Q 60: Quantum Information II

Time: Thursday 16:30–18:30 Location: P

Q 60.1 Thu 16:30 P

Adiabatic coupling via tapered optical fibers — •Tim Turan[1] and Tim Schröder[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

In a network where quantum information is shared via single photons, the coupling efficiency is crucial. One option to couple a quantum node, such as a vacancy center in diamond, to an optical fiber, is utilizing a tapered waveguide to tapered optical fiber interface. [1]

If the geometry is chosen right, the fundamental mode can be transferred adiabatically from the waveguide to the fiber with minimal losses. We use an established theory of this transfer [2] together with statistical methods to find optimal waveguide and fiber taper geometries for near-unity transmission. Furthermore, we provide methods to reliably fabricate these optimal fiber tapers.

[1] M. J. Burek et. al., Fiber-Coupled Diamond Quantum Nanophotonic Interface, Phys. Rev. Applied 8, 024026 (2017).
[2] J. D. Love et al., Tapered Single-Mode Fibers and Devices. Part 1: Adiabaticity Criteria, IEE Proc. J Optoelectron. UK 138, 343 (1991).

Q 60.2 Thu 16:30 P

Photon pair generation using spontaneous four-wave mixing (SFWM) in microring resonators on a photonic silicon chip — •Florian Vogel, Erik Fitzke, Jakob Kaltwasser, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt

We employ spontaneous four-wave mixing (SFWM) in ring resonators on a photonic chip with silicon nitride waveguides to generate a photon pair spectrum with a spectral shape determined by the mode of the resonator. The frequencies of the resulting photon pairs differ by a multiple of the free spectral range and can be separated from one another by wavelength division multiplexing. Various filters are also used to remove unwanted frequency components that make it difficult to identify the photon pairs from the spectrum. A Pound-Drever-Hall (PDH)-Locking is set up for the compensation of thermal changes in the length of the resonator.

Q 60.3 Thu 16:30 P

A scalable four user quantum key hub for phase-time coding quantum key distribution — •Maximilian Tippmann, Erik Fitzke, Lucas Bialowons, Oleg Nikiforov, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt

Quantum key distribution (QKD) systems have been widely tested with various protocols. However, there is a very limited number of experiments on QKD networks allowing the connection of more than two users within a single system. Here, we report on a QKD system with an untrusted node for simultaneous pairwise key exchange for four users based on phase-time coding. In terms of network scalability, the untrusted node consisting of an entangled photon pair source enables simultaneous operation of dozens of user pairs. Additionally, we demonstrate the interconnectibility of our system allowing plug-and-play reconfiguration of the linked parties. Our source is highly flexible to allow various operation modes in terms of repetition rates as well as integration of new coding modules.

Q 60.4 Thu 16:30 P

Time-dependent single photon detector tomography — •Maximilian Mengler, Erik Fitzke, Robin Krebs, Thorsten Haase, Gernot Alber, and Thomas Walther — TU Darmstadt, Institute for Applied Physics, 64289 Darmstadt

Many modern applications in quantum physics depend on the usage of single photon detectors. Especially for quantum key distribution a detailed understanding of the detector's reaction to certain input states is important. We present an experimental setup to perform time dependent detector tomography, to obtain time-dependent POVMs as a general way of describing the detector's behavior. We used coherent states of known mean photon numbers as a set of known input states to implement the tomography. Finally, we present results regarding timing jitter and detector efficiency for multiple single photon avalanche detectors.

Q 60.5 Thu 16:30 P

Simulation of fiber-based quantum key distribution (QKD) with highly entangled states including multi-photon pair effects — •Philipp Kleinpass, Erik Fitzke, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt

The security of QKD protocols relies on the fact that a potential eavesdropper reveals its presence by introducing additional errors to the final key. Thus, to ensure a secure key exchange, other errors, namely due to device imperfections within the setup, need to be quantified and minimized, while maintaining a sufficiently high bit rate. Here, a model is presented that may be used to simulate the expected key rates for entanglement-based phase-time coding, considering many important error sources like multi-photon pair creations, chromatic dispersion and interferometer imperfections by employing a phase-space approach. Depending on the entanglement of the states used for the protocol, two methods are discussed, distinguishing between highly entangled states featuring a large number of Schmidt modes and states that may be represented explicitly by their Schmidt decomposition.

