# HL 39: Materials and devices for quantum technology II

Time: Wednesday 9:30–12:45 Location: POT 112

**Invited Talk** HL 39.1 Wed 9:30 POT 112

**Quantum communication with entangled photons from quantum dots** — •Rinaldo Trotta — Department of Physics, Sapienza University of Rome, Piazzale Aldo Moro 5, 00185 Rome, Italy

The prospect of using the quantum nature of light for secure quantum communication keeps spurring the search of quantum emitters capable of delivering entangled photons on-demand, with high quality, and efficiency. Despite recent advances, however, the exploitation of deterministic quantum light sources in advanced quantum communication protocols remains a major open challenge. In this talk, I will show that photons generated on-demand by quantum dots can be used to implement a teleportation protocol whose fidelity violates the classical limit for any arbitrary input states [1]. Moreover, I will present the first experimental demonstration of all-photonic entanglement swapping using pairs of entangled photons from a quantum dot [2]. A discussion on future perspectives and challenges will conclude the talk. [1] M. Reindl, et al., Sci. Adv. 4, eaau1255 (2018). [2] F. Basso Basset, et al., Phys. Rev. Lett. 123, 160501 (2019).

HL 39.2 Wed 10:00 POT 112

**Tools for the Performance Optimization of Single-Photon Quantum Key Distribution** — Timm Kupko[1], Martin v. Helversen[1], Lucas Rickert[1], Jan-Hindrik Schulze[1], André Strittmatter[1,2], Manuel Gschrey[1], Sven Rodt[1], Stephan Reitzenstein[1], and •Tobias Heindel[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Institut für Experimentelle Physik,Otto-von-Guericke Universität Magdeburg, 39106 Magdeburg, Germany

Solid-state quantum light sources have the potential to boost quantum communication [1,2]. Here, we report on tools to optimize the performance of quantum key distribution (QKD) implemented with single-photon sources (SPSs). We analyze the performance of a receiver module designed for polarization-encoded QKD using deterministically-fabricated quantum dot SPSs. Exploiting two-dimensional temporal filtering and real-time security monitoring, we analyze the sifted key fraction, the quantum bit error ratio, and $g^{(2)}(0)$ expected in full implementations of the BB84 protocol as a function of the acceptance time-window. This routine enables us to choose optimal filter settings depending on the losses of the quantum channel [3]. Our findings are relevant 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)
[3] T. Kupko et al., arXiv:1908.02672 (2019)

HL 39.3 Wed 10:15 POT 112

**Efficient single photon extraction out of a photonic beer-glass** — •Jonathan Jurkat[1], Magda Moczała-Dusanowska[1], Ana Predojevic[2], Niels Gregersen[3], Christian Schneider[1], and Sven Höfling[1] — [1]Technische Physik, Julius-Maximilians Universität Würzburg, 97074 Würzburg — [2]department of Physics, Stockholm University, 106 91 Stockholm — [3]Department of Photonics Engeneering, Technical University of Denmark, 2800 Kgs. Lyngby

We demonstrate the fabrication and functionality of a photonic beer-glass cavity. This device combines the Purcell enhancement of a photonic micro-pillar structure with broadband photonic mode shaping of a vertical, tapered waveguide (sometimes referred to as a photonic trumpet). Our device is based on a MBE grown GaAs/AlGaAs heterostructure containing a low density layer of InAs Quantum Dots. Carefull optimization of the subsequent reactive ion etching step allows us to implement beer-glass shaped photonic microcavities, which support broadband optical resonances and promise efficient photon extraction efficiencies and significant Purcell effects over a spectral range up to 11 nm.

HL 39.4 Wed 10:30 POT 112

**Deterministic fabrication of quantum dot single-photon sources with emission in telecom c-band** — •Niklas Kanold[1], Andrei Kors[2], Sven Rodt[1], Johann Peter Reithmaier[2], Mohamed Benyoucef[2], and Stephan Reitzenstein[1] — [1]Institute of Solid State Physics, Technische Universität Berlin, Berlin, Germany — [2]Institute of Nanostructure Technologies and Analytics, CINSaT, University of Kassel, Kassel, Germany

