QI 25: Materials and Devices for Quantum Technology II (joint session HL/QI)

Time: Thursday 14:00–16:45 Location: EW 203

Invited Talk QI 25.1 Thu 14:00 EW 203
Compact, plug-and-play module to generate high-quality photon states from quantum dots — •Vikas Remesh — Institute für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria

As the quantum revolution gathers pace, there is a constant need to develop novel architectures to control quantum systems. Semiconductor quantum dots (QD) are regarded as the most promising sources of quantum light, due to their wavelength-tunability, high purity, high degrees of entanglement, and scalability. To realize a resource-efficient and scalable platform, it is desirable to have an ensemble of quantum dots that can be collectively excited with high efficiency. Shaped laser pulses have been remarkably effective in the development of controllable quantum systems. The most efficient optical excitation method of quantum dots relies on chirped laser pulses, as it offers robustness against spectral and intensity fluctuations. Yet, the existing methods to generate chirped laser pulses coupled to a quantum emitter are lossy and mechanically unstable, severely hampering the prospects of a practical quantum dot device. In this talk, I will briefly navigate through the impact of pulse-shaping schemes in advancing quantum dot control. Subsequently, I will present a compact, robust, and plug-and-play architecture for chirped pulse excitation of quantum dots, and demonstrate high-quality photon generation. Our method is a significant milestone in realizing a direct fiber-coupled, multipurpose quantum dot photon source.

QI 25.2 Thu 14:30 EW 203
Light-matter correlations in Quantum Floquet Engineering — •Beatriz Pérez-González[1], Gloria Platero[1], and Álvaro Gómez-León[2] — [1]Instituto de Ciencia de Materiales de Madrid (ICMM-CSIC), Madrid, Spanien — [2]Instituto de Física Fundamental (IFF-CSIC), Madrid, Spanien

Quantum Floquet engineering requires a proper gauge-invariant description of light-matter interaction to correctly capture the physics of the system beyond the strong-coupling regime. This means that such models typically involve a highly non-linear dependence on the photonic operators which makes their analysis and simulation complex.

In this talk, we present a non-perturbative truncation scheme for the light-matter Hamiltonian, which is valid for arbitrary coupling strength. This method can successfully capture the physics of both, fermions and photons, in agreement with the predictions of gauge-invariant models. Importantly, it also keeps track of the role of light-matter correlations, which are essential to correctly predict the properties of the many-body system.

We find that, even in the high-frequency regime, light-matter correlations can spontaneously break key symmetries. We focus on the implications this has when the electronic system has topological properties, since the breaking of a certain symmetry can jeopardize topological properties and their robustness. We exemplify our findings with the SSH chain, and show that a topological phase transition can be induced by coupling to a cavity and that the critical point can be predicted from the spectral function.

QI 25.3 Thu 14:45 EW 203
Near-Ideal Room Temperature Single Photon Emitters hosted in hexagonal Boron Nitride for Quantum Optics Application — •Tjorben Matthes[1,2], Anand Kumar[2], Chanaprom Cholsuk[1,2], Mohammad Nasimuzzaman Mishuk[2], Josefine Krause[2], Mouli Hazra[2], Kabilan Sripathy[2], and Tobias Vogl[1,2] — [1]Technical University of Munich, TUM School of Computation, Information and Technology, Arcisstraße 21, 80333 München — [2]Friedrich Schiller University Jena, Institute of Applied Physics, Albert-Einstein-Straße 15, 07745 Jena

In this talk, we will give an insight into our work done on single photon emitters hosted in hexagonal Boron Nitride (hBN) and the integration of those emitters into integrated photonics chips that have laser-written waveguides with controllable crosslinks at their heart.

We recently demonstrated the deterministic creation of identical single-photon emitters in hexagonal Boron Nitride that show exceptional characteristics regarding purity, stability, and brightness. In a follow-up work, we determined additional optical characteristics and carefully compared them to those predicted for numerous defect complexes by density functional theory (DFT) calculations. Currently, we are extending this work, bringing us closer to understanding the actual nature of the defect creation.

Furthermore, we are working on the technical utilisation of single photon emitters for quantum communication and optical circuits. In particular, we focus on laser-written waveguides that can be used for numerous applications having crosslinks with tunable splitting ratios.

