Q 17: Quantum Repeater and Quantum Communication

Time: Tuesday 11:00–13:00 Location: P 3

Q 17.1 Tue 11:00 P 3

Device-Independent Secret Key Rates for Quantum Repeater Setups — •Timo Holz, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40225 Düsseldorf, Germany

The device-independent approach to quantum key distribution (QKD) aims to distribute a secret key between two or more parties with untrusted devices, possibly under full control of a quantum adversary. The performance of a QKD-protocol can be quantified by the secret key rate R, which can be lower-bounded via the violation of an appropriate Bell-inequality. We study secret key rates in the device-independent bipartite case for different quantum repeater setups and compare them to their device-dependent analogon [1]. The quantum repeater setups under consideration are the original protocol by Briegel et al. [2] and the hybrid quantum repeater protocol by van Loock et al. [3]. For a given repeater scheme and a given QKD-protocol, the secret key rate depends on a variety of parameters, such as the gate quality or the fidelity of initially distributed states. We investigate the impact of these parameters and suggest optimized strategies.

[1] S. Abruzzo et al., Phys. Rev. A 87, 052315 (2013)
[2] H. J. Briegel et al., Phys. Rev. Lett. 81, 5932 (1998)
[3] P. van Loock et al., Phys. Rev. Lett. 96, 240501 (2006)

Q 17.2 Tue 11:15 P 3

Cavity-enhanced quantum memory at telecommunication wavelength — •Benjamin Merkel, Natalie Wilson, and Andreas Reiserer — Max Planck Institute of Quantum Optics, Garching, Germany

Quantum networks are based on the distribution of entangled photon pairs between distant nodes. Ideally, the photonic links have to operate at telecommunication wavelengths, where loss in glass fibers is minimal, and one has to implement fault-tolerant quantum repeater protocols. The exceptional coherence properties of rare-earth-ions in crystalline hosts have made them a prime candidate for the implementation of such quantum repeaters. In particular, Erbium has an optical transition at a telecom wavelength, for which ensemble-based quantum memories have already been demonstrated. However, the dipole-dipole interaction between densely-packed Erbium ions poses a limit to the achievable coherence time.

To overcome this challenge, we use crystals with a very low impurity concentration. While this minimizes ion-ion interaction and thus enables long coherence times, it comes at the price of a reduced memory efficiency caused by the lower optical depth. We therefore investigate embedding the crystals into optical resonators to enhance the ion-photon coupling. In the limit of weak doping, high resonator quality factor and small mode volume, this approach might even enable us to resolve and control single Erbium ions in a crystal, making them a unique resource for the implementation of global-scale quantum networks.

Q 17.3 Tue 11:30 P 3

An atomic memory suitable for semiconductor quantum dot single photons — •Janik Wolters, Lucas Beguin, Andrew Horsely, Jan-Philipp Jahn, Richard Warburton, and Philipp Treutlein — Universität Basel

Quantum networks will consist of many quantum memory nodes that are interconnected via photonic links, transporting single photons carrying quantum information. In the future, such quantum networks may enable: high-speed quantum cryptography for unconditionally secure communication; large scale quantum computers; and quantum simulators that will allow for exponential speed-up in solving specific complex problems. A promising route towards functional quantum networks is the heterogeneous approach, where different and separately optimized physical systems are used for single photon generation and storage. For example semiconductor quantum dots may be used as efficient, fast and deterministic single photon sources, while atomic ensembles allow for efficient storage of these photons.

We demonstrate a photonic memory in hot Rb vapor with on-demand storage and retrieval. In principle the memory is suitable for storing single photons emitted by an GaAs droplet quantum dot. Operation of the memory is demonstrated using attenuated laser pulses. For pulses with a bandwidth of ~ 100 MHz $\sim 0.5\mu$eV we achieve $\sim 25\%$ storage and retrieval efficiency, while the storage time approaches 1 μs. The developed quantum memory might become a cornerstone for future hybrid quantum dot-atom based quantum networks.

Q 17.4 Tue 11:45 P 3

Memory for photonic polarization qubits with long coherence time — •Matthias Körber, Olivier Morin, Stefan Langenfeld, Andreas Neuzner, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

The ability to faithfully store quantum information is one of the key requirements for many quantum technologies. Here, we present a quantum memory based on a single ^{87}Rb atom in a high-finesse optical resonator, capable of storing and retrieving single-photon polarizaion qubits with an overall efficiency of 18% when probed with highly attenuated coherent laser pulses containing one photon on average. Based on seminal work, the polarization of the photon is mapped onto the atom via a stimulated Raman adiabatic passage (STIRAP). The two atomic levels used to encode the qubit shift in opposite directions in the presence of a magnetic field due to the Zeeman effect. The memory is therefore susceptible to magnetic field fluctuations limiting the coherence time of the memory to a few hundred microseconds. Using an optical Raman transfer we temporarily map the qubit to a protected subspace, thereby extending the coherence time to tens of milliseconds. The coherence time can be further increased to more than 100 milliseconds by means of a spin-echo technique. Our results are an important milestones towards the implementation of a quantum repeater allowing for long distance quantum communication.

Q 17.5 Tue 12:00 P 3

Two-Color Time Entanglement for Quantum Communication — •Tobias Kohl, Chris Müller, and Oliver Benson — AG Nanooptik, Institut für Physik, Humboldt-Universität zu Berlin

Losses over long distances are a big challenge in creating a global quantum communication network. One possibility to minimize those effects is a quantum repeater which can be realized with entangled photons [1]. At certain nodes of a QR these photons have to be matched to dissimilar quantum systems, e.g. a storage or processing unit.