The availability of reliable single-photon sources (SPS) with emission wavelength compatible with long-range communication in existing fiber-networks is one crucial requirement to implement large-scale quantum key distribution. Beyond that, applications in quantum metrology and information can profit form the availability of such non-classical light sources. Self-assembled semiconductor quantum dots (QDs) are very attractive candidates to realize on-demand SPS as they combine high emission rates with excellent single-photons purity and high indistinguishability, however almost exclusively at emission wavelengths in the 900-950 nm range. Here, we report on the development of QD SPSs in the InAs/InP-material system with emission at 1.55 micron. The QDs are grown via molecular beam epitaxy and include a back-side on a distributed Bragg reflector. We apply in-situ electron-beam lithography to deterministically integrate such QDs e.g. into mesa structures in order to maximize the photon extraction efficiency. The realized telecom SPSs are studied by optical and quantum optical tools to evaluate for instance the single-photon purity of emission.

HL 39.5 Wed 10:45 POT 112

**High-frequency electronics for quantum technologies** — •Kai J. Spychala, Alex Widhalm, Björn Jonas, Sebastian Krehs, Dirk Reuter, and Artur Zrenner — Department of Physics, University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany

The implementation of quantum effects in computation, simulation, sensing and communication in commercial technology requires a miniaturization and standardization effort which interfaces it with current technology. A very important aspect for scalability is the implementation of state of the art electronics in order to provide a link to the known digital technologies. As quantum phenomena are mostly short-lived and observed under cryogenic environments, robust high-frequency electronics which can operate in the cryogenic regime is needed. Further, the integration between quantum systems and high-frequency electronics plays an important role.

We show results on the ultrafast electric phase manipulation of an exciton qubit [1], the rapid adiabatic passage of an exciton qubit and present a scheme for Ramsey-based optoelectronic sampling. Additionally, we present electronics for a spin-photon interface which consists of a QD molecule controlled by a BiCMOS chip. Our chip generates electric pulses in order to entangle the spins of the electrons trapped in the QD molecule.

**Ref:** [1] A.Widhalm et al., APL112, 111105(2018)

**30 min. break.**

HL 39.6 Wed 11:30 POT 112

**Spin shuttling in a silicon double quantum dot** — •Florian Ginzel[1], Adam R. Mills[2], Jason R. Petta[2], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [2]Department of Physics, Princeton University, Princeton, New Jersey 08544, USA

Motivated by the demand[1] for long and intermediate range interaction in quantum information devices and recent developments[2,3] we theoretically analyze the dynamics of an electron during a detuning sweep in a silicon double quantum dot (DQD) occupied by one electron, and investigate possibilities and limitations of spin transport. Spin-orbit interaction and an inhomogeneous magnetic field which can introduce errors are included in our model. Interactions that couple the position, spin and valley degrees of freedom open a number of avoided crossings in the spectrum allowing for diabatic transitions and interfering paths. The outcome of a spin shuttling protocol is explored by means of numerical simulations and an approximate analytical model based on the solution to the Landau-Zener problem. We find that constructive interference can ensure a high transport fidelity even for a fast protocol. Exploiting destructive interference between different paths the DQD can also act as a spin or valley filter.

This work was supported by the ARO grant W911NF-15-1-0149.

[1] J. M. Taylor *et al.*, Nat. Physics **1**, 177 (2005)
[2] T. Fujita *et al.*, npj Quan. Inf. **3**, 22 (2017)

[3] A. R. Mills *et al.*, Nat. Communs. **10**, 1063 (2019)

HL 39.7 Wed 11:45 POT 112

**Purcell enhancement in hemispherical Fabry-Perot fiber-microcavities with InAs-QDs** — •Sascha Böhrkircher[1], Steffen Both[1], Thomas Herzog[2], Michael Jetter[2], Simone Luca Portalupi[2], Peter Michler[2], and Thomas Weiss[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, 70550, Stuttgart, Germany — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen (IHFG), Center for Integrated Quantum Science and Technology (IQST ) and SCoPE, University of Stuttgart, D-70569 Stuttgart, Germany

The Purcell effect is responsible for the modification of spontaneous emission rate of quantum emitters when embedded and resonant with cavities. Recent investigations of quantum-dot (QD) transitions in Fabry-Perot-based fiber microcavities demonstrate clearly the presence of Purcell enhancement [1]. That depends significantly on the resonant states of the cavity and their capability to couple to the QD. We discuss possible limitations of calculating these resonant states within the paraxial approximation [2] by comparing the results with finite-element simulations, and we provide design rules for an optimal Purcell enhancement.

