HL 26: Focus Session: Quantum light sources for applications in quantum communication networks

The present focus session aims at discussing current state-of-the-art of non-classical light sources which can be found compatible with short- (few meters), mid- (few kilometers) or long-distance (several tens of km) quantum networks. Different approaches for the generation of non-classical light will be discussed, both experimentally and theoretically. We aim at stimulating the discussion on advantages and limitations of these approaches and under which aspects they can be find promising.

Organizers: Simone Luca Portalupi and Peter Michler (Uni Stuttgart)

Time: Wednesday 9:30–13:00 Location: H34

Invited Talk HL 26.1 Wed 9:30 H34

GaAs quantum dots as tunable sources of entangled and indistinguishable photons — •Armando Rastelli — Institut für Halbleiter und Festkörperphysik, Johannes Kepler Universität Linz, Österreich

Among different solid-state emitters of quantum light, epitaxial GaAs quantum dots (QDs) have recently emerged as nearly-ideal sources of triggered polarization entangled photon pairs [1]. This property, combined with the strongly suppressed probability of multiphoton emission [2] has allowed the implementation of quantum teleportation using photons subsequently emitted by a single QD [3].

In this talk I will discuss the peculiar properties of GaAs QDs, their performance as emitters of both single and entangled photons, as well as possible methods to engineer their light emission characteristics [1,4] to meet the demanding requirements imposed by photonic quantum technologies.

[1] D. Huber et al. Phys. Rev. Lett. 121, 033902 (2018).
[2] L. Schweickert et al. Appl. Phys. Lett. 112, 093106 (2018).
[3] M. Reindl et al. Science Adv. (2018).
[4] X. Yuan et al. Nat. Comm. 9, 3058 (2018).

HL 26.2 Wed 10:00 H34

Influence of the excitation scheme on coherence properties of InAs/InGaAs quantum dots emitting in the telecom C-band — •Cornelius Nawrath, Fabian Olbrich, Matthias Paul, Jan Kettler, 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

The emission of semiconductor quantum dots (QDs) has been shown to exhibit excellent properties in terms of single-photon purity, photon indistinguishability and entanglement fidelity, i.e. essential prerequisites for most applications in the field of quantum computing and quantum communication. The latter will benefit strongly from emission around 1550nm (telecom C-band) due to the global absorption minimum in standard silica fibers employed in the existing global fiber network.

The coherence properties of photons emitted from InAs/InGaAs QDs, grown on a metamorphic buffer to achieve C-band emission, are examined by measurements in the frequency and time domain comparing different optical charge carrier excitation schemes, namely above the band gap of the barrier material (above-band), via the phonon sideband (phonon-assisted) and in resonance fluorescence. This work highlights the importance of quasi-resonant or resonant excitation for applications relying on good coherence.

Invited Talk HL 26.3 Wed 10:15 H34

Phonon-assisted bright and dark exciton preparation in a semiconductor quantum dot — •Doris Reiter — Institut für Festkörpertheorie, Universität Münster, 48149 Münster, Germany

To use semiconductor quantum dots as source of single or entangled photons, a reliable control of the excitonic states in a quantum dot is required. An obstacle to overcome for several preparation schemes like Rabi rotations or adiabatic rapid passage is the interaction of the electrons with the phonons, which in these schemes may strongly hinder the state preparation [1]. In contrast, the phonon-assisted state preparation makes use of phonons to prepare the exciton or biexciton state in a robust way [2]. Phonon-assisted schemes in combination with a tilted magnetic field can further be used to prepare the dark exciton in a quantum dot, which has parallel electron and hole spin and hence is optically inactive [3]. The dark exciton state can be very useful for a controlled biexciton preparation to act as source of entangled photons. In my talk, I will discuss how to make use of the electon-phonon interaction to prepare different exciton states.

[1] Reiter et al., J. Phys.: Condens. Matter 26, 423203 (2014)
[2] Barth et al., Phys. Rev. B 94, 045306 (2016)
[3] Lüker et al., Phys. Rev. B 95, 195305 (2017)

HL 26.4 Wed 10:45 H34

Optical properties of qubit centers in SiC — •Michel Bockstedte — Chemistry and Physics of Materials, University of Salzburg, Salzburg, Austria — Solid State Theory, Friedrich-Alexander-Universität Erlangen-Nürnberg

Several defect centers in silicon carbid represent quantum bits for applications like quantum sensing or can be employed as single photon emitters. The excited defect states and the photons emitted in transitions between them and the groundstate alongside spin-selective, non-radiative transitions via intermediate low-spin states are pivotal parts of the mechanism underlying qubit applications. Optical excitation of the qubit may also lead to an ionization into other charge states in which the qubit is silent. The ability to control and deliberately switch the charge state is pivotal for applications and has recently been explored in experiments [1]. However, the charge states actually involved in the switching and their optical properties are often not clear. Here we investigate the optical ionization of the divacancy and the silicon vacany within the frame work of the CI-CRPA approach [2]. We shine light onto ionizing single and two-photon processes. Our results show that an enhanced ionization cross section can occure for photon energies well above the ionization thresholds. This determines the charge state yielded by the ionization.

[1] Golter and Lai, Sci. Reports 7, 13406 (2017).
[2] Bockstedte *et al.* njp Quantum Materials 3, 31 (2018).

