Q 19: Quantum Networks, Repeaters, and QKD II (joint session Q/QI)

Time: Tuesday 11:00–13:00 Location: AP-HS

Q 19.1 Tue 11:00 AP-HS

Standalone mobile quantum memory system — •Martin Jutisz[1], Alexander Erl[2,3], Janik Wolters[2,3], Mustafa Gündoğan[1], and Markus Krutzik[1,4] — [1]Humboldt-Universität zu Berlin and IRIS Adlershof, Berlin, Germany — [2]Technische Universität Berlin, Berlin, Germany — [3]Deutsches Zentrum für Luft- und Raumfahrt, Berlin, Germany — [4]Ferdinand-Braun-Institut (FBH), Berlin, Germany

Quantum memories (QMs) are central to many applications in quantum information science. As a necessary element of quantum repeaters, these devices should be able to operate in non-laboratory environments, and as such their future deployment in space could advance global quantum communication networks [1]. In this context, warm-vapor QMs are particularly promising due to their low complexity and low size, weight and power.

We will present the implementation and performance analysis of a portable rack-mounted standalone warm vapor quantum memory system [2]. The optical memory is based on hyperfine ground states of Cesium which are connected to an excited state via the D_1 line at 895 nm in a lambda-configuration. The memory is operated with weak coherent pulses containing on average < 1 photons per pulse. The long-term stability of the memory efficiency and storage fidelity is demonstrated over a period of 28 hours together with operation in a non-laboratory environment.

[1] M. Gündoğan et al., npj Quantum Information 7, 128 (2021)

[2] M. Jutisz et al., arXiv:2410.21209 (2024)

Q 19.2 Tue 11:15 AP-HS

On-demand storage of single quantum-dot photons in a warm-vapour quantum memory — •Norman Vincenz Ewald[1,2,3], Benjamin Maass[1,3], Avijit Barua[3], Elizabeth Robertson[1], Kartik Gaur[3], Suk In Park[4], Sven Rodt[3], Jin-Dong Song[4], Stephan Reitzenstein[3], and Janik Wolters[1,3] — [1]DLR, Institute of Optical Sensor Systems, Berlin — [2]PTB, FB 8.2 Biosignals, Berlin — [3]TU Berlin — [4]KIST, Seoul, Republic of Korea

On-demand storage and retrieval of quantum information in coherent light–matter interfaces is key to optical quantum communication. Warm-alkali-vapour memories offer scalable and robust high-bandwidth storage at high repetition rates which makes them a natural fit for interfaces with solid-state single-photon sources. Recently, we deterministically stored and retrieved single photons from an InGaAs quantum dot after a storage time of 17(2) ns [1], an order of magnitude longer than previously reported [2]. Electro-optical laser pulse control allows for variable retrieval times from our ladder-type quantum memory that operates on the Cs D1 line at 895 nm [3]. Employing weak coherent pulses with 0.06(2) photons per pulse, we achieve an internal memory efficiency of $\eta_{\text{int}} = 15(1)\%$, a $1/e$-storage time of $\tau_s \approx 32$ ns, and a high SNR of 830(80). The memory's wide spectral acceptance window of 560(60) MHz enables storage of broadband photons from sources prone to spectral diffusion and frequency drifts.

[1] Manuscript under peer review. [2] S.E. Thomas et al., *Sci. Adv.* **10**, eadi7346 (2024). [3] B. Maaß, N.V. Ewald, A. Barua, S. Reitzenstein, and J. Wolters, *Phys. Rev. Appl.* **22**, 044050 (2024).

Q 19.3 Tue 11:30 AP-HS

All-optical control and readout of individual ^{167}Er nuclear spin qubits — Alexander Ulanowski, •Fabian Salamon, Johannes Früh, Adrian Holzäpfel, and Andreas Reiserer — Technical University of Munich, TUM School of Natural Sciences and Munich Center for Quantum Science and Technology (MCQST), 85748 Garching, Germany

Nuclear spins in solids exhibit exceptional coherence times and their coupling to nearby electron spins can enable optical interfacing [1]. In this work, we focus on the nuclear spin of ^{167}Er dopants, which feature an optical transition within the low-loss wavelength window of optical fibers. Using a high-finesse cryogenic Fabry-Perot cavity [2], we achieve all-optical control and readout of individual ^{167}Er dopants in a thin yttrium orthosilicate crystal. In our experiment we demonstrate a single-shot readout fidelity of 92(1)% and a hyperfine coherence time exceeding 0.2 s under dynamical decoupling. This makes our system well-suited for spin-photon entanglement, an important step towards developing long-range, fiber-based quantum networks and quantum repeaters.

[1] M. Zhong, M. Hedges, R. Ahlefeldt et al., Nature 517, 177-180 (2015).

[2] A. Ulanowski, J. Früh, F. Salamon, A. Holzäpfel & A. Reiserer, Adv. Optical Mater., 12, 2302897 (2024).