QI 25.4 Thu 15:00 EW 203
Theory of optical ionization of Silicon Vacancies in 4H-SiC — •Maximilian Schober and Michel Bockstedte — Institute for Theoretical Physics, Johannes Kepler University Linz, Altenbergerstr. 69, A-4040 Linz, Austria

The Silicon Vacancy (V_{Si}) in 4H-SiC represents a quantum bit with advantageous properties for applications like quantum sensing and as a single-photon emitter. Optical readout of its spin state is achieved via a spin-selective optical cycle enabled by coupled defect electron spins and associated spin-dependent interactions. An alternative readout method involves spin-to-charge conversion through optical ionization [1] of the qubit, followed by the electrical detection of the resulting spin-sensitive photocurrents. Relatively little is known, however, regarding the photophysics of the optically silent charge states of V_{Si} created throughout this process. To tackle this issue, we investigate such systems with a combined ab initio framework of density functional theory and CI-cRPA [2] capable of including the crucial multiplet physics of such qubit centers. We discuss the relevant single and two-photon processes for optical charge state switching and electrical detection of the spin states. Furthermore, we shine light on the nominally "dark" neutral and doubly negatively charged centers as potential infrared emitters.

[1] M. Niethammer et al., Nat Commun 10, 5569 (2019).
[2] M. Bockstedte et al., npj Quant Mater 3, 31 (2018).

15 min. break

QI 25.5 Thu 15:30 EW 203
Inhomogenous broadening of donor bound exciton transitions in ultra-pure 28-Si:P — •Nico Eggeling[1], Finja Tadge[1], Dolores García de Viedma[1], N.V. Abrosimov[2], Jens Hübner[1], and Michael Oestreich[1] — [1]Leibniz Universität Hannover, Germany — [2]IKZ Berlin, Germany

Donor-bound excitons in ultra-pure silicon offer distinct characteristics which qualify them as well-suited candidates for applications in the field of quantum computing [1]. Using a combination of numerical and analytical calculations, we analyze the influence of statistical electric field fluctuations on donor-bound excitonic transitions in ultra-pure 28-Si:P. Our results show good agreement with current measurements of the inhomogeneously broadened excitonic linewidth. Employing approximations concerning screening effects and Monte-Carlo-type simulations, linewidth predictions are made and confirmed. The inhomogeneous nature of the excitonic complex is shown using spectral hole burning [2]. The next steps include measurements and discussion of temporal broadening of the hole-burning linewidth due to donor-acceptor recombination.

[1] Sauter, et al. Phys. Rev. Lett. **126**, 137402, (2021).
[2] Yang, et al. Appl. Phy. Lett. **95**, 122113, (2009).

QI 25.6 Thu 15:45 EW 203
All-dry Pick-Up and Transfer Method for Quantum Emitters in hBN — •Mohammad Nasimuzzaman Mishuk[1,2], Mouli Hazra[2], Anand Kumar[1,2], and Tobias Vogl[1,2] — [1]Department of Computer Engineering, School of Computation, Information and Technology, Technical University of Munich, 80333 Munich, Germany — [2]Abbe Center of Photonics, Institute of Applied Physics, Friedrich Schiller University Jena, 07745 Jena, Germany

Quantum emitters (QE) hosted by defects in hexagonal Boron Nitride (hBN) can operate at room temperature, serving as stable single photon emitters. They can also be integrated into various materials and devices, making them highly versatile in quantum technologies and photonic integrated circuits. However, creating these quantum emitters directly on different surfaces is challenging. That's why more often they are created on standard silicon chip coated with thin silicon dioxide layer. Owing to this difficulty, various transfer processes are developed which are mostly wet. In this study, we present an all-dry transfer method for transferring quantum emitters onto arbitrary substrates. Using our pick-up and transfer method, we have achieved a success probability of 1 in 4 for any single photon emitter. The validity of our results has been confirmed through second-order correlation measurements. We are actively working on improving its quality, quantity, and accuracy.

