1], Ronny Schmidt[1], Arsenty Kaganskiy[1], Fabian Gericke[1], André Strittmatter[1,2], Tobias Heindel[1], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg, Germany

Combinations of quantum dots (QDs) and deterministically fabricated microlenses can act as efficient single-photon sources with low $g^{(2)}(0)$-values and a high photon indistinguishability. Applications in the field of advanced quantum communications, however, require in addition high extraction efficiencies as well as a flexible technology platform, which can be extended for strain tuning or electrical contacts.
Here, we realize a deterministic single-photon source based on a QD microlens with a backside gold mirror, providing high reflectivity even at large angles of incidence. The utilized flip-chip process with thermo-compression gold bonding was realized with a distance of 60 nm between mirror and QD to achieve a maximum enhancement of the emission. The geometry of the structures is optimized using finite-element simulations. Suitable target QDs are selected by cathodoluminscence lithography at cryogenic temperatures and are integrated into devices by 3D in-situ electron-beam lithography. Photoluminescence measurements demonstrate high extraction efficiencies as well as a second order autocorrelation value $g^{(2)}(0) < 0.02$.

HL 33.9 Tue 12:15 POT 81

Theoretical modelling of absorption spectra from differently charged quantum dots — •Matthias Holtkemper, Doris E. Reiter, and Tilmann Kuhn — Institut für Festkörpertheorie, Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster

Semiconductor quantum dots (QDs) are promising structures for realisations in quantum information technology and spintronics. Apart from the ground state exciton also excited exciton states become relevant for dynamical processes like optical spin control, relaxation or charged biexciton cascades. Here we present a systematic analysis of absorption spectra for negatively, neutrally and positively charged QDs with a focus on excited excitonic states. To be specific, we model the QD using kp-theory within a configuration interaction approach. The QD confinement is approximated by a harmonic potential. We include the direct and short range exchange Coulomb interaction. The role of the different interactions is investigated in detail to give a fundamental understanding of the relevant effects. We discuss trends in the spectra while tuning the interaction strengths and study the differences and commonalities between differently charged QDs.

HL 33.10 Tue 12:30 POT 81

Bulk AlInAs on InP(111) as a novel material system for pure single photon emission — •Michael Deppisch[1], Sebastian Unsleber[1], Christian M. Krammel[2], Minh Vo[1], Christopher D. Yerino[3], Paul J. Simmonds[4], Minjoo Larry Lee[3,5], Paul M. Koenraad[2], Christian Schneider[1], and Sven Hoefling[1,6] — [1]Technische Physik and Wilhelm Conrad Roentgen Research Center for Complex Material Systems, Physikalisches Institut, Universitaet Wuerzburg, Am Hubland, D-97074 Wuerzburg, Germany — [2]Department of Applied Physics, Eindhoven University of Technology, Eindhoven 5612 AZ, The Netherlands — [3]Department of Electrical Engineering, Yale University, PO Box 208284, New Haven, CT 06520, USA — [4]Boise State University, Departments of Physics and Materials Science and Engineering, Boise, ID 83725, USA — [5]Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA — [6]SUPA, School of Physics and Astronomy, University of St. Andrews, St. Andrews, KY16 9SS, UK

We report on quantum light emission from bulk AlInAs grown on InP(111) substrates. Indium rich clusters in the bulk $Al_{0.48}In_{0.52}As$ (AlInAs) were observed, resulting in quantum dot (QD)-like energetic traps for charge carriers. QD-like emission signals appear as sharp lines in our photoluminescence spectra at near infrared wavelengths around 860 nm, and with linewidths as narrow as 50 μeV. Moreover, single photon emission is demonstrated as we extract $g^{(2)}$-values as low as $g^{(2)}_{\mathrm{cw}}(0) = 0.05$ for continuous wave excitation and $g^{2}_{\mathrm{pulsed,\ corr}}(0) = 0.24$ for pulsed excitation.

HL 33.11 Tue 12:45 POT 81

Deterministic generation of bright single resonance fluorescence photons from a Purcell-enhanced quantum dot-micropillar system — •Stefan Gerhardt[1], Sebastian Unsleber[1], Yu-Ming He[1,3], Sebastian Maier[1,3], Niels Gregersen[4], Martin Kamp[1], Christian Schneider[1], and Sven Hoefling[1,2,3] — [1]Technische Physik, Physikalisches Institut and Wilhelm Conrad Roentgen-Research Center for Complex Material Systems, Universitaet Wuerzburg, Am Hubland, 97074 Wuerzburg — [2]SUPA, School of Physics and Astronomy, University of St Andrews, St Andrews, KY16 9SS, United Kingdom — [3]Hefei National Laboratory for Physical Sciences at the Microscale and Department of Modern Physics & CAS Center for Excellence and Synergetic Innovation Center in Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei, Anhui 230026, China — [4]Department of Photonics Engineering, Technical University of Denmark, Ørsteds Plads, 2800 Kgs. Lyngby, Denmark

We report on the observation of bright emission of single photons generated via pulsed, resonance fluorescence conditions from a quantum dot deterministically centered in a micropillar cavity device via cryogenic optical lithography. The brightness of the QD fluorescence is greatly enhanced on resonance with the fundamental mode of the pillar, leading to an overall device efficiency of $\nu = (74 \pm 4)\,\%$ for a single photon emission as pure as $g^{(2)}(0) = 0.0092 \pm 0.0004$ with a two-photon wave packet overlap up to $\nu = (88 \pm 3)\,\%$.