HL 18: Quantum Dots and Wires (joint session HL/TT)

Time: Thursday 13:30–16:30 Location: H4

Invited Talk HL 18.1 Thu 13:30 H4

Telecom wavelength quantum dot-based single-photon sources for quantum technologies — •Anna Musial — Department of Experimental Physics, Faculty of Fundamental Problems of Technology, Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland

Important building blocks for quantum technology applications are non-classical light sources, in particular those emitting single photons on demand. Among pursued approaches to realize them semiconductor epitaxial quantum dots (QDs) stand out in terms of single-photon purity, compatibility with semiconductor technology including deterministic fabrication of photonic structures, integration into photonic circuits and fiber infrastructure as well as unprecedented possibilities of engineering their electronic structure and optical properties. The current status, recent developments and future prospects of the single-photon sources based on single GaAs-based and InP-based epitaxial QDs emitting in the telecommunication spectral range will be given. Reviewed aspects include thermal stability of emission, energies for efficient quasi-resonant excitation, optimization of photon extraction efficiency, approaches to maximize coupling to a single mode telecom fiber, single-photon emission purity as well as tests of a fully operational plug&play fiber-based single-photon source.

HL 18.2 Thu 14:00 H4

Electric-field induced tuning of electronic correlation in weakly confining quantum dots — Huiying Huang[1], Diana Csontosová[2,3], Santanu Manna[1], Yongheng Huo[4], Rinaldo Trotta[5], Armando Rastelli[1], and •Petr Klenovský[2,3] — [1]Johannes Kepler University Linz, Linz, Austria — [2]Masaryk University, Brno, Czech Republic — [3]Czech Metrology Institute, Brno, Czech Republic — [4]University of Science and Technology of China, Hefei, Anhui, China — [5]Sapienza University of Rome, Rome, Italy

We conduct a combined experimental and theoretical study of the quantum confined Stark effect in GaAs/AlGaAs quantum dots obtained with the local droplet etching method. In the experiment, we probe the permanent electric dipole and polarizability of neutral and positively charged excitons weakly confined in GaAs quantum dots by measuring their light emission under the influence of a variable electric field applied along the growth direction. Calculations based on the configuration-interaction method show excellent quantitative agreement with the experiment and allow us to elucidate the role of Coulomb interactions among the confined particles and – even more importantly – of electronic correlation effects on the Stark shifts. Moreover, we show how the electric field alters properties such as built-in dipole, binding energy, and heavy-light hole mixing of multiparticle complexes in weakly confining systems, underlining the deficiencies of commonly used models for the quantum confined Stark effect.

HL 18.3 Thu 14:15 H4

Towards deterministic generation of time-bin entangled photons from GaAs quantum dots — •Florian Kappe[1], Yusuf Karli[1], Vikas Remesh[1], Santanu Manna[2], Armando Rastelli[2], and Gregor Weihs[1] — [1]Institute for Experimental Physics, University of Innsbruck, Austria — [2]Institute of Semiconductor and Solid State Physics, Johannes Kepler University of Linz, Austria

Semiconductor quantum dots are bright, on-demand single photon sources to realise quantum communication devices. We present our progress towards the deterministic generation of time-bin entangled photon states utilizing single GaAs/AlGaAs quantum dota as photon sources. Our scheme relies on the use of highly chirped picosecond laser pulses and an optically dark exciton state acting as a metastable state. The fidelity of the state preparation is supported by numerical simulations on the quantum dot dynamics. To demonstrate the effect of chirped excitation pulses on the quantum dot, we present an adiabatic-rapid-passage acting on a two-photon resonant transition to the neutral biexciton state. This scheme allows the implementation of a deterministic two-photon source insensitive to power fluctuations of the pump laser.

HL 18.4 Thu 14:30 H4

Quantum Efficiency and Oscillator Strength of InGaAs Quantum Dots for Single-Photon Sources emitting in the Telecommunication O-Band — •Jan Grosse[1], Paweł Mrowiński[1,2], Nicole Srocka[1], and Stephan Reitzenstein[1] — [1]Technische Universität Berlin, Institute for Solid State Physics, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Laboratory for Optical Spectroscopy of Nanostructures, Wrocław University of Technology, Wybrzeze Wyspiańskiego 27, Wrocław, Poland

We demonstrate experimental results based on time-resolved photoluminescence spectroscopy to determine the oscillator strength and the internal quantum efficiency (IQE) of InGaAs quantum dots (QDs) capped by a strain-reducing layer [1] which have been used in single-photon sources (SPS) emitting in the telecom O-Band [2]. The oscillator strength and IQE are evaluated by determining the radiative and non-radiative decay rate under variation of the optical density of states at the position of the QD [3]. We measure a QD sample with different thicknesses of the capping layer realized by a controlled wet-chemical etching process. From numeric modelling the radiative and nonradiative decay rates dependence on the capping layer thickness, we determine an oscillator strength of 24.6 * 3.2 and a high IQE of about (85 * 10)% for the long-wavelength InGaAs QDs [4].