15 min. break

Invited Talk HL 26.5 Wed 11:15 H34

Towards Quantum Communication Networks Exploiting Solid-State Quantum-Light Sources — •Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

Tremendous progress has been achieved in the engineering of solid-state-based non-classical light sources during the last two decades. In this context, quantum-light sources based on semiconductor quantum dots (QDs) are of particular interest. Allowing for the generation of close-to-ideal flying qubits these devices are predestinated for implementations of quantum communication.

In my talk, I will review our progress in this field, striving towards the ultimate goal of a global secure communication. I will revisit first proof-of-concept QKD experiments and discuss the development of state-of-the-art components for quantum key distribution (QKD), such as plug-and-play single-photon sources and receiver modules. In this context, the metrology of the quantum light sources together with a thorough security analysis of the measurement devices are essential for implementations of QKD. Assembling these building blocks to finally realize functional multi-user quantum-secured communication networks will be a grand challenge in quantum technologies, which is tackled within my recently founded Junior Research Group at Technische Universität Berlin.

Invited Talk HL 26.6 Wed 11:45 H34

Single Organic Molecules for Quantum Optics — •Ilja Gerhardt[1,2], Mohammad Rezai[1], and Jörg Wrachtrup[1,2] — [1]Institute for Quantum Science and Technology (IQST) and 3rd Institute of Physics, D-70569 Stuttgart, Germany — [2]Max Planck In-

stitute for Solid State Research, Heisenbergstr. 1, D-70569 Stuttgart, Germany

Single organic molecules at cryogenic conditions allow for the generation of narrow-band (14 MHz), and simultaneously high-flux single photons. In the last years, we managed to combine them with atomic vapors such that effects like slow light on the sodium D_2-line (589 nm) could be observed [1]. Now we extend our experiments towards all-optical configurations and high-visibility Hong-Ou-Mandel interference [2]. This configuration is extended towards a "delayed-choice" quantum eraser and allows for the generation of degenerate entangled photon-pairs. The raw data violates Bell's inequality with a Bell parameter of S=2.24 [3].

[1] – *Molecular photons interfaced with alkali atoms*, Petr Siyushev, Guilherme Stein, Jörg Wrachtrup, and Ilja Gerhardt, Nature, **509**, 66-70 (2014);
[2] – *Coherence Properties of Molecular Single Photons for Quantum Networks*, Mohammad Rezai, Jörg Wrachtrup, and Ilja Gerhardt, Phys. Rev. X, 2018, **8**, 9 (2018);
[3] – *Polarization-entangled photon pairs from a single molecule*, Mohammad Rezai, Jörg Wrachtrup, and Ilja Gerhardt, Optica, **6**, 34-40 (2019);

HL 26.7 Wed 12:15 H34

Receiver Module for QKD using Real-Time Security Monitoring with Single-Photon Sources — •Timm Kupko, Lucas Rickert, Stephan Reitzenstein, and Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

Solid-state single-photon sources have the potential to boost the performance of quantum-key-distribution (QKD) systems [1]. The security of QKD, however, critically relies on the performance of the quantum light source [2]. In addition, many attacks are known for trusted-device QKD, making a profound security analysis mandatory. Here, we evaluate the performance of a receiver module designed for free-space polarization-encoded QKD via the BB84 protocol using solid-state single-photon sources. The receiver module is tested with respect to the susceptibility to spatial-side-mode channel attacks. Furthermore, we analyze the effect of temporal filtering on the performance of QKD systems implemented with realistic quantum-light sources. A trade-off between quantum bit error rate and sifted key rate is necessary to achieve optimum performance. Finally we show, that real-time monitoring of the antibunching $g^{(2)}(0)$ inside the quantum channel enables a convenient security assessment during key generation. Our work lays the basis for the development of QKD-secured communication networks based on quantum-light sources.

[1] T. Heindel et al., New J. Phys. 14, 083001 (2012)
[2] E. Waks et al., Phys. Rev. A **66**, 042315 (2002)

Invited Talk HL 26.8 Wed 12:30 H34

Quantum repeater development based on entangled photons from quantum dots — •Michael Zopf[1,2], Robert Keil[1], Yan Chen[1], Jingzhong Yang[1,2], Fei Ding[1,2], and Oliver G. Schmidt[1,3] — [1]Institute for Integrative Nanosciences, Leibniz IFW Dresden, Germany — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [3]Material Systems for Nanoelectronics, Technische Universität Chemnitz, Germany

Distributing entangled states over long distances is essential for quantum communication networks. However, due to the transmission losses in optical fibers quantum repeaters have to be developed, as an equivalent for classical signal amplifiers. A promising approach is the combination of the polarization entangled photon emission from semiconductor quantum dots with atomic quantum memories. Here we show that, with an emerging family of GaAs/AlGaAs quantum dots, the stringent requirements for quantum repeaters can be addressed: Large ensembles of polarization-entangled photon emitters are obtained, with precisely tailored emission wavelengths for coupling with rubidium-based quantum memories. Unprecedented entanglement fidelities and photon indistinguishabilities of >90% are observed. Integration with piezoelectric actuators enables wavelength tuning and frequency-stabilization to rubidium transitions. On-demand photon generation with extraction efficiencies up to 65% is achieved with dielectric optical antenna structures, facilitating event-ready applications. These quantum light sources therefore enable entanglement swapping schemes, a major step for quantum repeater applications.