

A hybrid glass-crystal integrated quantum memory

Lorenzo Perruccio^{1,2}, Mattia Vidotto², Francesco Ceccarelli², Jelena V. Rakonjac³, F elicien Appas³, Hugues de Riedmatten³, Roberto Osellame², Giacomo Corrielli²

1. Dipartimento di Fisica, Universit a di Pavia, Pavia, Italy

2. Istituto di Fotonica e Nanotecnologie – CNR, Milano, Italy

3. ICFO-Institut de Ci ncies F ot niques, Castelldefels (Barcelona), Spain

Abstract: Integrated quantum memories are key components for advancing quantum photonic networks.

We demonstrate a hybrid platform combining YSO crystal waveguides with reconfigurable glass interferometers using femtosecond laser micromachining to enable integrated cryogenic quantum state storage.

Integrated quantum memories are key components in quantum communication architectures, serving as synchronization elements in complex photonic networks [1]. Rare-earth-ion-doped crystals represent a highly promising quantum memory platform, offering long atomic coherence times at cryogenic temperatures. Furthermore, as solid-state substrates, they are highly amenable to integration within photonic integrated circuits (PICs) [2,3] to scale the number of stored modes. However, realizing complex integrated photonic circuitry in these materials, particularly when embedding active reconfiguration elements, remains challenging. A promising approach to circumvent this difficulty involves the hybrid integration of crystal waveguides for photon storage with mature glass PIC technologies for light manipulation and routing.

In this work, we detail the manufacturing of several components via femtosecond laser micromachining (FLM), which are essential for realizing hybrid glass/crystal photonic circuits embedding integrated quantum memories, leveraging the versatility of this fabrication technique.

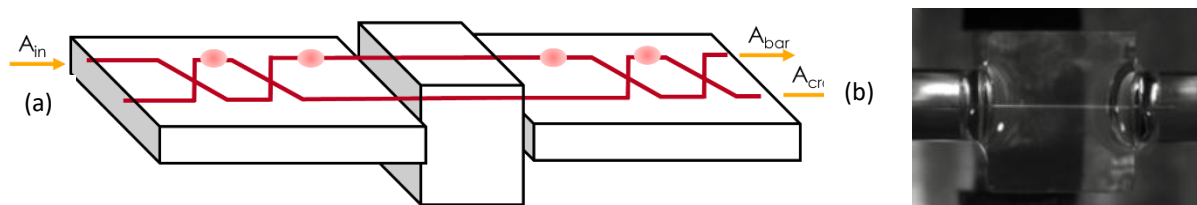


Fig. 1 (a) Schematic of the hybrid device encompassing two Mach-Zehnder interferometers, laser-written in glass substrates and two waveguides written in the doped crystal acting as two parallel quantum memories. (b) Example of a waveguide written in a Pr:YSO crystal and directly pigtailed to two optical fibers. The fluorescence excited by the light propagating in the waveguide makes it visible.

First, we optimize low-loss waveguides within rare-earth-doped YSO crystals. Through direct core irradiation and thermal annealing, we achieve single-mode guidance from 600 nm to 1550 nm, yielding insertion losses of 1.5 dB for 1 cm waveguides at 600 nm, and below 1 dB in the telecom regime. Next, we present glass-based, reconfigurable Mach-Zehnder interferometers (MZIs) designed for 607 nm operation. Utilizing gold-patterned microresistors, these devices achieve thermo-optic phase shifts with extinction ratios exceeding 30 dB at extreme cryogenic temperatures (3 K). Finally, we assemble a fully integrated hybrid platform linking Praseodymium-doped YSO waveguides with the glass MZIs, exhibiting excellent mode overlap and total system losses limited to 4 dB. This device demonstrates the possibility to store quantum states distributed in different spatial modes while, thanks to the phase stability achieved in PICs, these multiple memories preserve the state coherence. This chip presents a promising, scalable route for on-chip quantum state encoding, storage, and tomography.

References

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