Q 21: Quantum Communication III

Time: Tuesday 11:00–13:00 Location: HS 3219

Q 21.1 Tue 11:00 HS 3219

Polarization entanglement in whispering gallery resonators — •Sheng-Hsuan Huang[1,2], Thomas Dirmeier[1,2], Golnoush Shafiee[1,2], Kaisa Laiho[3], Dmitry Strekalov[1], 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 — [3]German Aerospace Center (DLR e.V.), Institute of Quantum Technologies, Ulm, Germany

Cavity-assisted spontaneous parametric down conversion (SPDC) sources are a key component to connect different nodes in quantum networks. Sources based on crystalline whispering gallery mode resonators (WGMRs) have been shown to be capable of generating SPDC states that are both narrow-band and single mode[1,2] and interacting efficiently with alkali atoms[3]. However, to our knowledge, polarization entanglement hasn't been demonstrated in WGMRs.

In our work, we demonstrate the generation of polarization entangled states from a WGMR in an interferometric scheme[4]. Using non-local two-photon interference effects, we demonstrate the generation of genuine entangled states. We also evaluate the S parameter of the CHSH inequality to be 2.45 ± 0.07, which violates the inequality by more than six standard deviations.

[1]J. U. Fürst, et al., Physical review letters 104.15 153901 (2010)
[2]M. Förtsch, et al., Nature communications 4.1 (2013)
[3]G. Schunk, et al., Optica 2.9 (2015)
[4]S-H. Huang, et al., arXiv preprint arXiv:2310.16589 (2023).

Q 21.2 Tue 11:15 HS 3219

Generation of indistinguishable single photons from a single ^{40}Ca^{+}-ion using short laser pulses — •Pascal Baumgart, Max Bergerhoff, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Hong-Ou-Mandel interference on a beam splitter, a key step in quantum repeater schemes involving entanglement swapping, requires indistinguishability of single photons [1]. A commonly used method to create single photons from single atoms is continuous laser excitation of a Λ-type Raman transition. This renders indistinguishability difficult, as multiple back-decays and re-excitations on the driven transition, governed by the branching ratio of the excited state, lead to an uncertainty in the photon emission time [2]. An alternative approach that limits the number of back-decays is excitation by short laser pulses, on the order of the excited state lifetime. Using a Raman transition in a single trapped ^{40}Ca^{+}-ion with an excited state lifetime of 7 ns, we investigate the feasibility of this approach. We present an experimental setup to generate few-nanosecond laser pulses at the excitation wavelength of 393 nm, and we examine the dependence of the photon purity on the pulse length and amplitude.

[1] T. van Leent et al., Nature 607, 2022
[2] P. Müller et al., Phys. Rev. A 96, 2017

Q 21.3 Tue 11:30 HS 3219

Phase stabilization for high bandwidth fiber-based continuous variable quantum key distribution — •Sophie Verclas, Benedict Tohermes, and Roman Schnabel — Institut für Quantenphysik und Zentrum für Optische Quantentechnologien, Universität Hamburg, Deutschland

Quantum Key Distribution (QKD) is a technology for secure communication between two parties, using the principles of quantum mechanics. Our QKD experiment implements a fiber-based, continuous variable QKD scheme, connecting two laboratories in two separated buildings (building A and B). We set up an EPR entanglement source in building A, consisting of two squeeze lasers and overlapped their outputs at a 50/50 beamsplitter to generate two-mode squeezed states, which are shared between the two buildings via optical fiber.

In both buildings, the entangled states are measured with balanced homodyne detectors. Due to the entanglement, the results are random but also correlated and can be used to generate a secret key. Attacks on the channel as well as on devices in building B reduce the entanglement strength and can thus be quantified.

A major challenge in this setup is the phase stabilization and synchronization between the two buildings. In this presentation I will introduce the experiment, discuss the problem of phase noise and our approach to a control scheme for its compensation.

Q 21.4 Tue 11:45 HS 3219

Controlling individual erbium dopants in silicon — •Johannes Früh[1,2], Andreas Gritsch[1,2], Alexander Ulanowski[1,2], Fabian Salamon[1,2], Adrian Holzäpfel[1,2], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]TU München and Munich Center for Quantum Science and Technology, 85748 Garching, Germany

Erbium dopants are promising candidates for the implementation of large-scale quantum networks since they can combine second-long ground state coherence (1) with coherent optical transitions at telecommunication wavelengths. So far, the long lifetime of the excited state made it difficult to spectrally resolve and control individual ions in order to harness them for quantum networks. To overcome this challenge, we embed erbium dopants into silicon photonic crystal resonators (2) and Fabry-Perot resonators (3) with small mode volume, which facilitates the direct comparison of the two approaches. While the nanophotonic resonators give Purcell enhancements up to 170, the Fabry Perot geometry avoids the proximity of interfaces and thus offers better optical coherence and narrower spectral diffusion linewidths down to 3 MHz. Reducting the latter down to lifetime limit, this approach is thus promising towards the entanglement of remote dopants.