Q 60.6 Thu 16:30 P

Quantum Key Distribution based on time-bin entanglement in a scalable star-shaped network — •Till Dolejsky, Erik Fitzke, Maximilian Tippmann, Lucas Bialowons, Oleg Nikiforov, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt

We demonstrate quantum key distribution in a star-shaped multi user network with time-bin entangled photon pairs employing four users simultaneously. The setup is tested at a facility of Deutsche Telekom AG and photons are sent over a commercial optical fiber route. We achieve stable key distribution over distances of more than 75 km and durations of up to several hours. This QKD system is robust and allows to extend the network to dozens of users by standard multiplexing techniques, such as wavelength division multiplexing and time division multiplexing.

Q 60.7 Thu 16:30 P

Double nondestructive detection of an optical photon — •Lukas Hartung, Emanuele Distante, Severin Daiss, Stefan Langenfeld, Philip Thomas, Olivier Morin, Stephan Welte, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

In this talk, we will present an experiment demonstrating the double nondestructive detection of an optical photon [3]. The photon propagates in a 60 m long glass fiber, to which two nondestructive detectors are attached. Each detector consists of a single rubidium atom strongly coupled to an optical resonator. To detect a photon, each of the atoms is prepared in superposition state. When reflecting a photon off the cavity, a π-phase shift is imprinted on the superposition state. The photon is successively reflected from the two resonators and the subsequent readout of the phase of the superposition state of each atom heralds the presence of the photon. Correlations between the detector clicks are observed, and it is demonstrated that the detection efficiency of the two concatenated detectors surpasses the detection efficiencies of each individual detector. Furthermore, the experiment shows that the signal-to-noise ratio of the double detection is enhanced by about two orders of magnitude compared to the signal-to-noise ratios of the individual detectors.

[1] E. Distante et al., Phys. Rev. Lett. 126, 253603 (2021)

Q 60.8 Thu 16:30 P

Quantum teleportation with only a single photon as a resource — •Lukas Hartung, Stefan Langenfeld, Stephan Welte, Severin Daiss, Philip Thomas, Olivier Morin, Emanuele Distante, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

We report on the teleportation of a single qubit between two distant rubidium atoms each trapped at the center of a cavity in the strong-coupling regime connected by a 60m long glass fiber.

The teleportation of a quantum state allows for the deterministic transmission of qubits over lossy channels. In the common implementation of teleportation experiments, the sender and the receiver have to share a pair of entangled qubits to then transmit the source qubit to the receiver. The novel approach of our teleportation protocol is that a preshared entangled qubit pair is not required. The only necessary resource is a single photon which is first reflected off the receiver's cavity and afterwards off the cavity of the sender and subsequently detected. The detection of the photon combined with feedback on the receiver's atom heralds the succesful teleportation. This protocol allows for, in principle, unconditional teleportation. We teleport six mutually unbiased qubit states with an average fidelity $F = (88.3 \pm 1.3)\%$ at a rate of 6Hz over 60m [1].

[1] Langenfeld et al., Phys. Rev. Lett. 126, 130502 (2021)

Q 60.9 Thu 16:30 P

A nondestructive Bell-state measurement on two distant atomic qubits — •Matthias Seubert, Stephan Welte, Philip Thomas, Lukas Hartung, Severin Daiss, Stefan Langenfeld, Oliver Morin, Emanuele Distante, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

To exploit the full capability of quantum networks, it is necessary to develop schemes to generate, store and detect entanglement. Most of the detection techniques presented so far, are impaired by being local, destructive or not complete.

Here, we describe a complete and nondestructive entanglement detection scheme on two spatially separated network nodes. Each node is realized by a single ^{87}Rb atom stored in a strong coupling optical resonator connected by a 60 m optical fiber link. At first, an ancillary photon is consecutively reflected on each resonator, performing atom-photon gates at each reflection [1]. Repeating this sequence with a second ancillary photon, any initial two atom state is projected onto one of the four Bell-states [2]. The generated state is identified by polarization measurements of both photons. As this scheme does not destroy the quantum states, it can be utilized in future applications to preserve entanglement from dephasing by repetitive measurements using the quantum Zeno effect.

