Q 47: Quantum Information (Quantum Repeater)

Time: Wednesday 14:00–16:00 Location: K 1.020

Group Report Q 47.1 Wed 14:00 K 1.020

High-fidelity entanglement between a trapped ion and a telecom photon via quantum frequency conversion — •Matthias Bock, Pascal Eich, Stephan Kucera, Matthias Kreis, Andreas Lenhard, Christoph Becher, and Jürgen Eschner — Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

Entanglement between a stationary quantum system and a photonic flying qubit is an essential ingredient of a quantum-repeater network. Most stationary quantum bits, however, have transition wavelengths in the blue, red or near-infrared spectral regions, whereas long-range fiber-communication requires wavelengths in the low-loss, low-dispersion telecom regime. A proven tool to interconnect flying qubits at visible/NIR wavelengths to the telecom bands is quantum frequency conversion.

Here we present a complete device that produces entangled states between an atomic Zeeman qubit in a single trapped ^{40}Ca^{+} ion and the polarization state of a telecom photon with a Bell-state fidelity of 98.2 ± 0.2%. We achieve this by combining a trapped-ion quantum node producing ion-photon entanglement with a fidelity of 98.3 ± 0.3% and a polarization-preserving frequency converter connecting 854 nm to the telecom O-band. The converter, realized by difference-frequency generation in a PPLN waveguide embedded in single-crystal Mach-Zehnder-interferometer, combines 99.75 ± 0.18% process fidelity for the polarization-state conversion, 26.5% external conversion efficiency and 11.4 photons/s conversion-induced unconditional background.

Q 47.2 Wed 14:30 K 1.020

Atom-to-photon quantum-state transfer for quantum networks — •Pascal Eich, Matthias Bock, Stephan Kucera, Andreas Lenhard, Christoph Becher, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Quantum interfaces between atomic nodes and photonic quantum channels are crucial building blocks for single-atom-based quantum networks. In previous work, we demonstrated the quantum-state transfer from a single photon at 854 nm onto the electronic state of a single trapped ^{40}Ca^{+} ion [1]. Here we demonstrate the inverse mapping, of an atomic quantum state onto the polarization state of a single 854-nm photon. This experiment completes our fully bi-directional atom-photon quantum interface that provides compatibility with low-loss telecom-fiber communication through polarization-preserving quantum frequency conversion (QFC) [2].

[1] S. Kucera et al., DPG-Verhandlungen 2017, Q 2.5

[2] M. Bock et al., arXiv:1710.04866 (2017)

Q 47.3 Wed 14:45 K 1.020

A Gate between Two Matter Qubits Using Cavity QED — •Severin Daiss, Stephan Welte, Bastian Hacker, Lin Li, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Cavity QED systems have been established as an ideal interface to connect flying and stationary qubits in a future quantum network. Exchange of photons between the resonator-based network nodes enables the distribution of quantum states and the generation of remote entanglement [1]. To build a scalable network architecture, each node is required to contain several qubits that are connected by quantum gate operations. To this end, we have trapped two neutral atoms inside an optical cavity so that they are both strongly coupled to light impinging onto the resonator [2]. In this setup, we realize a quantum gate between two atomic qubits by reflecting an optical photon that arrives via the network channel. We show the functionality of our gate as a CNOT and demonstrate its entangling capabilities on the two atoms. The presented mechanism offers perspectives towards one-step many-atom gates or hybrid gates between several atoms and a network photon.

[1] A. Reiserer, G. Rempe, Rev. Mod. Phys. 87, 1379 (2015).

[2] S. Welte, B. Hacker, S. Daiss, S. Ritter, G. Rempe, Phys. Rev. Lett. 118, 210503 (2017).

Q 47.4 Wed 15:00 K 1.020

Remote two-photon interference at 1550 nm via quantum frequency conversion of quantum dot photons — •Benjamin Kambs^{1}, Jonas Heinrich Weber^{2}, Jan Kettler^{2}, Simon Kern^{2}, Matthias Bock^{1}, Hüseyin Vural^{2}, Simone Luca Portalupi^{2}, Michael Jetter^{2}, Christoph Becher^{1}, and Peter Michler^{2} — ^{1}Universität des Saarlandes, Naturwissenschaftlich-Technische Fakultät, Campus E2.6, 66123 Saarbrücken, Germany — ^{2}Institut für Halbleiteroptik und Funktionelle Grenzflächen, Research Centers SCoPE und IQST, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