(1) M. Rancic, M. P. Hedges, R. L. Ahlefeldt, M. J. Sellars, Nat. Phys. 14, 50 (2018)
(2) A. Gritsch, A. Ulanowski, A. Reiserer, Optica 10, 783-789 (2023)
(3) A. Ulanowski, B. Merkel, A. Reiserer, Sci. Adv, 8 (2022)

Q 21.5 Tue 12:00 HS 3219

Spectroscopy and cavity-enhanced emission of Eu-based molecular systems — •Evgenij Vasilenko, Vishnu Unni C, Weizhe Li, Nicholas Jobbitt, Senthil Kuppusamy, Mario Ruben, and David Hunger — Karlsruhe Institute of Technology

Rare-earth ions in solid-state hosts are a promising candidate for optically addressable spin qubits, owing to their excellent optical and spin coherence times. Recently, also REI-based molecular complexes have shown excellent optical coherence properties [1]. However, Eu ions have a long optical lifetime of the ^{5}D$_0$-^{7}F$_0$ transition ($T_{1,opt}$ ∼ ms) and a low branching ratio (< 1%), limiting single-ion experiments. Both issues can be solved by high-finesse fiber-based microcavities. We study Eu-doped molecular crystalline materials, including a Trensal complex that yields 7 min spin lifetime and a homogeneous linewidth of 2.8 MHz at 4.2 K [2]. On a single, macroscopic molecular crystal [Eu(Ba)4(pip)] [1], we measure narrow inhomogeneous linewidths, hour-long spin T_1 and photon echoes at < 1K. Steps to integrate molecular crystals into a fiber cavity at cryogenic operation are reported. Open-access fiber cavities have been demonstrated to achieve high quality factors and low mode volumes, while simultaneously offering large tunability and efficient collection of the cavity mode [3]. The results are important steps towards single-ion readout and control being necessary for scalable quantum registers.

[1] Serrano et al., Nature, 603, 241-246 (2022)
[2] Kuppusamy et al., J. Phys. Chem. C 127, 22 (2023)
[3] Hunger et al., New J. Phys 12, 065038 (2010)

Q 21.6 Tue 12:15 HS 3219

Frequency Conversion in a high pressure hydrogen gas — •Anica Hamer[1], Priyanka Yashwantrao[1], Seyed Mahdi Razavi Tabar[1], Alireza Aghababaei[1], Frank Vewinger[2], and Simon Stellmer[1] — [1]Physikalisches Institut, Nussallee 12, Universität Bonn, 53115 Bonn, Germany — [2]Institut für Angewandte Physik, Wegelerstraße 8, Universität Bonn

Quantum networks, as envisioned for quantum computation and quantum communication applications, are based on a hybrid architecture. Such a layout may include solid-state emitters, network nodes based on single or few atoms or ions, and photons as so-called flying qubits. This concept requires an efficient and entanglement-preserving exchange of photons between the individual components, which often entails frequency conversion of the photon.

Our approach is based on coherent Stokes and anti-Stokes Raman scattering (CSRC and CARS) in dense molecular hydrogen gas. This four-wave mixing process sidesteps the limitations imposed by crystal properties, it is intrinsically broadband and does not generate an undesired background. We have demonstrated conversion between 434 nm (F donors in ZnSe) to 370nm (Yb^+ ions) and between 863 nm (InAs/GaAs quantum dots) and the telecom O-band. We will present first steps towards integrated frequency conversion in gas-filled hollow-core fibers.

Q 21.7 Tue 12:30 HS 3219

Co-doping a Crystalline Membrane for Improved Spectral Multiplexing of Rare-earth Emitters — Alexander Ulanowski[1,2], Johannes Früh[1,2], •Fabian Salamon[1,2], Adrian Holzäpfel[1,2], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Technische Universität München, TUM School of Natural Sciences, James-Franck-Straße 1, 85748 Garching, Germany

Erbium dopants in solids exhibit a coherent optical transition at a telecommunication frequency and spin coherence times exceeding a second. This offers an exceptional potential for extended quantum networks [1].

To realise an efficient spin-photon interface, a 10 μm thin crystalline membrane is embedded into a Fabry-Perot resonator. The narrow optical transitions of the emitters then allow for spectral multiplexing [2]. In this context, we show that the spectral density and thus the number of individually resolvable qubits can be tailored by co-doping an erbium-doped YSO crystal with europium [3]. Using this technique, more than 360 emitters with an optical coherence that reaches the lifetime limit can be optically resolved with Purcell factors up to 110.

These advances constitute a key step towards large-scale multiplexed entanglement generation for a global quantum network.

[1] A. Reiserer, Rev. Mod. Phys. 94, 041003 (2022). [2] A. Ulanowski, B. Merkel & A. Reiserer, Sci. Adv. 8, eabo4538 (2022). [3] A. Ulanowski, J. Früh, F. Salamon, A. Holzäpfel & A. Reiserer, arXiv:2311.16875 (2023).

Q 21.8 Tue 12:45 HS 3219

A compact and portable room temperature atomic vapor quantum memory — •Alexander Erl[1,2], Martin Jutisz[3], Elisa Da Ros[3], Luisa Esguerra[2,1], Leon Messner[2], Mustafa Gündoğan[3], Markus Krutzik[3,4], and Janik Wolters[2,1] — [1]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Optische Sensorsysteme, Berlin — [3]Humboldt-Universität zu Berlin, Institut für Physik, Berlin — [4]Ferdinand-Braun-Institut, Institut für Hochstfrequenztechnik, Berlin

In recent years, considerable progress has been made in the field of room temperature quantum memories. The inherent simplicity of this platform makes it very promising for use outside of laboratory environments, including in space-based applications. As an essential component of quantum repeaters, space-compatible memories could advance global quantum communication networks [1]. Here we present the implementation and performance analysis of a portable rack-mounted system, operated inside and outside of lab environment. This optical memory utilizes a lambda-scheme based on the Cesium D_1 line transitions at 895 nm [2]. We achieve internal memory efficiencies of >40% for storage times of 500 ns. Employing attenuated coherent pulses, we observe storage and retrieval fidelities exceeding the classical threshold [3].

[1] M. Gündoğan et. al., npj Quantum Information 7, 128 (2021)
[2] L. Esguerra et al., Phys. Rev. A 107, 042607 (2023)
[3] M. Jutisz et. al., in preparation (2024)