FM 54: Quantum Networks: Quantum Memory and Gates

Time: Wednesday 14:00–16:00 Location: 1015

Invited Talk FM 54.1 Wed 14:00 1015

Quantum memories for photons — •Mikael Afzelius — Department of Applied Physics, University of Geneva

Optical quantum memories are devices that can store and later retrieve quantum states encoded onto single photons [1]. These are essential components of future quantum technologies such as quantum repeaters, which can increase quantum communication (e.g. quantum cryptography) to continental distances.

In this talk I will introduce quantum memories, their role in quantum repeaters and challenges in terms of memory requirements for repeaters. I will then briefly introduce different quantum memory schemes and some physical systems where memories are currently investigated, with a specific focus on current state-of-the-art in solid-state memories based on rare-earth doped crystals.

[1] Quantum memory for photons, M. Afzelius, N. Gisin, and H. de Riedmatten, Physics Today 68, 42 (2015)

FM 54.2 Wed 14:30 1015

Towards a single photon memory based on electromagnetically induced transparency — •Esteban Gomez Lopez[1], Tim Kroh[1], Chis Müller[1], Janik Wolters[2], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin, Germany — [2]Universität Basel, Switzerland

Quantum networks promise to bring secure communications to our increasingly technology-dependent society. In order to create a truly scalable quantum network, quantum repeaters are needed to overcome the irremediable losses in quantum channels [1]. Such devices have at their core a quantum memory capable of mapping the state of a photon into a long lived matter state, such as a spin coherence, in a reversible manner [2]. Here we present a variable delay stage for photons using electromagnetically induced transparency (EIT) as a first step towards an EIT quantum memory. A maximum EIT window width of 150 MHz was obtained in Cs. This bandwidth is compatible with photon pairs emitted by a cavity enhanced SPDC source [3]. Faint light pulses were delayed up to 62.4(0.7) ns. This storage device can be used as the base for a quantum memory if also the coupling beam is pulsed. Storage times of up to seconds are feasible [4].

[1] N. Gisin and R. Thew, Nat. Photonics 1, 165 (2007).
[2] A. I. Lvovsky, B. C. Sanders, and W. Tittel, Nat. Photonics 3, 706 (2009).
[3] A. Ahlrichs and O. Benson, Appl. Phys. Lett. 108, 021111 (2016).
[4] O. Katz and O. Firstenberg, Nat. Commun. 9, 2074 (2018).

FM 54.3 Wed 14:45 1015

Quantum Memories for Single Photons — •Tom Schmit, Luigi Giannelli, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

Quantum memories are storage units of a quantum network [1]. In this work we theoretically characterize quantum memories for flying qubits based on single photons [2]. The quantum memories we analyse are i) a single atom inside an optical resonator and ii) a solid-state medium such as a rare-earth-ion doped crystal. We determine the efficiency of storage protocols based on adiabatic dynamics in the different setups and identify the parameter regimes where adiabatic protocols are preferable. We further discuss analogies and differences between the storage dynamics of a single photon [3] and of a weak coherent pulse [4]. Finally, we analyse the dynamics of propagation of a single photon which dispersively interact with an inhomogeneously broadened medium and explore perspectives to use inhomogeneous broadening for tailoring the single photon's spectral shape.

[1] H. J. Kimble, Nature **453**, 1023 (2008).
[2] N. Sangouard and H. Zbinden, Jour. of Mod. Opt., **59:17**, 1458-1464 (2012).
[3] L. Giannelli, T. Schmit, T. Calarco, C. P. Koch, S. Ritter, and G. Morigi, New J. Phys. **20**, 105009 (2018)
[4] L. Giannelli, T. Schmit, and G. Morigi, Phys. Scr. **94**, 014012 (2018).

FM 54.4 Wed 15:00 1015

Storing single photons in a room temperature vapor cell — •Roberto Mottola[1], Gianni Buser[1], Janik Wolters[1,2], Chris Müller[3], Tim Kroh[3], Sven Ramelow[3], Oliver Benson[3], and Philipp Treutlein[1] — [1]Universität Basel, Schweiz — [2]DLR Institut für optische Sensorsysteme Berlin — [3]HU Berlin

Quantum memories are a key ingredient for the realization of quantum networks [1]. Furthermore, they allow the synchronization of probabilistic single photon sources significantly enhancing the generation rates of multiphoton states [2].

We implemented a broadband, optical quantum memory in hot Rb vapor with on-demand storage and retrieval [3]. With a bandwidth matched spontaneous parametric downconversion (SPDC) source, we can generate heralded single photons suited for storage [4] with a heralding efficiency $\approx 50\%$. We report on our recent achievements in storing SPDC single photons with a linewidth of 230MHz with an end-to-end efficiency $\eta_{e2e} = 1.3(1)\%$ for a storage time of $T = 50$ns. A signal to noise ratio of 1.9(2) and a memory lifetime $\tau = 380$ns are achieved. The measurement of the second order autocorrelation of retrieved single photons results in $g^{(2)} = 0.91(3)$, showing that the non-classical properties of the stored light are maintained.