We produce highly non-degenerate photon pairs with wavelengths at the Cs D1 line (894.3 nm) and the telecom O-band (1313.1 nm) by parametric down conversion in a periodically poled Lithium-Niobat crystal. We already demonstrated polarization entanglement [2] when operating in a folded-sandwich geometry. However, polarization is difficult to maintain over long-distance optical fibers. Therefore, we set up a Franson interferometer [3] to create entanglement in time and position.

The goal is to establish a hybrid quantum interface in which we teleport the electronic state of a quantum dot onto a photon at telecom wavelength for long distance communication.

[1] Bussières F., et al. Nature Photonics 8, 775-778 (2014)
[2] Dietz O., et al. Appl. Phys. B 122, 33 (2016)
[3] Franson J. D. Phys. Rev. Lett. 62, 2205 (1989)

Q 17.6 Tue 12:15 P 3

Conversion of polarization to time-bin entanglement for applications in quantum networks — •Chris Müller, Tim Kroh, Andreas Ahlrichs, and Oliver Benson — AG Nanooptik, Institut für Physik, Humboldt-Universität zu Berlin

A key requirement for the acceptance of quantum communication as new technology is its compatibility with existing classical fiber networks. Such a quantum network should also contain quantum repeaters [1], which can be realized using entangled photon pair sources. However, many of the entangled photon sources rely on polarization entanglement, which is challenging to maintain over long-distance fiber networks.

Entanglement in time and position [2] is a suitable candidate for overcoming the loss of polarization entanglement in fibers. We set up a converter which allows for transfer of entanglement from polarization to time and position. In this presentation we want to demonstrate the preliminary results of such a conversion with the goal of using optical fibers for building a quantum network [3].

[1] Bussières F., et al. Nature Photonics 8, 775-778 (2014)
[2] Franson J. D., Phys. Rev. Lett. 62, 2205 (1989)
[3] Kimble H. J., Nature 453, 1023-1030 (2008)

Q 17.7 Tue 12:30 P 3

Quantum Frequency Down-Conversion of Ca$^+$–Resonant Polarization–Entangled Photons to the Telecom O-Band — •Matthias Bock, Stephan Kucera, Jan Arenskötter, Benjamin Kambs, Sebastian Rühle, Andreas Lenhard, Jürgen Eschner, and Christoph Becher — Universität des Saarlandes, Fakultät NT, FR Physik, Campus E2.6, 66123 Saarbrücken

A typical quantum repeater scenario comprises stationary atomic quantum memories and photonic fiber links to distribute information between these memories. In order to link the photons to the internal states of the atomic system, it is useful to encode the information in their polarization degree of freedom. A drawback is that the typical transition wavelengths in the red or NIR spectral region suffer high losses in optical fibers. Thus, an interface between these transition wavelengths and the low–loss telecom regime, which moreover preserves the polarization state of the photons, is required.
We present the implementation of a polarization–preserving frequency converter connecting 854 nm, the wavelength of the $4^2P_{3/2} \leftrightarrow 3^2D_{5/2}$ transition of a trapped Ca$^+$–ion, to the telecom O-band at 1312 nm. It is achieved via difference frequency generation in a nonlinear waveguide, which is arranged in a Sagnac configuration to ensure polarization independence. With high external conversion efficiency of 32.5% and low unconditional noise of 50 cts/s we are able to convert photons from a polarization–entangled pair at 854 nm generated by a cavity–enhanced pair source (linewidth: 10MHz) to the telecom O-band, and we show the preservation of the entanglement with high fidelity.

Q 17.8 Tue 12:45 P 3

Towards two-photon interference with a whispering gallery photon pair source — •Gerhard Schunk[1], Golnoush Shafiee[1], Ulrich Vogl[1], Dmitry Strekalov[1], Alexander Otterpohl[1], Florian Sedlmeir[1], Harald G. L. Schwefel[1,2], Gerd Leuchs[1], and Christoph Marquardt[1] — [1]Max Planck Institute for the Science of Light, Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Erlangen, Germany — [2]The Dodd-Walls Centre for Photonic and Quantum Technologies, Department of Physics, University of Otago, Dunedin, New Zealand

Single photons and photon pairs are an important resource for quantum information processing. We use parametric down-conversion (PDC) in a whispering-gallery resonator (WGR) made of lithium niobate to generate photon pairs [1] and squeezed light [2]. Single-mode operation of this source has been shown [4]. We recently demonstrated coupling of heralded single photons with MHz-bandwidth to different atomic transitions in the near-infrared [4,5].

Currently, we investigate PDC in counter-propagating modes of one WGR. Here we study interference of the counter-propagating signals above and below the oscillation threshold. This system opens up novel possibilities for the creation of polarization-entangled photon pairs for proposed quantum repeater schemes.

[1] M. Förtsch et al., Nat. Commun. 4, 1818 (2013). [2] J. U. Fürst et al., Phys. Rev. Lett. 106, 113901(2011). [3] M. Förtsch et al., Phys. Rev. A 91, 023812 (2015). [4] G. Schunk et al., Optica 2, 773 (2015). [5] G. Schunk et al., J. Mod. Opt. 63, 2058 (2016)