FRI 5: QIP Implementations: Solid-State Devices II

Time: Friday 10:45–12:45 Location: ZHG006

FRI 5.1 Fri 10:45 ZHG006

The challenges of developing electronic design automation tools for quantum technology — Karen Bayros[1], Martin Cyster[1], Jackson Smith[1], Jesse Vaitkus[1,2], Nicolas Vogt[1,2], Salvy Russo[1], and •Jared Cole[1] — [1]Theoretical, Computational and Quantum Physics group, School of Science, RMIT University, Melbourne, Australia — [2]HQS Quantum Simulations GmbH, Karlsruhe, Germany

Large-scale quantum computing requires extremely high precision qubits, with long coherence times, accurately calibrated control and free from unpredictable parameter drift.

Equivalent constraints have been addressed in conventional semiconductor electronics and other branches of engineering, often with the help of advanced computer simulation tools - referred to as Electronic Design Automation (EDA). For quantum technology, we are facing entirely new difficulties in terms of the scale and precision required for creating quantum EDA tools.

I will discuss the fundamental challenges in developing EDA tools for quantum technology, specifically those relevant to superconducting and semiconducting qubits. These challenges ultimately stem from the fundamental structure of quantum physics, which is ironic given that we need to solve quantum physics problems to build a quantum computer, in order to efficiently solve those quantum physics problems!

In discussing these issues, I will present our recent efforts to develop proof-of-principle multi-scale quantum EDA tools.

FRI 5.2 Fri 11:00 ZHG006

Semiconductor quantum dots in fiber-based microcavities — •Jonas Grammel[1], Nam Tran[2], Simone Luca Portalupi[2], Peter Michler[2], and David Hunger[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart

Semiconductor single photon sources are fundamental building blocks for quantum information applications. The current limitations of such quantum dot sources are the emitting wavelength and insufficient collection efficiency in fiber-based implementations. In the project *Telecom Single Photon Sources* we aim to realize high brightness, fiber coupled sources of single and indistinguishable photons at the telecom wavelength for the upcoming realization of fiber-based quantum networks. We employ open cavities realized with fiber-based mirrors, in combination with InGaAs quantum dots emitting in the telecom O-band and C-band. To achieve Fourier-limited photons we utilize the lifetime reduction of the emitters via the Purcell effect. We optimize the mode matching between the cavity mode and the guided fiber mode by introducing a fiber-integrated mode-matching optics that can basically reach near-unity collection efficiency. Fundamentally new is also the combination of Fabry-Perot micro-cavity modes with lateral micro- and nanostructures to reduce the cavity mode volume and thereby boost the emission enhancement and efficiency of the single photon emitters.

FRI 5.3 Fri 11:15 ZHG006

Two-photon spectrum and dynamics of a quantum dot under phonon-assisted excitation — •Lennart Jehle[1], Lena Maria Hansen[1], Thomas Sando[1], Patrik Isene Sund[1], Raphael Joos[2], Simone Luca Portalupi[2], Mathieu Bozzio[1], Peter Michler[2], and Philip Walther[1] — [1]University of Vienna, Faculty of Physics, Vienna Center for Quantum Science and Technology (VCQ), 1090 Vienna, Austria — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, University of Stuttgart, 70569 Stuttgart, Germany

Quantum dots promise to emit with high probability exactly one photon when pumped by a short laser pulse. However, there exists a finite chance of exciting the quantum dot twice within the duration of a single laser pulse, leading to the consecutive emission of two photons and imposing a fundamental limit on the multiphoton probability. Here, we resolve the distinct temporal shape of each of the photons' wavepackets using fast coincidence detection and report an asymmetric two-photon spectrum unique to phonon-assisted excitation. We demonstrate how this two-photon process provides insights into the emission dynamics and enables a direct measurement of the effective Rabi frequency, thus allowing us for the first time to extract the Rabi frequency of a non-resonantly driven quantum dot. By extending the temporal and spectral analysis further, we uncover correlations between the emission time and wavelength. Finally, we use this new understanding of the re-excitation process to maintain a low multiphoton probability regardless of the laser pulse length and thus improve the performance for quantum cryptography and quantum computing.