[1] T. Herzog et al. , Quantum Sci. Technol. **3** 034009 (2018)
[2] Dustin Kleckner et al. , Phys. Rev. A, **81** 043814 (2010)

HL 39.8 Wed 12:00 POT 112

**Local vibrational modes of Si vacancy spin qubits in SiC** — •z. shang[1], y. berencén[1], a. hashemi[2], a. krasheninnikov[1,2], g. astakhov[1], h-p. komsa[2], and p. erhart[3] — [1]Institute of Ion Beam Physics and Materials, HZDR, Dresden, Germany — [2]Department of Applied Physics, Aalto University, Aalto, Finland — [3]Department of Physics, Chalmers University of Technology, Gothenburg, Sweden

Since the first demonstration of promising quantum properties of intrinsic point defects in SiC, they have been used to implement room-temperature quantum emitter as well as to realize quantum sensing. Radiative recombination of these point defects is accompanied by phonon emission due to the interaction with crystal vibrations. This process results in the so-called phonon side band (PSB). A high ratio of the emitted light from the zero-phonon line (ZPL) to the all emitted light, the Debye-Waller factor, is required for the implementation of quantum repeaters. Although the understanding of the PSB is important for quantum applications, it has not been yet investigated systematically in SiC.In this work, we uncover the local vibrational modes of the Si vacancy spin qubits in pristine 4H-SiC. The ZPL and six equally separated phonon replicas are observed in the optically-detected magnetic resonance spectra. We present first-principles calculations of the photoluminescence line-shape, which are in excellent agreement with the experiments. We experimentally obtain the resonance phonon energy and the Debye-Waller factor associated with the Si vacancy qubits. Our approach can be applied to a large variety of optically-active spin defects in wide-bandgap materials.

HL 39.9 Wed 12:15 POT 112

**Rectifying the zero-field splitting of the NV centers in silicon carbide** — •Timur Biktagirov, Wolf Gero Schmidt, and Uwe Gerstmann — University of Paderborn, Paderborn, Germany

The negatively charged nitrogen-vacancy (NV) center in silicon carbide is an attractive class of spin-triplet qubits, analogous to its counterpart in diamond [1]. One of the key spectroscopic fingerprints of the NV center is the splitting of its spin sublevels in the absence of external magnetic fields [2]. Herein, we show that the theoretical prediction of the zero-field splitting with the density functional theory is challenged by the so-called spin contamination of the two-particle spin density [3]. Subsequently, an efficient scheme to correct the zero-field splitting is devised showing excellent agreement with the experiment.

[1] H. J. Von Bardeleben, *et al.*, *PRB* **94**, 121202 (2016).
[2] T. Biktagirov, W. G. Schmidt, and U. Gerstmann *PRB* **97**, 115135 (2018).
[3] S. Sinnecker, and F. Neese, *J. Phys. Chem. A* **110**, 12267-12275 (2006).

HL 39.10 Wed 12:30 POT 112

**Incoherent effects in hot-electron quantum optics** — •Lewis Clark[1], Clarissa Barratt[1], Masaya Kataoka[2], and Clive Emary[1] — [1]Joint Quantum Centre Durham-Newcastle, School of Mathematics, Statistics and Physics, Newcastle University, Newcastle upon Tyne NE1 7RU, United Kingdom — [2]National Physical Laboratory, Hampton Road, Teddington, Middlesex TW11 0LW, United Kingdom

Using dynamical quantum dot single electron pumps, high-energy (hot) single electrons may be injected into semiconductor systems both reliably and at a high rate. When combined with energy and time-resolved detection, electrons from these sources provide us with a new platform to probe fundamental semiconductor physics in unprecedented detail.

In this contribution, we discuss coupling single-electron sources into interferometer geometries, such as the Mach-Zehnder interferometer, where the visibility of the quantum interference acts as a sensitive probe of the properties both of the electrons and their environment. We investigate the effect of the uncertainty in injection energy on the phase contributions of the path lengths and quantum point contacts.

We also present theoretical calculations of the decay rate of a hot electron subject to phonon scattering, and determine how these rates are affected by parameters such as the injection energy and the magnetic field. Using our calculations for both phase averaging and phonon rates, we derive strategies for minimising the effects of these processes, thus maximising the quantum-coherent properties of the electrons.