[1] Andreas Reiserer *et al.*, Nature **508**, 237 (2014)
[2] Stephan Welte *et al.*, Nature Photonics **15**, 504-509 (2021)

Q 60.10 Thu 16:30 P

Towards a WGMR based source optimized for photon-ion coupling in a deep parabolic mirror — •Sheng-Hsuan Huang[1,2], Thomas Dirmeier[1,2], Hadi Sedaghat-Pisheh[1,2], Martin Fischer[1,2], Markus Sondermann[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

Optical Whispering Gallery Mode Resonators (WGMR) have been proven to be compact and efficient sources of quantum states, e.g. squeezed states [1] or narrow-band heralded single photons. It has been shown, that they can be tuned to the resonance alkali metal vapours [2]. In addition to this versatility, it is also possible to operate WGMRs in a genuinely single-mode regime [3]. Together, it is these characteristics that make WGMRs a suitable system to efficiently couple to narrow-band atomic systems.

In our presentation, we discuss the concept and progress of the realization of a compact WGMR source that is specifically tailored to couple to the $D_{3/2} \Rightarrow D[3/2]_{1/2}$ transition at 935 nm of $^{174}Yb^{+}$ ions.

[1]A. Otterpohl, et.al., Optica 6, 1375-1380 (2019)
[2]G. Schunk, et.al., Journal of Modern Optics 63 (2016)
[3]M. Förtsch, et al., Physical Review A 91(2) 023812 (2015)

Q 60.11 Thu 16:30 P

A compact and versatile DM-CV QKD system for the QuNET initiative — •Stefan Richter[1,2], Ömer Bayraktar[1,2], Kevin Jaksch[1,2], Bastian Hacker[1,2], Imran Khan[1,2,5], Emanuel Eichhammer[1,5], Emmeran Sollner[1,5], Twesh Upadhyaya[3], Jie Lin[3], Norbert Lütkenhaus[3], Florian Kanitschar[4], Stefan Petscharnig[4], Thomas Grafenauer[4], Ömer Bernhard[4], Christoph Pacher[4], Gerd Leuchs[1], and Christoph Marquardt[1] — [1]QIV Research Group, MPI for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nuremberg, Erlangen, Germany — [3]Institute for Quantum Computing, Dept. of Physics and Astronomy, University of Waterloo, Canada — [4]Security & Communication Technologies Unit, Austrian Institute of Technology, Vienna, Austria — [5]now with KEEQuant GmbH, Fürth, Germany

Continuous-variable quantum key distribution (CV-QKD) is poised to become a key technology for securing critical communication infrastructure against the emerging threats of quantum computers. We present our implementation of a compact and versatile fiber-coupled discrete modulation CV-QKD system for metropolitan networks. We also show preliminary key rate estimates and channel characterization results obtained during a public technology demonstration in August 2021. Some aspects and challenges of the implementation are discussed, including error correction requirements.

Q 60.12 Thu 16:30 P

QKD and key management at KEEQuant — •Ulrich Eismann, Emanuel Eichhammer, Emmeran Sollner, Martin Hauer, Oliver Maurhart, and Imran Khan — KEEQuant GmbH, Gebhardtstr. 28, 90762 Fürth, Germany

In the advent of the quantum computer threat, we aim to make QKD a commodity by relying on standard telecom components, integrated photonics and electronics. This makes QKD invisible for the end user, and hence commercially viable.

We present our first QKD product and its the fitting into existing telecommunication networks. One layer above the physical layer of such networks, keys need to be handled using key management systems (KMS) and we will discuss the interplay between QKD, KMS and the application layer.

Q 60.13 Thu 16:30 P

Towards a quantum memory on a silicon chip — •Stephan Rinner[1], Lorenz Weiss[1], Andreas Gritsch[1], Johannes Früh[1], Florian Burger[1], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Ludwig-Maximilians-Universität, München, Germany

For the implementation of large-scale quantum networks Erbium dopants are promising candidates since they can combine second-long ground state coherence with coherent optical transitions at telecommunication wavelength. Among the potential host crystals for erbium, silicon stands out because it allows for the scalable fabrication of nanophotonic devices based on established processes of the semiconductor industry. In contrast to observations made in previous studies, we have shown that erbium ions implanted into silicon nanostructures can be integrated at well-defined lattice sites with narrow inhomogeneous ($\sim$1 GHz) and homogeneous ($<$0.1 GHz) linewidths. By optimizing the implantation conditions and by using high-purity silicon-on-insulator samples, we have recently decreased the homogeneous linewidth down to 20 kHz at 2 K. These improvements are a crucial step towards the implementation of coherent storage of light in a scalable physical platform. We will present recent results in spectroscopy and give an outlook on realizing a silicon based on-chip quantum memory operated at telecom wavelength.

