Rare-earth ion doped quantum memory for photonic quantum bits

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The ability of coherent and reversible mapping of the state of light onto and from matter plays a crucial role in quantum information and communication science. It enables the realization of light storage devices, or quantum memories, that are building blocks of possible future quantum repeater architectures. In this talk I will summarize our experiments on quantum information storage based on rare-earth ion doped (REID) systems. The particular atomic system in our experiments is a Pr^{3+}:Y_2SiO_5 crystal. In this talk, I will first briefly discuss the experiments where we stored and recalled photonic polarization qubits encoded in single photon level weak coherent pulses. We demonstrated storage and recall fidelities >95%, proving the quantum character of the storage, taking into account the finite storage efficiency and the Poissonian statistics of the input field [1]. This experiment made use of the excited state only and the storage time was limited to predetermined time of around 500 ns. However, the transfer of the input field to the long-lived spin-states in REIDs is not straightforward. In Pr^{3+}:Y_2SiO_5, the relevant hyperfine levels are seperated by only 10.2 MHz, which makes the filtering of the noise created by the strong transfer pulses quite challenging. In the second experiment, we demonstrate the transfer of the single photon level input pulses to the long-lived hyperfine levels of Pr^{3+}. The noise induced by the transfer pulses are filtered by employing a narrow-band spectral filter based on spectral hole burning in a second crystal of the same kind, enabling us to store and on-demand recall of input fields with mean photon numbers as low as 0.07 with a signal-to-noise ratio (SNR) >1. The high SNR that we reached finally allowed us to store and recall time-bin qubits with fidelities of around 90%, again surpassing the achievable value with a measure-and-prepare strategy. These results make our storage device the first on-demand quantum memory for time-bin qubits [2].

[1] Mustafa Gündoğan, Patrick M. Ledingham, Attaallah Almasi, Matteo Cristiani, and Hugues de Riedmatten, *Quantum Storage of a Photonic Polarization Qubit in a Solid*, Phys. Rev. Lett. **108**, 190504 (2012).

[2] Mustafa Gündoğan, Patrick M. Ledingham, Kutlu Kutluer, Margherita Mazzera, and Hugues de Riedmatten, *Solid State Spin-Wave Quantum Memory for Time-Bin Qubits*, Phys. Rev. Lett. **114**, 230501 (2015).