QI 25.7 Thu 16:00 EW 203

Plug-and-play quantum light from semiconductor quantum dots in fiber-pigtailed hybrid circular Bragg Gratings — •Lucas Rickert[1], Kinga Zolnacz[2], Daniel Vajner[1], Martin v. Helversen[1], Johannes Schall[1], Shulun Li[1,4], Sven Rodt[1], Anna Musial[3], Grzegorz Sek[3], Zhichuan Niu[4], Stephan Reitzenstein[1], and Tobias Heindel[1] — [1]Institute of Solid State Physics, Technical University Berlin, Berlin, Germany — [2]Department of Optics and Photonics, Wroclaw University of Science and Technology, Wroclaw, Poland — [3]Department of Experimental Physics, Wroclaw University of Science and Technology, Wroclaw, Poland — [4]Institute of Semiconductors, Chinese Academy of Sciences, Beijing, China

We report on the fabrication of hybrid circular Bragg gratings (hCBGs) with deterministically integrated semiconductor quantum dots (QDs), and discuss in detail the fabrication methods to deterministically match the emitter spatially and spectrally to the cavity mode. The devices exhibit bright, pure and indistinguishable single photon emission with experimentally measured Purcell enhancement >15 with high reproducibility.

Finally, we show how these high-performance hCBGs can be combined with directly attached single-mode fibers to harness the high quality quantum light in a plug-and-play fashion, and discuss excitation schemes suitable for optimum performance of these fiber-coupled systems.

QI 25.8 Thu 16:15 EW 203

Optical dipole orientation of single photon emitters in MoS_2 — •Katja Barthelmi[1,2], Lukas Sigl[1], Tomer Amit[3], Mirco Troue[1], Thomas Klokkers[1], Anna Herrmann[1], Takashi Taniguchi[4], Kenji Watanabe[4], Sivan Refaely-Abramson[3], and Alexander Holleitner[1,2] — [1]Walter Schottky Institut and Physik Department, Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Weizmann Institute of Science, Revohot, Israel — [4]National Institute for Materials Science, Tsukuba, Japan

Single photon emitters in monolayer MoS_2 can be formed by helium ion irradiation. The irradiation results in defects with an emission energy of 1.75 eV and a high position accuracy [1-3]. To further understand the microscopic structure of the defects, we study their emission dipole orientation by back focal plane imaging. We find that the optical dipole of the quantum emitters is in-plane orientated. Additionally, we resolve the far-field emission pattern spectrally through back focal plane spectroscopy. The novel method allows us to also study emission lines of low intensity.

[1] K. Barthelmi et al., in: Applied Physics Letters 117, 070501 (2020). [2] J. Klein et al., in: Nature Communications 10, 2755 (2019). [3] J. Klein and L. Sigl., in: ACS Photonics 8, 669-677 (2021). [4] K. Barthelmi et al., (2024).

QI 25.9 Thu 16:30 EW 203

Optimization of Circular Bragg Grating Resonators for Quantum Dot Photonic Cluster State Sources in the Telecom C-Band — •Yorick Reum, Jochen Kaupp, Simon Betzold, Felix Kohr, Tobias Huber-Loyola, Sven Höfling, and Andreas Pfenning — Technische Physik, Julius-Maximilians-Universität Würzburg, Germany

A major technological bottleneck for the realization of measurement-based optical quantum computing is the production of strings of highly-entangled photons, *photonic cluster states*. Semiconductor quantum dots (QDs) were shown to be promising candidates for cluster state sources, but spin-decoherence and non-negligible excitionic lifetimes currently limit fidelity and length of the emitted states [1]. This challenge can be tackled by embedding the QD into a cavity with high Purcell enhancement, inducing faster recombination times. We show Purcell-enhanced single-photon emission in the *telecom C-band* from InAs quantum dots inside *circular Bragg grating ("bullseye")* cavities, with excitonic decay times of down to $\tau = (180 \pm 3)$ ps, corresponding to a Purcell factor of $F_P = (6.7 \pm 0.6)$ [2]. To further optimize these resonators, we develop *best-fitting cavities* with 3D finite-difference time-domain simulations and discuss novel strategies for *post-fabrication tuning* via atomic layer deposition.

[1] Cogan, D., et al., Deterministic generation of indistinguishable photons in a cluster state. Nat. Photon. 17, 324-329 (2023).

[2] Kaupp, J., et al., Purcell-Enhanced Single-Photon Emission in the Telecom C-Band. Adv Quantum Technol. 2023, 2300242.