THU 5: QIP Implementations: Interfaces

Time: Thursday 14:15–16:15 Location: ZHG006

THU 5.1 Thu 14:15 ZHG006

Quantum repeater applications with single trapped ions and single photons — •Pascal Baumgart, Max Bergerhoff, Jonas Meiers, Stephan Kucera, Christian Haen, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

For the realization of large-distance quantum networks, quantum repeaters (QR) are needed to overcome the exponential loss of direct transmission by dividing a transmission link into asynchronously driven cells [1] and segments [2]. We report on the implementation of these QR building blocks with free-space-coupled photons from two $^{40}Ca^{+}$ ions in the same Paul trap as quantum memories. Atom-photon entanglement is generated by controlled emission of single, separately fiber-coupled photons from the individually addressed ions. In the QR cell, entanglement is swapped from the ions to two asynchronously generated photons by a Mølmer-Sørensen gate and subsequent state detection [3], while in the QR segment, atom-atom entanglement is generated by a photonic Bell-state measurement.

In preparation for real-world QR applications, quantum communication protocols using a parametric down-conversion source of entangled photon pairs and a trapped-ion quantum memory, together with quantum frequency conversion, have been demonstrated over the 14.4 km Saarbrücken urban fiber link [4].

[1] D. Luong et al., Appl. Phys. B 122, 96 (2016)
[2] P. van Loock et al., Adv. Quantum Technol., 3: 1900141 (2020)
[3] M. Bergerhoff et al., Phys. Rev. A 110, 032603 (2024)
[4] S. Kucera et al., npj Quant. Inf. 10, 88 (2024)

THU 5.2 Thu 14:30 ZHG006

An Efficient Spin-Photon Interface for Tin-Vacancy Centers in Diamond — •Kerim Köster[1], Andras Lauko[1], Philipp Grasshoff[2], Dominic Reinhardt[3], Thomas Hümmer[4], Cyril Popov[2], Jan Meijer[3], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Uni Kassel — [3]Uni Leipzig — [4]Qlibri GmbH

The realization of long-distance quantum networks requires efficient interfaces of photons and stationary memories. The Tin-Vacancy (SnV) center in diamond emerged as a promising solid-state based spin photon interface, featuring spin-selective optical transitions, long memory times and efficient spin control. However, scaling to multi-node networks remains challenging, as they rely on the efficient coupling between these defect centers and optical cavities. Here, we present the integration of single addressable SnV centers in a micrometer-thin membrane into an open, fully tuneable and cryogenic microcavity to attain emission enhancement in a single optical mode. The cavity platform operates within a dilution cryostat at temperatures around 1K, featuring a passive mechanical stability below 10 pm. We observe a significant Purcell-induced lifetime shortening, indicating strong light-matter interaction. The system operates in the high-cooperativity regime, which allows us to probe the coherent coupling evidenced by emitter-induced extinction in the transmission profile of the cavity. Our platform further supports the integration of a superconducting magnet and a microwave antenna, enabling spin readout and coherent control. This represents a significant step towards realizing an efficient spin-photon interface for group IV color centers in diamond.

THU 5.3 Thu 14:45 ZHG006

Single erbium dopants in silicon resonators — •Benedikt Braumandl, Andreas Gritsch, Jakob Pforr, Alexander Ulanowski, Arantza Pineda Gonzalez, and Andreas Reiserer — Technical University of Munich, TUM School of Natural Sciences and Munich Center for Quantum Science and Technology (MCQST), 85748 Garching, Germany

Establishing long-distance quantum networks requires not only low-loss photon transmission, but also efficient, scalable interfaces between stationary and flying qubits. One promising approach leverages rare-earth ions, whose optical transitions lie directly in the telecom band, ensuring compatibility with existing fiber infrastructure [1]. In particular, erbium dopants in silicon offer a robust route to integrating quantum emitters with photonic circuitry, combining telecom-wavelength emission with the scalability of silicon nanotechnology [2].

We investigate the optical coherence of single erbium dopants embedded in high-Q silicon nanophotonic resonators, where Purcell enhancement enables efficient coupling between the emitter and photonic modes [3]. We further evaluate photon indistinguishability via Hong–Ou–Mandel-type interferometry, observing high visibility at short time delays. This demonstrates the emitter's suitability for photon-mediated entanglement protocols between distant qubits.

[1] Reiserer, A. Rev. Mod. Phys. 94, 041003 (2022)
[2] Gritsch, A. et. al. Phys. Rev. X 12 (4): 041009 (2022)
[3] Gritsch, A. et. al. Nat Commun 16, 64 (2025)

THU 5.4 Thu 15:00 ZHG006

Large-scale Localization of Diamond Color Centers for Deterministic Fabrication of Nanophotonic Spin-Photon Interfaces — •Maarten H. van der Hoeven[1], Julian M. Bopp[1,2], Marco E. Stucki[1,2], Tommaso Pregnolato[1,2], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany — [2]Ferdinand-Braun-Institut (FBH), Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

Quantum photonic circuits are fundamental building blocks for quantum information applications. Over the past decades, it has been demonstrated that color centers in diamond have excellent properties to serve as qubits in such systems [1]. To create an efficient spin-photon interface, the color centers have to be coupled to nanostructures. Achieving scalable fabrication of such devices with high yield and optimal performance requires deterministic fabrication techniques [2]. In this work, we use a widefield fluorescence microscope to localize tens of color centers per image frame and thousands across a diamond chip with uncertainties of just a few tens of nanometers. We then characterize all emitters and deterministically fabricate nanostructures at their positions. Our results show a device placement with high accuracy and precision. This makes it a powerful tool for the scalable and efficient integration of photonic spin qubits into quantum circuits.