[1] J. Bloch et al., Appl. Phys. Lett. 75, 2199 (1999). [2] A. Musiał et al., Adv. Quantum Technol. 3, 2000018 (2020). [3] J. Johansen et al., Phys. Rev. B 77, 073303 (2008). [4] J. Große et al, arXiv:2106.05351 (2021).

HL 18.5 Thu 14:45 H4

Resonance fluorescence of single In(Ga)As quantum dots emitting in the telecom C-band — •Julius Fischer, Cornelius Nawrath, Hüseyin Vural, Richard Schaber, Simone Luca Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

Quantum dots represent a rapidly developing platform as sources of non-classical states of light for tackling quantum communication and computation tasks. Especially quantum dots emitting in the telecom C-band (1530nm-1565nm) are promising candidates due to the low absorption losses in the existent telecommunication fiber network.

In this study, we investigate In(Ga)As quantum dots emitting in the telecom C-band under resonant excitation to examine coherence properties and to investigate their single-photon purity as well as photon indistinguishability. Under strong resonant cw excitation, high-resolution fluorescence spectra, namely the Mollow triplet, of a single quantum dot are investigated. These spectra, in combination with a comprehensive fitting procedure, are used as a method to quantitatively attribute decoherence processes and thus presenting an excellent method to provide important insights for future sample optimizations. In addition, under pulsed resonant excitation, the capability of emitting highly pure single photons ($g^{(2)}(0) = 0.023 \pm 0.019$) with a non-postselected indistinguishability of subsequently emitted photons of $V_{\mathrm{TPI}} = 0.144 \pm 0.015$ is demonstrated.

15 min. break

HL 18.6 Thu 15:15 H4

Evaluating a Plug&Play Telecom-Wavelength Single-Photon Source for Quantum Key Distribution — Timm Gao[1], •Lucas Rickert[1], Felix Urban[1], Jan Grosse[1], Nicole Srocka[1], Sven Rodt[1], Anna Musiał[2], Kinga Żołnacz[3], Paweł Mergo[4], Kamil Dybka[5], Wacław Urbańczyk[3], Grzegorz Sek[2], Sven Burger[6], Stephan Reitzenstein[1], and Tobias Heindel[1] — [1]Institute of Solid State Physics, Technical University Berlin, 10623 Berlin, Germany — [2]Department of Experimental Physics, Wrocław University of Science and Technology, 50-370 Wroclaw, Poland — [3]Department of Optics and Photonics, Wroclaw University of Science and Technology, 50-370 Wrocław, Poland — [4]Institute of Chemical Sciences, Maria Curie Sklodowska University, 20-031 Lublin, Poland — [5]Fibrain Sp. z o.o., 36-062 Zaczernie, Poland — [6]Zuse Institute Berlin, 14195 Berlin, Germany

We report on quantum key distribution (QKD) tests using a 19-inch benchtop single-photon source at 1321 nm based on a fiber-pigtailed quantum dot (QD) integrated into a Stirling cryocooler. Emulating the polarization-encoded BB84 protocol, we achieve an antibunching of $g^{(2)}(0) = 0.10 \pm 0.01$, a raw key rate of up to 4.72 ± 0.13 kHz, and a maximum tolerable loss of 23.19 dB exploiting optimized temporal filters in the asymptotic limit [1]. Our study represents an important step forward in the development of fiber-based quantum-secured communication networks exploiting sub-Poissonian quantum light sources.

[1] T. Kupko et al., arXiv.2105.03473 (2021)

HL 18.7 Thu 15:30 H4

Emission and absorption of a radiative Auger transition — •Clemens Spinnler[1], Liang Zhai[1], Giang N. Nguyen[1], Julian Ritzmann[2], Andreas D. Wieck[2], Arne Ludwig[2], Alisa Javadi[1], Doris E. Reiter[4], Paweł Machnikowski[3], Richard J. Warburton[1], and Matthias C. Löbl[1] — [1]Department of Physics, University of Basel, Switzerland — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany — [3]Department of Theoretical Physics, Wrocław University of Science and Technology, Poland — [4]Institut für Festkörpertheorie, Universität Münster, Germany

In multi-electron systems, such as charged semiconductor quantum dots (QD), several electron-hole recombination processes can take place. Besides the well-known resonance fluorescence, Coulomb interactions can lead to radiative Auger processes (shake-up) where part of the recombination energy is transferred to another electron. This Auger electron is left in an excited state and the emitted photon is correspondingly red-shifted.

