Towards Efficient and Broadband Quantum Memory

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Quantum memory (QM) is a device that can convert and store photonic qubits in stationary matter qubits and retrieve on demand. It is a crucial component for many quantum information applications, such as quantum repeater for long-distance entanglement distribution or enhancement of multi-photon generation rate by spontaneous parametric down-conversion (SPDC). However, to achieve a quantum memory with high specifications in all aspects (e.g. efficiency, fidelity, bandwidth, and coherence time) is still a great challenge. We focus our report on achieving high efficiency and broad bandwidth. In a previously work, we have achieved record-high (92%) efficiency for coherent optical memory based on electromagnetically induced transparency (EIT) with cold atomic ensembles [1]. We also achieved quantum memory for polarization qubits with an efficiency of > 70% and a fidelity of 96% for single photons generated by cavity-enhanced SPDC [2]. Towards broadband QM, we performed a theoretical study on the requirement for achieving broadband EIT memory and identify that the demanding on optical depth and control intensity are very high [3]. Experimentally, we have achieved an efficiency of > 50% for a probe bandwidth of 31 MHz, limited by the available control intensity [3]. To achieve a higher bandwidth with less stringent requirement on the optical depth, the Aulter-Townes splitting (ATS) [4] or superradiance-mediated (SR) [5] memory schemes have been demonstrated. We will make a comparison of the three memory schemes in this report. The requirement on the optical depth is the lowest for the SR scheme but its implementation requires single photons with exponentially-rising temporal waveform and an intense and short (~100 ps) control pulse with an area of π. We will report a systematic theoretical and experimental study on the cooperative forward scattering in optically dense two-level atomic system, which is a foundation of the SR memory. We also report our development of the single-photon source with exponentially-rising waveform and our plan to build a laser source for intense and short π-pulse.

References

1. Y-F Hsiao, P-J Tsai, H-S Chen, S-X Lin, C-C Hung, C-H Lee, Y-H Chen, Y-F Chen, I. A. Yu, and Y-C Chen, "Highly efficient coherent optical memory based on electromagnetically induced transparency", *Phys. Rev. Lett.* 120, 183602(2018).
2. Y.-C. Tseng, Y.-C. Wei and Y.-C. Chen, "Efficient quantum memory for heralded single photons generated by cavity-enhanced spontaneous parametric down-conversion", *Opt. Express*, 30, 19944 (2022).
3. Y-C Wei, Y.-F. Hsiao, B.-H. Wu, P.-J. Tsai, and Y.-C. Chen, "Broadband coherent optical memory based on electromagnetically induced transparency", *Phys. Rev. A* 102, 063720(2020).
4. E. Saglamyurek et. al., "Coherent storage and manipulation of broadband photons via dynamically controlled Aulter-Townes splitting", Nature Photonics 12, 774(2018).
5. A. Rastogi et al., "Superradiance-mediated photon storage for broadband quantum memory", Phys. Rev. Lett. 129, 120502(2022).