Storage of frequency-multiplexed heralded single photons in a laser-written waveguide

D. Lago-Rivera[1]*, A. Seri*[1]*, G. Corrielli*[2]*, A. Lenhard*[1]*, R. Osellame*[2]*, M. Mazzera*[1] *and H de Riedmatten*[1,3]

[1]*Institut de Ciències Fotòniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels, Spain*
[2]*IFN - Istituto di Fotonica e Nanotecnologie, CNR and Dipartimento di Fisica, Politecnico di Milano, 20133 Milano, Italia*
[3]*ICREA - Institució Catalana de Recerca i Estudis Avançats, 08015 Barcelona, Spain*

Quantum memories for light are important devices in quantum information science, in particular for applications such as quantum networks and quantum repeaters [1]. It has been predicted that multimode quantum memories able to store independently multiple modes would greatly help the scaling of quantum networks by decreasing the entanglement generation time between remote quantum nodes [1]. Current research focus mostly on time multiplexing in rare-earth doped crystals and in spatial multiplexing in atomic gases. Beyond these demonstrations, rare-earth doped crystals, thanks to their large inhomogeneous broadening, represent a unique quantum system which could also add another degree of freedom for multiplexing, the storage of multiple frequency modes [2]. In this contribution, we report on the first demonstration of quantum storage of a frequency multiplexed single photon into a laser-written waveguide integrated in a Pr^{3+}:Y_2SiO_5 crystal. The great advantage of using a confined waveguide for this task is that the power required to prepare the quantum memory is strongly reduced due to the increased light-matter interaction in the waveguide. This enables simultaneous preparation of several memories at different frequencies, with a moderate laser power.

In [3, 4], the atomic frequency comb (AFC) protocol has been used to store heralded single photons, created in a cavity-enhanced spontaneous parametric downconversion (C-SPDC) source. This source generates frequency-multiplexed photon-pairs, where one photon is in resonance with the transition of the Pr^{3+}:Y_2SiO_5 and the other at telecom wavelength. However, so far, only one of this frequency modes was heralded and stored [3, 4]. The storage of the full spectrum of the frequency-multiplexed heralded single photon would increase the coincidence rate and would allow the storage of the entanglement present in the biphoton state generated by the source [5].

We demonstrate storage of frequency-multiplexed heralded single photons produced by C-SPDC, in the same waveguide of [4]. We show that we can store the main part of the spectrum of the multiplexed photon, consisting of about 14 modes. This leads to an increase of our count-rates by 5.5 with respect to the single frequency mode storage, expected from the contribution of the spectral modes of the stored photons. This high count-rate allows us to make a detailed analysis of the multiplexed-biphoton state after the storage. We study the non-classicality of the stored photons after being stored for 3.5 μs. The measured cross-correlation violates the classical bound, as well as the heralded autocorrelation of the stored photons. We show that we are able to increase the non-classicality by lowering the pump-power of the C-SPDC source, at the expense of decreasing proportionally the count-rate. We then demonstrate that filtering out only one mode of the idler and storing only the corresponding mode of the signal, the cross-correlation increases 16 times, showing that by detecting independently the spectral modes of the idler and of the signal, we would increase the count rate while preserving a high cross-correlation.

Our results show that integrated laser written waveguides can be used as powerful light-matter interaction platforms with both time and frequency multiplexing capabilities. The unique 3 dimensional fabrication capability of this technique also hold promises for implementing large memory arrays in one crystal. The ability to combine several multiplexing capabilities in one system would open the door to the realization of massively multiplexed quantum memories.

References

[1] N. Sangouard et al, Rev. Mod. Phys. **83**, 33 (2011).
[2] N. Sinclair et al, Phys. Rev. Lett. **113**, 053603 (2014)
[3] A. Seri et al. Phys. Rev. X **7**, 021028 (2017).
[4] A. Seri et al. arXiv:1805.02494 (2018).
[5] D. Rieländer et al. Quantum Science and Technology **3**, 014007 (2017).