Storage and analysis of light-matter entanglement in a fibre-integrated system

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Quantum memories are essential in order to distribute quantum information in certain quantum repeater schemes. A high entanglement distribution rate is needed for a quantum repeater to be practical, thus requiring the use of a highly multiplexed quantum memory. Rare-earth ion-doped crystals are a particularly attractive system to use as a memory due to their long coherence times and potential multiplexability. Integration, such as by fabricating a waveguide in the crystal, opens up the possibility of directly interfacing the memory with on-chip photonic components or improving the scalability of the system.
In this work, we use a $Pr^{3+}:Y_2SiO_5$ crystal as a quantum memory, in which a type-I waveguide is fabricated with femtosecond laser micromachining. The memory is directly accessed with optical fibres glued to the facets of the crystal [1]. We demonstrate the capability of our fibre-integrated memory by storing single photons. We use cavity-enhanced spontaneous parametric down conversion to generate entangled photon pairs, with the signal photon at 606 nm (compatible with storage in the memory), and the idler photon at a telecom wavelength (necessary for heralding entanglement in a quantum repeater). We use the Atomic Frequency Comb (AFC) protocol [2] to store photons in the optically excited state, from 2 μs up to 28 μs (Figure 1). We also demonstrate that the entanglement of the photon-pairs is preserved after storage in the memory. We use the Franson scheme [3] to perform a tomography of the resulting light-matter entanglement in the two cases where the signals photons were stored in the AFC for 3 μs and 10 μs. The resulting two-qubit fidelity (after corrections for experimental imperfections) is (86 ± 2) % for 3 μs and (86 ± 4) % for 10 μs. The demonstrated storage time for light-matter entanglement is up to 3 orders of magnitude longer than previous demonstrations in integrated memories [4,5]. These results thus show that our fibre-integrated solid-state platform is a suitable candidate for a practical integrated quantum memory.

References

[1] J. V. Rakonjac et al, arXiv:2201.03361 (2022)
[2] M. Afzelius et al, Phys. Rev. A, 79 (2009) 052329
[3] J. D. Franson, Phys. Rev. Lett., 62 (1989) 2205-2208
[4] E. Saglamyurek et al, Nature, 469 (2011) 512-515
[5] E. Saglamyurek et al, Nat. Photonics, 9 (2015) 83-87

Figures

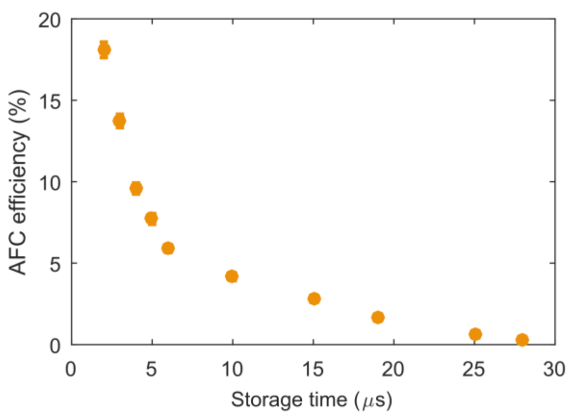

Figure 1: AFC storage efficiency of heralded single photons as a function of storage time.