Q 60.14 Thu 16:30 P

Quantum Frequency Conversion of SnV-Resonant Photons to the Telecom C-Band — •David Lindler, Tobias Bauer, and Christoph Becher — Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

Quantum nodes such as Tin-Vacancy-Centers (SnV) in diamond store and distribute quantum information in quantum communication networks. Transferring the spin state of the SnV-Center onto single photons enables the exchange of information between these nodes over long distances through optical fiber links. The problem of high loss in fibers for SnV-resonant photons is solved by quantum frequency down-conversion of the photons into the low-loss telecom bands.

We here present a 2-step scheme for quantum frequency conversion of SnV-resonant photons to the telecom C-band based on difference frequency generation in PPLN waveguides. Due to pumping in the long wavelength regime, the two step process $619\,\mathrm{nm} - 2061\,\mathrm{nm} = 885\,\mathrm{nm}$, $885\,\mathrm{nm} - 2061\,\mathrm{nm} = 1550\,\mathrm{nm}$ drastically reduces noise at the target wavelength compared to the single step process $619\,\mathrm{nm} - 1030.5\,\mathrm{nm} = 1550\,\mathrm{nm}$. We will present the characterization of key components as well as first results on wavelength stabilization of the the Cr^{2+}:ZnS/Se pump laser, which is needed to avoid conversion-induced frequency fluctuations of the single photons.

Q 60.15 Thu 16:30 P

Two-Stage Quantum Frequency Down-Conversion of Single Photons from Silicon-Vacancy Centers in Diamond — •Marlon Schäfer, Benjamin Kambs, Dennis Herrmann, Tobias

Bauer, and Christoph Becher — Universität des Saarlandes, FR Physik, Campus E2 6, 66123 Saarbrücken

The silicon-vacancy (SiV) center in diamond is a promising system as qubit for quantum communication networks due to its long spin coherence time, fourier-limited linewidth and all-optical coherent spin control. Since SiV centers show optical transitions in the visible red spectral range, quantum frequency conversion (QFC) to low-loss telecommunication wavelengths is vital for fiber-linked networks [1]. However, direct conversion schemes suffer from strong conversion-induced noise caused by Raman scattering and SPDC of the pump beam [2].
Here, we present efficient and low-noise QFC of single photons emitted by SiV centers into the telecom C-band using a two-stage conversion scheme. Through difference frequency generation in PPLN waveguides SiV photons at 737 nm are first converted to 999 nm followed by a conversion to 1549 nm. As a key advantage, the large spectral distance to the pump wavelength at 2813 nm bypasses SPDC noise and minimizes Raman noise. Thereby, we achieve a low unconditional conversion noise of less than 1 photon/s/GHz, an overall external conversion efficiency of 29 % and preservation of the single photon statistics.

[1] Bock, M. et al., Nat Commun 9, 1998 (2018).
[2] Zaske, S. et al., Opt. Express 19, 12825-12836 (2011).

Q 60.16 Thu 16:30 P

Polarization-preserving quantum frequency conversion for entanglement distribution in trapped-atom based quantum networks — •Tobias Bauer[1], Jan Arenskötter[1], Matthias Bock[1,2], Stephan Kucera[1], Benjamin Kambs[1], Jürgen Eschner[1], and Christoph Becher[1] — [1]Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken, Germany — [2]Universität Innsbruck, Institut für Experimentalphysik, Technikerstrasse 25/4, A-6020 Innsbruck, Austria

In quantum communication networks information is stored in internal states of quantum nodes, which can be realized e.g. in trapped ions like $^{40}Ca^+$. By transferring the states onto flying quantum bits, i.e. photons, it is possible to exchange information between these nodes over long distances via optical fiber links. In order to minimize attenuation in fibers, which is particularly high for typical transition frequencies of trapped ions, quantum frequency down-conversion of the transmitted photons to low-loss telecom bands is utilized.

We present a high-efficiency, rack-integrated quantum frequency converter for polarization-preserving conversion of $^{40}Ca^+$-resonant photons to the telecom C-band. It relies on the difference frequency generation process 854 nm - 1904 nm = 1550 nm in a PPLN waveguide, which is arranged in a Sagnac configuration to achieve polarization preservation. We will further present the application of the converter in entanglement distribution experiments, e.g. the distribution of entangled SPDC-photon pairs and quantum state teleportation over large fiber distances.