[1] M. Ruf et al., Journal of Applied Physics 130, 070901 (2021)
[2] S. Rodt et al., J. Phys: Condensed Matter 32, 153003 (2020)

THU 5.5 Thu 15:15 ZHG006

The Sawfish spin-photon interface: fabrication and characterization — •Marco E. Stucki[1,2], Alok Gokhale[2], Julian M. Bopp[1,2], Maarten H. v. d. Hoeven[2], Tommaso Pregnolato[1,2], and Tim Schröder[1,2] — [1]Ferdinand-Braun-Institut (FBH), Berlin, Germany — [2]Humboldt-Universität, Berlin, Germany

Color centers in diamond are promising qubit candidates. They offer individually addressable spin states with long coherence times. By coupling color centers to optical cavities, their emission into the zero-phonon line can be enhanced via the Purcell effect. Solid-state cavities with a small mode volume are typically realized as photonic crystal cavities (PhCCs). The most common design for PhCCs consists of a periodic pattern of holes in a dielectric material. These features are difficult to fabricate in diamond due to its hardness and chemical stability. We recently proposed a new 1D PhCC geometry, the "Sawfish" cavity, that uses a cosine-based corrugation pattern to avoid creating these high aspect-ratio holes. Here, we fabricate Sawfish cavities in diamond. We investigate the structural and spectroscopic properties of the devices by a scanning electron microscope and a confocal optical setup, respectively. From our investigation we find that, despite roughness and erosion, quality factors exceeding 3800 were achieved. To increase the quality of the fabricated devices and make the fabrication more reliable, improvements in the etching processes are currently investigated. Using image analysis software developed in-house, we examine the erosion in our structures and compensate for it in our lithography mask.

THU 5.6 Thu 15:30 ZHG006

Near Lifetime-limited NV Centers Integrated into Diamond Photonic Crystal Cavities — •Alok Gokhale[1], Julian M. Bopp[1,2], Laura Orphal-Kobin[1], Kilian Unterguggenberger[1], Marco E. Stucki[1,2], Tommaso Pregnolato[1,2], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt Universität zu Berlin, Berlin, Germany — [2]Ferdinand Braun Institute (FBH), Berlin, Germany

Candidate quantum network node platforms need to satisfy a variety of properties. These include: interfacing between stationary and flying qubits, long storage times, indistinguishable photons and a large photon flux. Nitrogen-vacancy centers in diamond (NV) weakly coupled to cavities fulfil most of these criteria. Nanofabrication leads to a large number of unstable charge traps on the material surface, close to the emitter. The unstable fields cause a Stark-shift in the NV energies, leading to inhomogeneous broadening of the NV zero-phonon-line (ZPL) and loss of indistinguishability. It was recently demonstrated that narrow (150 MHz) NVs can exist in nanopillars [1]. Here, we adapt and extend the developed methods and show NV centers with linewidths as low as 21 MHz, in a Sawfish photonic crystal cavity [2,3]. We also demonstrate the tuning of the cavity resonance, through N2 gas deposition, over 20 nm. We show initial indications of Purcell enhancement of the NV ZPL as the cavity is tuned through it.

[1] L. Orphal-Kobin et al., Phys. Rev. X 13, 011042 (2023).
[2] J. M. Bopp et al., Adv. Optical Mater. 12, 2301286 (2024).
[3] T. Pregnolato et al., APL Photonics 9(3), 036105 (2024).

THU 5.7 Thu 15:45 ZHG006

Color centers for the secure processing of quantum tokens — •Gregor Pieplow[1], Yannick Strocka[1], Mohamed Belhassen[1], and Tim Schröder[1,2] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany

We present a quantum token scheme [1] for secure authentication or payment. Building on Wiesner's quantum money concept, tokens are encoded as multi-qubit states generated by a single-photon source, then transmitted and securely stored in a quantum-memory register. To manipulate and verify the token, we employ a sawfish nanophotonic-crystal cavity as a spin-photon interface, enabling the required spin-photon entangling gates. High-fidelity fractional quantum gates are realized via trains of optical $\pi/8$ pulses, achieving fidelities above 99% under realistic conditions. Although all-optical methods yield superior rates, limited storage times may constrain some applications. Incorporating microwave control, and leveraging long-lived nuclear spins extends token viability but lowers operational rates, highlighting a key trade-off for practical deployment.

[1] Strocka et al., arXiv:2503.04985 (2025)

THU 5.8 Thu 16:00 ZHG006

Towards laser cooling of erbium crystals — Daniele Amato[1,2], Florian Burger[1,2], Justus Edelmann[1,2], •Nilesh Goel[1,2], Andreas Gritsch[1,2], Till Nemolclev[1,2], Andrew Propper[1,2], Stephan Rinner[1,2], Stefano Romboni[1,2], Kilian Sandholzer[1,2], and Andreas Reiserer[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, 85748 Garching, Germany — [2]Zentrum für QuantumEngineering, ZQE, 85748 Garching, Germany

Thermal management in nanophotonic devices is vital in various research and technology fields, including quantum photonics. This necessitates a consistent measurement and control of temperature within nanophotonic devices. Established methods employ sensors attached to the components, which provide poor spatial resolution and hence hamper the assessment of local heating effects. To address such limitations, we investigate an alternate temperature sensing approach that measures the luminescence of erbium emitters directly incorporated into nanophotonic silicon waveguides. To span the temperature range from 295 K to 2 K, we look at two approaches: thermal activation of non-radiative decay channels above 200 K and thermal depopulation of spin- and crystal-field levels at lower temperatures [1]. To further analyse the applicability of this method, we look at the properties of erbium crystals and laser cooling of solids with erbium dopants. We investigate the efficacy of such a technique for cooling a solid system to enable quantum and optomechanical applications.

[1] Sandholzer, K., et al. Nanophotonics 14, 20250067 (2025).