

A novel integrated platform for quantum storage of heralded single photons

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The efficient and reversible mapping of quantum states of light into collective excitations of atomic ensembles represents one of the most promising routes towards the realization of quantum memories. Rare earth doped crystals, in particular, offer long lived spin states and are naturally suitable for miniaturization and integration of several quantum memories onto a single substrate, e.g. in form of waveguides. The latter would greatly facilitate the scalability and, thanks to the tight confinement of light, would lead to a strong enhancement of the light matter interaction. $\text{Pr}^{3+}:\text{Y}_2\text{SiO}_5$ is currently one of the best systems for quantum memory applications, in fact it is the only solid-state system in which externally generated heralded single photons have been stored with on-demand retrieval [1]. Moreover with this crystal have been demonstrated very efficient storage of weak coherent states [2] as well as the longest storage time ever demonstrated in any system (in the regime of 1 minute for classical images) [3]. Despite this, only two approaches for integration have been reported so far in this material [4, 5]. The first one is based on evanescent coupling with TeO2 waveguides deposited on a bulk crystal [4]. The second one is based on femtosecond laser micromachining (FLM) [6]: a fs-pulsed laser is highly focused in the crystal to create pairs of parallel damage tracks. As a consequence of a positive change of refractive index between the two tracks, the light is guided (type II waveguide). In this approach, the interaction between the light confined in the waveguide and the active ions was shown to be higher and storage with on-demand retrieval was performed with bright light pulses using the atomic frequency comb (AFC) protocol, demonstrating the first implementation of an integrated on-demand spin wave optical memory [5].

We propose a new platform for integrated optical memories, based again on FLM: we fabricate a single mode *type I* waveguide in $\text{Pr}^{3+}:\text{Y}_2\text{SiO}_5$, performing just one long damage track along the crystal in which, due to different fabrication parameters, the positive change of refractive index coincides with the track itself. Contrary to the *type II* waveguides studied in [5], *type I* waveguides provide higher confinement without increasing the losses, thus further increasing the light-ions interaction. Moreover they can be easily addressed with fibers and standard glass chips (differently from *type II* waveguides). We demonstrate that the coherence properties of the material are in the same order of magnitude as for the bulk (a factor 3 lower), despite the invasive fabrication process. To prove that this platform is suitable for being used as a quantum memory, we perform storage of ultra-narrowband single photons generated by spontaneous parametric down conversion (SPDC) and with telecom heralding, using the AFC protocol for storage times in the order of μs . In Fig. 1a is shown an experimental trace of the storage, and in Fig. 1b the measured second-order cross-

correlation function $g_{AFC,i}^{(2)}$ of the retrieved single photons versus the storage time τ , the dotted line being the classical upper bound.

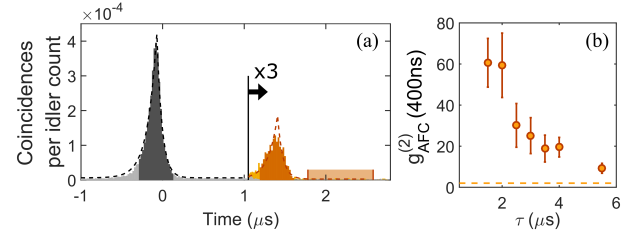


Figure 1: (a) Time-resolved histograms of the idler-signal coincidences for signal photons before the storage (gray histogram) and stored for $\tau = 1.5 \mu\text{s}$ (orange histogram). For clarity the counts in the AFC are multiplied by 3. The darker regions of the peaks show the windows considered for the calculation of the $g_{AFC,i}^{(2)}$. The black and brown dotted lines are the temporal decays of the correlations from which the linewidth of the biphotons before and after the storage can be extracted. The shaded rectangle is the region in which the accidental counts for the AFC echo are measured; (b) $g_{AFC,i}^{(2)}$ of the correlations between idler photons and stored signal photons for different storage times τ . The orange dotted line is the classical upper bound.

All the measured $g_{AFC,i}^{(2)}$ in Fig. 1b are clearly above the classical bound, thus proving that laser written memories can operate in the quantum regime. This device opens new perspectives for the implementation of miniaturized and integrated quantum memories.

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