Q 60.17 Thu 16:30 P

Efficient spin-photon interface for NV centers in diamond — •Kerim Köster[1], Maximilian Pallmann[1], Matthias Klausmann[1], Jonathan Körber[2], Jeremias Resch[1], Jonas Grammel[1], Julia Heupel[3], Cyril Popov[3], Rainer Stöhr[2], and David Hunger[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie — [2]3. Physikalisches Institut, Universität Stuttgart — [3]Institut für Nanostrukturtechnologie und Analytik, Universität Kassel

Building a long distance quantum network is one of the big challenges in the field of quantum communication, which requires the development of a quantum repeater. A crucial component of this device is an efficient, coherent spin photon interface. Coupling color centers in diamond to a microcavity is a promising approach therefore.

In our experiment, we integrate a diamond membrane into an open access fiber-based Fabry-Perot microcavity to attain emission enhancement in a single well-collectable mode. We present our fully tunable, cryogenic cavity platform operating in a closed-cycle cryostat, and we achieve a sub-picometer mechanical stability during quiet periods.

We observe cavity-enhanced fluorescence spectra of an ensemble of shallow-implanted nitrogen vacancy centers in diamond, showing Purcell-enhancement of the zero-phonon line (ZPL). Furthermore, the emission yields temporal bunching of ZPL photons, which indicates a collective behavior in the emission process that can be attributed to superradiance.

Q 60.18 Thu 16:30 P

Towards long Coherence Times for a Single-Atom Quantum Memory — •Florian Fertig[1,2], Tim van Leent[1,2], Yiru Zhou[1,2], Pooja Malik[1,2], Anastasia Reinl[1,2], Robert Garthoff[1,2], Wei Zhang[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

For large scale quantum networks, long coherence times are crucial to distribute high quality entanglement over long distances. Our experiment consists of two nodes employing optically trapped single-atoms as quantum memories including quantum frequency conversion to the low loss telecom S band. The two atoms are entangled using an entanglement swapping protocol. For fiber links with a length of multiple kilometers, the quality is limited by the coherence time of the atomic states [1].

Here, we report on the implementation of a new trap geometry mitigating any decoherence effects ($T_2 \approx 330\ \mu$s) stemming from the optical dipole trap (ODT). These effects emerge from longitudinal components of the electric field that arise due to the tightly focused ($w_0 < 2\ \mu$m) ODT beam. For this, we overlap the single ODT beam with another counterpropagating one to set up a standing-wave geometry. As the effective magnetic field of the second beam has an opposite sign, perfect overlap will cancel the effective magnetic field and increase the coherence time to the millisecond scale.

[1] T. van Leent et al., arXiv:2111.15526 (2021)

Q 60.19 Thu 16:30 P

Robust Qubit Encoding for a Single-Atom Quantum Network Link — •Yiru Zhou[1,2], Tim van Leent[1,2], Florian Fertig[1,2], Pooja Malik[1,2], Anastasia Reinl[1,2], Wei Zhang[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

The most fundamental task for a quantum network node is to serve as light-matter entanglement interface. For high-quality entanglement distribution over long distances, the quantum memories in such nodes need a quantum storage, i.e, coherence time that is much longer than the travel time of the photons used to distribute the entanglement. Here we represent the improvement of the coherence time of a single-atom quantum memory from 300 μs to more than 5 ms. This is realized via coherently transferring the initial qubit states $\{|F=1, m_F=-1>, |F=1, m_F=+1>\}$ to a magnetic-field-insensitive encoding states $\{F=1, m_F=-1>, |F=2, m_F=+1>\}$ by a state-selective Raman transfer [1]. Even longer coherence time should become possible by implementing spin-echo and Raman sideband cooling. With these measurement coherence time can increase the reach of our quantum network link from 33 km [2] to hundreds of kilometers.

[1] M. Körber et al., Nat. Photonics 12, 18 (2018)
[2] T. van Leent et al., arXiv: 2111.115526 (2021)

Q 60.20 Thu 16:30 P

Quantum Memories based on Spin Exchange between Alkali Metal and Noble Gas Vapours at Room Temperature — •Norman Vincenz Ewald[1], Luisa Esguerra[1,2], and Janik Wolters[1,2] — [1]German Aerospace Center (DLR), Institute of Optical Sensor Systems, Berlin — [2]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin

Quantum memories with optical interfaces and storage times well beyond 1 s will spawn manifold applications in quantum communication, e.g. as quantum tokens for authentication. Compactness and technological simplicity are key parameters for the memory platform to achieve large-scale applicability. Our goal is to realise such a quantum memory in atom vapours at room temperature. We present our approach to use a mixture of a noble gas—with its well isolated nuclear spins that remain coherent for hours [1] serving as long-term memory—and an alkali metal providing the optical interface based on EIT [2]. The optically inaccessible nuclear spins of the noble gas will be addressed by coherent, collisional spin exchange with the alkali metal atoms [3]. Compatibility with existing telecommunication infrastructure may be established by employing bi-chromatic sources of entangled photon pairs with one photon on the alkali atom's storage transition and one photon suitable for telecom fibres [4].

