MUSTAFA GÜNDOĞAN
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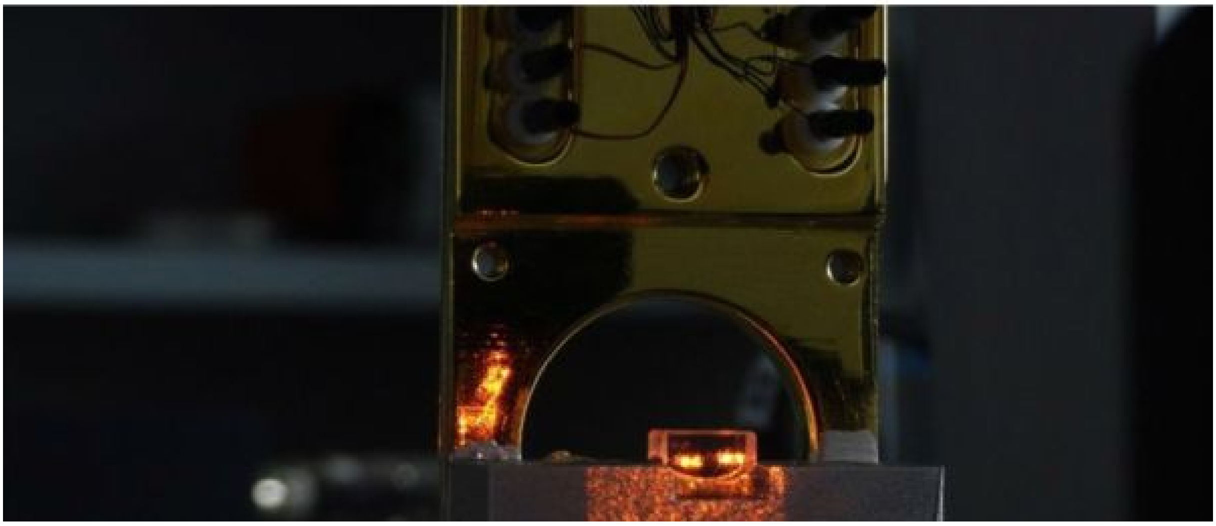

PhD Thesis Defense MUSTAFA GUNDOGAN 'Solid-State Quantum Memory for Photonic Qubits'

MUSTAFA GUNDOGAN

October 22, 2015

Thursday, October 22, 17:00. Blue Lecture Room

MUSTAFA GUNDOGAN

Quantum Photonics with Solids and Atoms

ICFO-The Institute of Photonic Sciences

Optical quantum memories (QMs) are one of the fundamental building blocks in quantum information science (QIS). They might find important use in quantum communication and computation applications. Rare-earth ions (REIs) have been investigated for decades for their optical properties. They exhibit excellent coherence properties when cooled down to cryogenic temperatures. Not surprisingly, they emerged as a promising candidate for use in QIS as QMs.

In this thesis, we investigated the quantum storage of photonic qubits in a Pr3+ :Y2SiO5 (PrYSO) crystal for potential use in quantum communication and networking applications. We started by constructing the experimental setup and laser system from scratch as our research group had just been established at the beginning of this PhD study.

First experiments included spectroscopy of the PrYSO system in order to identify the electronic transitions that are suitable for the QM experiments. We used the atomic frequency comb (AFC) memory protocol in all the experiments presented in this thesis. We also developed complex pulse sequences that are necessary for the optical preparation of an AFC.

As a first experiment, we demonstrated the storage of photonic polarization qubits encoded in weak coherent states in the excited states of Pr3+ ions for a predetermined storage time of 500 ns. This had not been achieved previously due to the polarization dependent absorption of the material. We achieved average storage delities of aprox. 95% which surpass the best achievable value with a measure and prepared strategy, thus proving the quantum character of our interface.

Nevertheless, in order to be implemented in realistic quantum networking architectures, a QM should have the capability of on-demand retrieval of the stored information. As a further step towards this goal, our next experiment concerned the transfer of the input pulses to and from the long-lived hyper ne ground levels of Pr3+ ions, albeit with bright pulses. Furthermore, by performing time-bin interference experiments, we demonstrated that the coherence is preserved during the storage, transfer and retrieval processes. Temporal multimode storage in the spin-states up to 5 modes was also shown.

Finally, in the last part of this thesis we demonstrated a solid-state spinwave quantum memory, with qubits encoded in weak coherent states at the single photon level. Storing and retrieving single-photon level fields in the ground levels of the PrYSO system is challenging as the strong control pulses and the weak input pulse to be stored in the memory are separated by only 10:2 MHz. The control pulses create noise, mostly as free-induction decay, fluorescence and scattering off the optical surfaces. In order to circumvent this problem we employed narrow-band spectral, temporal and spatial filtering. By using spectral-hole burning based narrow band filter created in a second PrYSO crystal, we could achieve signal-to-noise ratio (SNR) > 10 for input pulses with mean photon number of around 1. The high SNR we achieved allowed us to store and recall time-bin qubits with conditional fidelities again higher than that is possible with a measure and prepare strategy. This experiment also represents the first demonstration of a quantum memory for time-bin qubits with on demand read-out of the stored quantum information.

The results presented in this thesis fill an important gap in the field of solid-state quantum memories and open the way for the long-lived storage of non-classical states of light. They further strengthen the position of REI based systems in QIS, specifically as nodes in scalable quantum network architectures.

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