



# PhD Thesis Defense ALESSANDRO SERI 'A Multimode Solid-State Quantum Memory for Single Photons'

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Wednesday, July 3, 11:00. ICFO Auditorium

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Quantum Photonics With Solids And Atoms

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Quantum memories (QMs) for light represent a fundamental ingredient for the development of a quantum internet. Among other applications, they are a building block for the distribution of entanglement on large scale, i.e. for the realization of a quantum repeater architecture.

Rare earth doped crystals (REDCs) are a promising candidate towards this goal. In my thesis I

use a Pr<sup>3+</sup>:Y<sub>2</sub>SiO<sub>5</sub> crystal. The longest storage time and the highest retrieval efficiency for a solid-state memory measured so far, were demonstrated with this system (in the classical regime). However, the main advantages of solid-state platforms are their suitability for miniaturization and integration as well as their inhomogeneous broadening, which enables broadband storage and spectral multiplexing.

In this thesis we demonstrate an on-demand solid-state QM for real single photons. Moreover we study new platforms for integrated QM based on the same material. We employ the atomic frequency comb (AFC) technique, which is the most promising storage protocol in terms of temporal multiplexing up to now.

Until the start of my PhD there was still no demonstration of storage of a real quantum state of light with an on-demand readout in REDCs. We achieved this in the course of this thesis, measuring also for the first time (and only, at the time of writing) non-classical correlation between a single spin wave in a solid-state QM and a telecom photon.

After proving the suitability of Pr<sup>3+</sup>:Y<sub>2</sub>SiO<sub>5</sub> crystals for on-demand QMs, we demonstrated novel types of integrated optical memories based on the same system. We studied the spectroscopic and coherence properties of the ions in laser-written waveguides fabricated by fs-laser micromachining. These projects were developed in collaboration with Dr. R. Osellame and Dr. G. Corrielli at Politecnico di Milano, who fabricated the waveguides and analysed their guiding properties. In a first kind of waveguide, called type II, we performed the first storage with on-demand retrieval ever done in solid-state integrated optical memories (with classical light).

We continued analysing a so-called type I waveguide, in which the mode-size is comparable with the mode guided in a single-mode fiber at the same wavelength. Here we showed storage of heralded single-photons for a pre-programmed time. The demonstrated storage time, 5.5 ns, is the longest quantum storage demonstrated in any integrated waveguide up to now

Finally, we performed in the same waveguide storage of the whole spectrum of frequency-multiplexed heralded photon, spanning a range of frequencies of ~ 4 GHz. The photon is naturally multiplexed due to the generation method used, namely cavity-enhanced SPDC. The possibility of storing such a broad spectrum comes from the intrinsic inhomogeneous broadening present in REDCs. Together with the 15 frequency mode

constituting the multiplexed photon, 9 temporal modes were stored thanks to the intrinsic temporal multimodality of the AFC protocol.

The method used to fabricate our waveguides, fs-laser micromachining, is the only one to our knowledge that allows for direct 3D fabrication in the substrate. In the future, this will yield matrices of fiber-pigtailed waveguide-based QMs, thus enabling a high degree of spatial multiplexing, which nowadays is mostly exploited in atomic clouds, where temporal and spectral multiplexing are more difficult to achieve.

The crystal, the protocol and the waveguide fabrication technique employed in this thesis, represent all together a very promising system, opening the way for a future quantum repeater architecture based on scalable highly multiplexed QMs.

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