Entanglement between a telecom photon and an on-demand, solid-state, multimode quantum memory

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Entanglement between telecom photons and quantum memories is a crucial resource towards long-distance quantum communication [1]. To this end, we are developing a system which combines a solid-state quantum memory with a source of photon pairs [2]. The memory is based on a praseodymium (Pr) doped crystal where quantum information can be stored in the ions as a collective optical excitation using the Atomic Frequency Comb (AFC) protocol. On-demand retrieval of the information is realised by transferring the excitation to a long-lived spin state. Entangled pairs of single photons are generated by parametric down conversion in a periodically poled crystal placed inside an optical cavity. This allows us to generate narrow band photons pairs, where the signal is spectrally matched to the memory for storage, while the idler is in the telecom band to allow for higher optical transmission through fibre.

We here demonstrate energy-time entanglement between the telecom idler photon and the signal photon stored as a spin-wave excitation [3]. The entanglement analysis is performed using time-bin qubit analysers made of a fibre-based Mach-Zehnder interferometer for the idler photon, and a solid-state equivalent based on AFCs with different storage times for the signal photon. We have measured entanglement between the telecom photon and the excitation in an optically excited state for 10 μs, with a fidelity high enough to violate a Bell inequality. We then moved to storage in the spin-state of the Pr ions (Fig 1), where we calculate a two-qubit conditional fidelity of 77(2)%. Taking advantage of the on-demand retrieval from the spin state we extended the total storage to up to 50 μs. Our system then features multimode operation, with an advantage of a factor of 17 over a single mode equivalent, and telecom compatibility, which could allow the ilder photon to be distributed in the commercial telecom network.

References

[1] Duan, L.-M. et al. Nature 414, 413-418 (2001)

[2] Simon, C. et al. Phys. Rev. Lett. 98, 190503 (2007).

[3] Rakonjac, J. V. et al. Phys. Rev. Lett. 127, 210502 (2021)

Figures

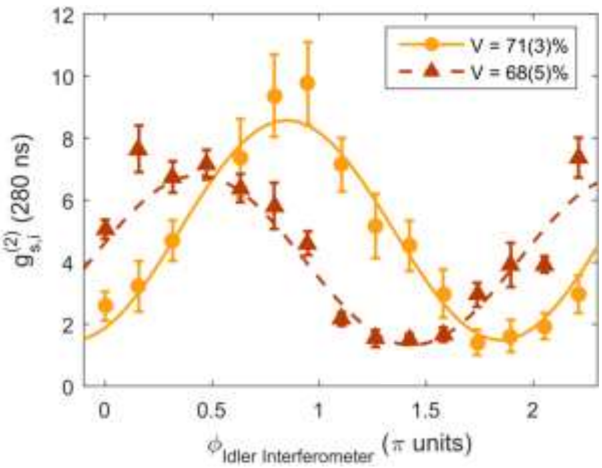

Figure 1: interference fringes for storage of energy time-entanglement in the spin wave of the quantum memory, measured through the second-order cross-correlation function of the idler and the retrieved signal photon.