We report the observation of emission and absorption of a radiative Auger transition from a negatively charged QD. By applying quantum optics techniques to the Auger emission we get insight into single-electron dynamics. We show photon absorption via the radiative Auger transition by driving the QD in a Λ-configuration: while monitoring the resonance fluorescence a second laser is tuned in resonance with the radiative Auger transition. A fluorescence reduction of up to 70% is observed - proving optical driving of the radiative Auger transition.

HL 18.8 Thu 15:45 H4

Interfacing colloidal quantum dots with nanophotonic circuits for integrated single photon sources — •Tobias Spiekermann, Alexander Eich, Helge Gehring, Lisa Sommer, Julian Bankwitz, Wolfram Pernice, and Carsten Schuck — Institute of Physics, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

Single photon sources are a key element for the realization of quantum communication, sensing and computing. While there exist several promising quantum emitter candidate systems, integration with nanophotonic networks in large numbers for wafer-scale quantum technologies has remained elusive. Here we show a lithographic technique that allows for interfacing nanophotonic waveguides with individual Colloidal Quantum Dots (CQD) from a solution applied across an entire chip [1]. We record the second order autocorrelation function to confirm single photon emission from CQDs into tantalum pentoxide (Ta_2O_5) waveguides that feature low intrinsic material fluorescence. Moreover, we demonstrate how iterative processing can be used to increase the yield of single CQDs with our technique. We further improve the photostability of CQDs positioned on a chip by subsequent site-passivation via atomic layer deposition of alumina (Al_2O_3). Our work paves the way for scalable integration of colloidal quantum dot single photon sources with photonic integrated circuits.

[1] Cherie R. Kagan, et al., Colloidal Quantum Dots as Platforms for Quantum Information Science, Chemical Reviews 121 (5), 3186-3233 (2021)

HL 18.9 Thu 16:00 H4

Electrical Characterisation of Te-doped InAs Nanowires grown by VS Molecular Beam Epitaxy — •Anton Faustmann, Pujitha Perla, Detlev Grützmacher, Mihail Lepsa und Thomas Schäpers — Peter-Grünberg-Institut PGI-9, FZ-Jülich, Jülich, Deutschland

InAs features high electron mobility and absence of a Schottky barrier at metal interfaces enabling ohmic contacts. In combination with large g-factor and high Rashba spin-orbit coupling this makes InAs nanowires a promising candidate for research of quantum effects. InAs nanowires with Te doping grown by molecular beam epitaxy were investigated in terms of their electrical transport properties at both room and cryogenic temperatures. The nanowires were grown in a catalyst-free vapour-solid process without using Au droplets. In contrast to Si, which shows amphoteric behaviour, Te acts as n-type dopant. It furthermore offers the possibility of an increased overall doping level. The Te doping concentration was found to affect both the morphology of the nanowires as well as electrical properties. The shape of the nanowires depends on Te uptake. Their intrinsic as well as contact resistances decrease considerably at increased doping level. Field-effect measurements using a global back gate show effect on the conductance, depending on the doping concentration. For higher doping no complete pinch-off was observable with conductance saturating at high negative gate voltages. Resistances were found to be only slightly increased at cryogenic temperatures.

HL 18.10 Thu 16:15 H4

Emission Time Statistics of a driven Single-Electron Transistor — •Johannes C. Bayer[1], Fredrik Brange[2], Adrian Schmidt[1], Timo Wagner[1], Christian Flindt[2], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]Department of Applied Physics, Aalto University, Finland

Precisely controllable single particle sources are an essential part of different quantum technologies operating at fixed clock cycles. A high level of accuracy in the time domain thereby requires detailed understanding of the interplay between an external drive and the response of the single particle source [1,2]. We here present the influence of periodically modulated tunneling rates on the emission time statistics of electrons emitted from a single-electron transistor (SET) [3]. A highly sensitive charge detector allows to detect tunneling events in real-time. By ramping up the driving frequency from slower to faster than the electron tunneling rate, the response of the SET undergoes a transition from adiabatic to non-adiabatic dynamics. This transition is accompanied by significant changes in the emission time statistics, which can be visualized in the waiting time distribution and is well described by our detailed theory.

[1] T. Wagner, et. al., Nat. Phys. 15, 330-334 (2019).
[2] R. Hussein, et. al., Phys. Rev. Lett. 125, 206801 (2020).
[3] F. Brange, et. al., Sci. Adv. 7, eabe0793 (2021).