Quantum Communication with Solid-State Atomic Ensembles

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Quantum interfaces between light and matter play an important role in the field of quantum information science. In particular, such an interface would allow for a quantum memory for light (QM), a key component for the realization of long distance quantum communication via quantum repeaters. Atomic systems are well suited for QMs as light can be absorbed on optical transitions and stored for long durations as excitations in the medium. Moreover, even longer storage times are possible if the optical excitations can be converted to spin-waves. Various systems have been implemented as QMs including single atoms, warm atomic vapours, laser cooled atomic ensembles and cryogenically cooled rare earth ion doped solids (REIDS).

Cryogenically cooled REIDS are an attractive candidate for a QM as they offer an atomic ensemble trapped within a host solid allowing for long optical and spin coherences. Moreover, there is a large static inhomogeneous broadening of the optical transition due to the crystal environment providing a large optical bandwidth. Furthermore, the inhomogeneously broadened line can be shaped at will using spectral hole-burning techniques, allowing for the creation of complex spectral features required for QM protocols such as the atomic frequency comb protocol (AFC).

Within the family of investigated REIDS, Pr3+:Y2SiO5 (transition at 606nm) shows great promise as a QM. Due to the long population lifetime of the hyperfine ground states, storage of classical light for up to 1 minute was realized. Moreover, the relatively strong oscillator strength allowed for quantum storage of weak coherent states with an efficiency of 69%.

In this experimental work we use the AFC protocol in a Pr3+:Y2SiO5 crystal cooled to 3K. Firstly, using an ultra-narrowband photon pair source based on cavity-enhanced spontaneous parametric down-conversion, we demonstrate quantum storage of heralded single photons for times up to 4.5µs. Secondly, we interface single-photon-level telecom light to our AFC memory via frequency up-conversion in a PPKTP waveguide. Finally, by transferring the initial excited state coherence to a ground state one, we demonstrate spin-wave storage of single-photon-level light. Pulses with on average 0.78 photons per 0.7µs pulse are stored with a 1:1 signal to noise ratio and a storage time of 10.3µs. These experimental results pave the way for use of solid-state ensembles within quantum repeater architectures.