FRI 5.4 Fri 11:30 ZHG006

Deterministic single-step fabrication of quantum dot-circular Bragg grating resonators with high process yield — •Avijit Barua[1], Kartik Gaur[1], Léo J. Roche[1], Suk In Park[2], Priyabrata Mudi[1], Sven Rodt[1], Jin-Dong Song[2], and Stephan Reitzenstein[1] — [1]Institut für Physik und Astronomie, Technische Universität Berlin (TUB), Berlin, Germany — [2]Korea Institute of Science and Technology (KIST), Seoul, Republic of Korea

The integration of quantum dot (QD) single-photon emitters into photonic structures is pivotal for the establishment of hybrid quantum networks. Here, we use the deterministic, single-step in-situ electron-beam lithography (i-EBL) for integrating QDs into circular Bragg grating (CBG) resonators with high accuracy and scalability. Notably, devices with two/three rings deliver photon extraction efficiencies comparable to structures with more rings, enabling faster fabrication, reduced device footprint, and compatibility with electrical contacting. To demonstrate scalability, we report on the fabrication of several hundred QD-CBG devices across multiple sessions and samples. The devices exhibit bright, narrow-linewidth single-photon emission with excellent optical quality. To evaluate QD placement accuracy, we perform cathodoluminescence mapping along with scanning electron microscopy, and the statistical analysis of these devices shows that our i-EBL concept allows for sub-40 nm alignment accuracy and >80% process yield across various CBG geometries. Our findings highlight a reliable route toward scalable, high-performance QD-based single-photon sources for future integration in hybrid quantum photonic networks.

FRI 5.5 Fri 11:45 ZHG006

Spectroscopy and coherent nuclear spin manipulation of Eu-based molecular systems — •Evgenij Vasilenko[1], Vishnu Unni C.[1], Barbora Brachnakova[1], Weizhe Li[2], Nicholas Jobbitt[1], Senthil Kuppusamy[1], Mario Ruben[1], and David Hunger[1] — [1]Karlsruhe Institute of Technology — [2]FAU Erlangen

Rare-earth ions in solid-state hosts are promising spin qubit candidates due to their excellent optical and spin coherence properties. Recent work on Eu^{3+}-based molecular materials has demonstrated exceptional optical coherence [1], showing that ligand fields can be chemically engineered to improve both optical and spin properties for quantum applications. We investigate Eu^{3+}-doped molecular crystals and powders that exhibit long spin lifetimes and narrow homogeneous linewidths at 4.2 K [1,2]. In a single macroscopic crystal of $[Eu(Ba)_4(pip)]$, we observe inhomogeneous linewidths of 1.95 GHz, homogeneous linewidths of 120 kHz, spin $T_{1,sp}$ on the order of hours, and photon echo decays around 3 μs at 4.2 K, representing an improvement over previous results [1]. A complete spin characterization was performed on the same molecular complex, including both hyperfine transitions. Spin echo experiments revealed a coherence time of 613 μs, extended to 2 ms via CPMG dynamical decoupling. We also demonstrate the integration of these molecular crystals into open-access Fabry-Pérot fiber cavities to enhance emission via the Purcell effect [3].

[1] Serrano et al., Nature, 603, 241-246 (2022)
[2] Kuppusamy et al., J. Phys. Chem. C 127, 22 (2023)
[3] Hunger et al., New J. Phys 12, 065038 (2010)

FRI 5.6 Fri 12:00 ZHG006

Superconducting parallel-plate resonators for the detection of single electron spins — •André Pscherer, Jannes Liersch, Patrick Abgrall, Hélène Le Sueur, Emmanuel Flurin, and Patrice Bertet — Quantronics Group, Université Paris-Saclay, CNRS, SPEC, 91191 Gif-sur-Yvette Cedex, France