[1] C. Gemmel et al., *Eur. Phys. J. D* **57**, 303–320 (2010).
[2] J. Wolters et al., *Phys. Rev. Lett.* **119**, 060502 (2017).
[3] O. Katz et al., arXiv:2007.08770v2 (2020).
[4] D. Rieländer et al., *New J. Phys.* **18**, 123013 (2016).

Q 60.21 Thu 16:30 P

Towards coherent single praseodymium ion quantum memories in optical fiber microcavities — •Sören Bieling[1], Evgenij Vasilenko[1], Roman Kolesov[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Universität Stuttgart, 70569 Stuttgart, Germany

Rare earth ions doped into solids show exceptional quantum coherence in their ground-state hyperfine levels. These spin states can be efficiently addressed and controlled via optical transitions and are thus ideally suited to serve as quantum memories and nodes of quantum networks. However, while long storage times, high storage efficiencies and storage on the single photon level have all been demonstrated separately, they could not yet be achieved simultaneously.

We aim to demonstrate both long and efficient single quantum storage in the ground-state hyperfine levels of single Pr^{3+} ions doped into yttrium orthosilicate (YSO) by integrating them as membrane into optical high-finesse fiber-based Fabry-Pérot microcavities. This allows for efficient addressing and detection of individual ions. In order to prolong the storage times, we aim to increase their hyperfine coherence times further by operating under a zero first-order Zeeman (ZEFOZ) shift magnetic field as well as by employing dynamical decoupling sequences. Together with the Purcell enhanced emission and ultrapure Pr^{3+}:YSO membranes this strives to realize efficient and coherent spin-photon interfaces that are suitable for deployment in scalable quantum networks.

Q 60.22 Thu 16:30 P

Quantum repeater node for unconditionally secure quantum key distribution — Stefan Langenfeld, •Philip Thomas, Olivier Morin, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

In classical communications a measure-and-resend strategy is used to amplify signals and overcome the exponential losses in optical fibers. In the quantum case this does not work due to the no-cloning theorem. An alternative concept which became known as the quantum repeater [1] aims at dividing a link into shorter segments across which entanglement is created independently. This leads to an effective increase in attenuation length by a factor equal to the number of segments.

Here, we demonstrate an elementary quantum repeater link consisting of a single repeater node and two classical end nodes, Alice and Bob. The repeater node is realized using two ^{87}Rb atoms in a high-finesse optical cavity [2]. Photons which are entangled with atom A are sent to Alice until she registers a detection event. Then, the same procedure is carried out on atom B and Bob, while the qubit on atom A is being stored. When Bob registers a photon, a Bell-state measurement is performed for entanglement swapping. We show an enhanced rate vs. distance scaling and thus the key signature of a quantum repeater. Furthermore, we demonstrate an error rate below 11 % which is essential for unconditional security in quantum key distribution protocols.

[1] H.-J. Briegel *et al.*, Phys. Rev. Lett. **81**, 5932 (1998)
[2] S. Langenfeld *et al.*, Phys. Rev. Lett. **126**, 230506 (2021)

Q 60.23 Thu 16:30 P

Portable warm vapor memory — •Martin Jutisz[1], Mustafa Gündoğan[1], Elisa Da Ros[1], Markus Krutzik[1], Janik Wolters[2,3], and Leon Messner[1,3] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]Technische Universität Berlin, Berlin, Germany — [3]Deutsches Zentrum für Luft- und Raumfahrt, Berlin, Germany

Warm vapor memories have seen significant progress in terms of efficiency and storage time in recent years. Their low complexity makes them a promising candidate for operation in non-lab environments including space-based applications. As necessary element of quantum repeaters, memories operating in space could advance global quantum communication networks [1].

We will present the overall design and status of a portable system with an emphasis on the miniaturized laser system. The implementation of the optical memory is based on electromagnetically induced transparency on the Cesium D1 line at 895nm. A distributed Bragg reflector laser is frequency stabilized by saturated absorption technique. Automated locking is realized via a FPGA-based tool for laser frequency stabilization.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50RP2090.

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