Quantum repeaters constitute a major milestone in establishing fiber-based quantum networks. Ideally, such networks are built upon a pool of identical emitters providing indistinguishable telecom photons. However, the achieved two-photon interference (TPI) visibilities of solid state telecom quantum emitters fall short of corresponding systems at shorter wavelengths so far. Moreover, solid state sources typically show mismatched emission frequencies and need to be tuned into resonance. Here we employ efficient quantum frequency down-conversion (QFDC) to meet both prerequisites: near infrared photons emitted by two distinct semiconductor quantum dots are transferred to a common wavelength in the telecom C-band. Subsequently testing their mutual indistinguishability, we obtain a TPI visibility of 25 % solely limited by spectral diffusion. Our results show that QFDC can be used to integrate state-of-the-art emitters into quantum networks and thus constitute a basic building block of quantum repeaters.

Q 47.5 Wed 15:15 K 1.020

Towards efficient quantum memories at telecom wavelength — Benjamin Merkel, Lorenz Weiss, Natalie Wilson, Valentin Crépel, Andreas Gritsch, and •Andreas Reiserer — MPI of Quantum Optics, Garching, Germany

Global-scale quantum networks require efficient interfaces between long-lived memory nodes and photons at a telecommunications wavelength, where loss in optical fibers is minimal. In this context, Erbium ions doped into suited crystals are a promising candidate, as they exhibit a coherent optical transition at 1.5 μm and spin lifetimes exceeding 100 ms. Unfortunately, such long coherence times require a low dopant concentration to avoid ion-ion interactions, which puts a limit on the achievable efficiency of quantum memories. In our group, we plan to overcome this challenge by embedding Erbium-doped crystals into high-finesse optical resonators. In initial experiments with crystals of low dopant ion concentration, we have observed spin lifetimes of up to 0.5 s. By applying microwave pulses, we explore the potential of dynamical decoupling to extend the coherence time to this lifetime limit. In addition, we investigate the use of nuclear spins as a route to longer memory times. Finally, we have inserted Erbium-doped crystals into optical cavities that give access both to the single-ion Purcell regime and to the collective strong coupling regime. This opens unique perspectives for the implementation of efficient quantum memories for telecom photons.

Q 47.6 Wed 15:30 K 1.020

An atomic memory suitable for semiconductor quantum dot single photons — •Roberto Mottola, Andrew Horsley, Gianni Buser, Janik Wolters, Lucas Béguin, Jan-Philipp Jahn, Richard Warburton, and Philipp Treutlein — Universität Basel, Switzerland

Quantum networks have been proposed to overcome current limitations in quantum communication and computing. A promising path to realize these networks is the heterogeneous quantum node approach. Each node consists of separate and thus individually optimizable physical systems to generate and store single photons.

Pursuing the heterogeneous approach we demonstrated a quantum memory in warm Rb vapor with on-demand storage and retrieval [1] that in principle is compatible to semiconductor quantum dot photons. Using attenuated laser pulses on the single-photon level with a 660MHz linewidth, we have achieved an end-to-end efficiency $\eta_{e2e} = 3.4(3)\%$ for a storage time of $T = 50$ns and an intrinsic storage and retrieval efficiency $\eta = 17(3)\%$. We are working to further improve the performance of our memory by applying a tesla-order magnetic field, entering the Paschen-Back regime, where the separation of atomic ground state hyperfine sublevels is larger than the optical linewidth. We will be able to optically address each sublevel individually, allowing us to engineer an almost ideal atomic three-level system. This will get rid of spurious single photon absorption and suppress noise due to four-wave mixing, enhancing the efficiency and signal-to-noise ratio of the memory.

[1] J. Wolters, et al., Phys. Rev. Lett. 119, 060502 (2017)

Q 47.7 Wed 15:45 K 1.020

Device-independent Secret Key Rate Analysis for Quantum Repeaters — •Timo Holz, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine University, Duesseldorf, Germany

The device-independent approach to quantum key distribution (QKD) aims to establish a secret key between two or more parties with untrusted devices, potentially under full control of a quantum adversary. The performance of a QKD protocol can be quantified by the secret key rate, which is linked to the violation of an appropriate Bell-inequality in a setup with untrusted devices. We study secret key rates in the device-independent scenario for different quantum repeater setups and compare them to their device-dependent analogon. The quantum repeater setups under consideration are the original protocol by Briegel *et al.* and the hybrid quantum repeater protocol by van *Loock et al.*. The secret key rate depends on a variety of parameters, such as the gate quality or the detector efficiency. We systematically analyze the impact of these parameters and suggest optimized strategies.

[1] T. Holz, H. Kampermann, and D. Bruß, arXiv:1711.06072 (2017)