Solid-state spins have been explored as a resource for quantum sensing, computation and communication using mostly optical transitions to control and read out single spins [1]. Even though detecting spins via their spin-flip transition in the microwave frequency range would extend the palette of usable spins to those without optical transitions, this path seems impractical for single spins due to their vanishingly low radiative decay rates. Only recently, our group demonstrated the microwave-only detection of a single spin [2], enabled by a superconducting resonator with a Purcell factor of 10^{14} and a single-microwave-photon detector [3]. In this talk, I will explain the design of the currently used resonator and our progress towards a significantly improved resonator, which will shorten the spin lifetime to $\sim 10\,\mu$s.

[1] D. Awschalom *et al.*, Nature Photonics, 12(9), 516-527 (2018)
[2] Z. Wang, L. Balembois *et al.*, Nature, 619, 276-281 (2023)
[3] R. Lescanne *et al.*, PRX 10, 021038 (2020)

FRI 5.7 Fri 12:15 ZHG006

Influence of dephasing on the indistinguishability of 2D and bulk-embedded semiconductor quantum emitters — •Steffen Wilksen, Alexander Steinhoff, and Christopher Gies — Institute for Physics, Faculty V, Carl von Ossietzky University Oldenburg, 26129 Oldenburg, Germany

The generation of high-quality single photons is an important prerequisite for a multitude of quantum applications, including linear (photonic) quantum computing and quantum communication. While antibunching has been demonstrated in many cases, limitations of the Hong-Ou-Mandel (HOM) indistinguishability, quantifying the ability of emitted photons to interfere with each other, remain an open research question especially in single-photon sources based on 2D van der Waals materials.

In this talk, we analyze the influence of the coupling to acoustic phonon modes on the photon indistinguishability in two types of semiconductor-based single-photon sources, i.e. quantum dots in transition-metal dichalcogenides (TMDs), and III-V quantum-dot molecules. We simulate the HOM experiment and determine the indistinguishability by numerically computing two-time correlation functions. Results are obtained using an exact diagonalization approach, taking into account both markovian and non-markovian contributions. An optical cavity is considered for altering the recombination rate via the Purcell effect. Our results reveal fundamental limitations of HOM indistinguishability in TMD-based single-photon sources, rooted in the two-dimensional nature of the phonons.

FRI 5.8 Fri 12:30 ZHG006

Two-photon polymerization of strip-loaded thin-film lithium niobate waveguides for high-efficient photon pair sources and quantum circuits — •Alexandra Rittmeier[1,2], Muhamed A. Sewidan[2,3], Elisavet Chatzizyrli[1,2], Philipp Gehrke[1,2], Laura Bollmers[4], Silia Babel[4], Laura Padberg[4], Christof Eigner[4], Christine Silberhorn[4], Douglas Bremner[5], Anna Karoline Rüsseler[1,2], Andreas Wienke[1,2], Dietmar Kracht[1,2,3], Moritz Hinkelmann[1,2], and Michael Kues[1,2,3] — [1]Laser Zentrum Hannover e.V., Germany — [2]PhoenixD, LUH, Germany — [3]Institute of Photonics, LUH, Germany — [4]Paderborn University, Germany — [5]Alter Technology, Livingston, UK

Advancements in integrated photonics are essential for future chip-scale photonic systems and depend on new materials and fabrication methods. Lithium niobate (LN) is highly attractive due to its strong nonlinearity and excellent electro-optical properties. We introduce an etchless fabrication method for strip-loaded thin-film LN waveguides using two-photon polymerization (2PP), achieving low propagation losses of 0.15 dB/cm and rapid production cycles. The approach enables LN substrate reuse, promoting sustainable manufacturing. Using this fabrication approach, we realized a photon pair source with a 201 MHz pair generation rate and a coincidence-to-accidental ratio of 379, outperforming platforms fabricated via etching methods. In addition, we realized key components such as grating and directional couplers, demonstrating the potential of 2PP-fabricated optical components on LN for scalable, high-performance quantum photonic circuits.