[1] N. Sangouard et al., *Rev. Mod. Phys.* **83**, 33 (2011).
[2] J. Nunn et al., *Phys. Rev. Lett.* **110**, 133601 (2013).
[3] J. Wolters, et al., *Phys. Rev. Lett.* **119**, 060502 (2017).
[4] A. Ahlrichs et al., *Appl. Phys. Lett.* **108**, 021111 (2016).

FM 54.5 Wed 15:15 1015

Electronic Dipole Spin Resonance of 2D Semiconductor Spin Qubits — •Matthew Brooks and Guido Burkard — Universität Konstanz, Konstanz, DE

Monolayer transition metal dichalcogenides (TMDs) offer a novel two-dimensional platform for semiconductor devices. One such application, whereby the added low dimensional crystal physics (i.e. optical spin selection rules) may prove TMDs a competitive candidate, are quantum dots as qubits. The band structure of TMD monolayers offers a number of different degrees of freedom and combinations thereof as potential qubit bases, primarily electron spin, valley isospin and the combination of the two due to the strong spin orbit coupling known as a Kramers qubit. Pure spin qubits in monolayer MoX_2 (where $X =$ S or Se) can be achieved by energetically isolating a single valley and tuning to a spin degenerate regime within that valley by a combination of a sufficiently small quantum dot radius and large perpendicular magnetic field. Within such a TMD spin qubit, we theoretically analyse single qubit rotations induced by electric dipole spin resonance. We employ a rotating wave approximation within a second order time dependent Schrieffer-Wolf effective Hamiltonian to derive analytic expressions for the Rabi frequency of single qubit oscillations, and optimise the mechanism or the parameters to show oscillations up to 250 MHz.

FM 54.6 Wed 15:30 1015

Dipolar interactions for robust entangling gates in the solid-state — •Eleanor Crane[1], Alexander Schuckert[2], Nguyen Huy Le[3], and Andrew Fisher[1] — [1]London Centre for Nanotechnology, University College London, Gower Street, London WC1E 6BT, United Kingdom — [2]Department of Physics, Technical University of Munich, 85748 Garching, Germany — [3]Advanced Technology Institute and Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom

Electron and nuclear spins of dopants in silicon offer some of the longest coherence times of all proposed quantum computing platforms. However, oscillations in the exchange interactions due to the periodicity of the crystal lattice make the fabrication of entangling gate configurations challenging. We study the feasibility of using dipolar interactions for the implementation of an entangling gate in silicon. These interactions decay as a power law with no oscillatory behavior, providing robustness to inter-donor distance fluctuations and thereby offering a route to scalability. Our study focuses on qubits encoded in the long-lived electron spin ground states of Si:Se+ and Si:P and we present several schemes with different technical requirements.

FM 54.7 Wed 15:45 1015

A temporally multiplexed quantum repeater node based

on laser-cooled atoms — •Lukas Heller[1], Pau Farrera[1], and Hugues de Riedmatten[1,2] — [1]ICFO - Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, Castelldefels, Barcelona, Spain — [2]ICREA-Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain

Future quantum repeater architectures, capable of efficiently distributing information encoded in quantum states of light over large distances, rely on quantum memories for light. Quantum repeaters can benefit from a modal multiplexing implementation of the memory, essentially scaling up the repeater's throughput. In this work we demonstrate a temporally multiplexed quantum repeater node in a laser-cooled cloud of 87 Rb atoms [1]. We employ the DLCZ protocol where pairs of photons and single collective spin excitations (so called spin-waves) are created [2]. The latter can then be efficiently transferred into a second single photon. For selective readout, we need to control the dephasing and rephasing of the spin-waves created in different temporal modes. We achieve this by a mag netic field gradient, which induces an inhomogeneous broadening of the involved atomic hyperfine levels [3]. By employing this steering technique, combined with cavity-enhanced emission and feed forward readout, we demonstrate distinguishable retrieval of up to 10 temporal modes. For each mode, we prove nonclassical correlations between the first and second photon. Furthermore, an enhancement in rates of correlated photon-photon pairs is observed as we increase the number of temporal modes stored in the memory. The reported device is a crucial key element of a quantum repeater architecture implementing multiplexed quantum memories.

[1] C. Simon, H. de Riedmatten and M. Afzelius; Phys. Rev. A 82 010304(R) (2010)

[2] L. Duan, M. Lukin, J. Cirac and P. Zoller, P; Nature 414 413 (2001)

[3] B.Albrecht, P. Farrera, G. Heinze, M. Cristiani and H. de Riedmatten; Phys. Rev. Lett. 115 160501 (2015)