Q 19.4 Tue 11:45 AP-HS

Single-Shot Readout and Coherent Control of a GeV-^{13}C System for a Multi-Qubit Quantum Repeater Node — •Prithvi Gundlapalli[1], Katharina Senkalla[1], Philipp J. Vetter[1], Nick Grimm[1], Jurek Frey[2,3], Tommaso Calarco[4,5,6], Genko Genov[1], Matthias M. Müller[4], and Fedor Jelezko[1] — [1]Institute for Quantum Optics, Ulm University, Albert-Einstein-Allee 11, 89081 Ulm, Germany — [2]Peter Grünberg Institute-Quantum Computing Analytics (PGI-12), Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany — [3]Theoretical Physics, Saarland University, D-66123 Saarbrücken, Germany — [4]Peter Grünberg Institute-Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany — [5]Institute for Theoretical Physics, University of Cologne, D-50937 Germany — [6]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

Quantum repeater nodes with efficient spin-photon interfaces and long-lived quantum memories are key to enabling practical quantum networks. We present our results on high-fidelity single-shot readout exceeding 90 % on the germanium-vacancy center in diamond and discuss the implementation of a real-time 'blink check' to improve the fidelity. We further present the efficient characterization of a proximal ^{13}C using pulsed optically detected magnetic resonance and correlation spectroscopy and discuss optimization of its coherent control. Leveraging the long coherence times exceeding 20 ms and 2.5 s of the germanium-vacancy and ^{13}C respectively, this work highlights the potential of this system as an efficient multi-qubit quantum repeater node.

Q 19.5 Tue 12:00 AP-HS

Simulation of a heterogeneous quantum network using NetSquid — •Daniel Ventker, Ann-Kathrin Müller, and Florian Elsen — Chair for Laser Technology, RWTH Aachen University

As the relevance of advancing quantum computers continues to grow, so does the need to establish quantum channels between various laboratories to create quantum networks. A quantum internet should be capable of connecting multiple types of qubit platforms, e.g. allowing the use of separate computing and storage nodes or the readout of distinct quantum sensors within the network. The fundamental resource required for such a network is entanglement shared among spatially separated nodes. One way to entangle states over larger distances is through Bell state measurements. In this process, locally entangled photons are emitted from individual nodes to interfere at a central midpoint. This in turn creates entanglement, that transfers over to the respective nodes.

The design of experimental implementations of heterogeneous networks is a complex task. The optimal working point is determined by the characteristics and performance of each individual component. For this reason, a simulation based on the Python package "NetSquid" is developed to combine the theoretical model with the parameters of real components. The goal is to analyze how each of the components influences the overall system and what needs to be considered when designing a new setup. Specifically, this work addresses a heterogeneous connection between an NV-center and a quantum dot, focusing on the system's behavior concerning a quantum frequency converter.

Q 19.6 Tue 12:15 AP-HS

Outlining the design for the receiver module for a scalable free-space quantum network — •Karabee Batta[1,2], Michael Steinberger[1,2], Moritz Birkhold[1,2], Adomas Baliuka[1,2], Harald Weinfurter[1,2,3], and Lukas Knips[1,2,3] — [1]Ludwig Maximilian University (LMU), Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Max Planck Institute of Quantum Optics (MPQ), Garching, Germany

QKD leverages principles of quantum mechanics to generate encryption keys that are resistant to eavesdropping. Here, we present the design for a modular receiver unit to establish secure quantum links for polarization-encoded quantum states for ground-based and low-earth orbit satellite systems. The receiver addresses key challenges, such as polarization drift and spatial mode mismatch, which are critical for maintaining high-fidelity quantum links. It does so by employing automated polarization-compensation mechanisms and spatial filtering to avoid dedicated QKD attacks. A key application of this will be communication with the QUBE-II satellite.

Q 19.7 Tue 12:30 AP-HS

Optical single-shot readout of spin qubits in silicon — •Jakob Pforr, Andreas Gritsch, Alexander Ulanowski, Stephan Rinner, Johannes Früh, Florian Burger, Jonas Schmitt, Kilian Sandholzer, Adrian Holzäpfel, and Andreas Reiserer — Technical University of Munich, TUM School of Natural Sciences and Munich Center for Quantum Science and Technology (MCQST), 85748 Garching, Germany

Individual erbium emitters are a promising hardware platform for quantum networks as their coherent optical transitions exhibit low loss in optical fibers. Using silicon as a host crystal for erbium allows for scalable fabrication using established processes of the semiconductor industry [1]. To address single dopants, we integrate them into nanophotonic resonators with high $Q \sim 10^5$ and small $V \sim \lambda^3$, thus reducing their lifetime by more than a factor of 60 via the Purcell effect [2]. We then optically initialize the spin, implement high-fidelity optical single-shot readout and realize coherent control of the spin with microwaves [3]. These advances constitute a major step towards quantum information processing with Er:Si. We will further present our measurements of the coherence of photons emitted by individual dopants, which paves the way towards the generation of remote entanglement.

[1] Rinner et. al., Nanophotonics 12(17): 3455-3462, 2023.
[2] Gritsch et. al., Optica 10: 783-789, 2023.
[3] Gritsch et. al., arXiv: 2405.05351, 2024.

Q 19.8 Tue 12:45 AP-HS

Tomography of a Rb-87 Quantum Memory — •Yiru Zhou[1,2], Florian Fertig[1,2], Pooja Malik[1,2], and Harald Weinfurter[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Neutral atoms with long coherence times are a promising platform for future quantum networks. While recent advances have significantly improved the coherence time of neutral atom quantum memories [1], a deeper understanding of the dynamics of the entangled states remains crucial for further optimization.

In this talk, we present an Rb-87 neutral atom quantum memory that uses magnetically less sensitive atomic qubits, $\{|F = 1, m_F = -1 >, |F = 2, m_F = +1 >\}$ or $\{|F = 1, m_F = +1 >, |F = 2, m_F = -1 >\}$, as the basis for quantum memory. To investigate the dynamics of quantum states stored in this memory in detail, we perform a series of overcomplete Pauli tomography measurements and reconstruct the density matrices of entangled state. These measurements enable us to analyze the impact of various experimental improvements on the fidelity of the entangled state, providing detailed insights into the evolution of the coherence and dephasing processes.

[1] Y. Zhou et al., PRX Quantum 5, 020307 (2024)