Bad Cavities for Good Memories: Storing Broadband Photons with Low Noise

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INTRODUCTION

Linear optical logic elements are non-deterministic, and cannot be efficiently concatenated unless a multiplexing strategy is employed to actively pick out successful gate operations. Quantum memories promise scalability via temporal multiplexing, where successful outputs are stored until all parts of a photonic circuit have executed [1].

Off-resonant Raman memory protocols, in which a strong *control* field mediates the two-photon absorption of a signal in a Λ-type ensemble, enable multimode spectral/temporal control of long pulses [2, 3], or extremely broadband storage of short pulses [4, 5].

But the strong control field can drive spontaneous Raman scattering that produces spurious excitations in the memory, which are then retrieved as noise [6, 7]. This *four-wave mixing* (FWM) noise degrades the non-classical character of single-photon states stored in the memory [8, 9], and is the last remaining roadblock to developing efficient, configurable, broadband quantum photonic memories capable of operating at room temperature or in the solid state.

PROPOSAL

Here, we propose a method to suppress FWM noise by means of a low-finesse optical cavity. In a non-degenerate Λ-system, spontaneous Raman emission from the ground state is Stokes-shifted in frequency, being distinguishable from both the control field and the signal to be stored. Placing the memory inside a cavity tuned so that the on-axis Stokes emission is anti-resonant with the cavity mode provides a suppression of the FWM noise proportional to the cavity finesse $\mathcal{F}$. While $\mathcal{F} > 10$ is generally sufficient to remove the influence of the FWM noise, the protocol is compatible with a broad acceptance bandwidth for the memory.

The scheme has several other advantages: first, the effective length of the memory is enhanced by the cavity, since the signal field makes multiple passes through the memory medium [10]. This, combined with the cavity-enhanced control field, confined to a smaller mode volume than in free space, enables a higher memory efficiency in a smaller footprint. Interestingly, the cavity also constrains the memory interaction to a single longitudinal spatial mode, which in turn means that only a single optical mode, of arbitrarily configurable shape, is coupled to the memory. This has applications in quantum optical signal processing [11].

EXPERIMENT

We also describe an experimental implementation of the above scheme, in which a small caesium vapour-cell is mounted inside a birefringent ring cavity, stabilised via two-colour Hänsch-Couillaud phase locking, with a resonance blue-detuned from the Cs D_2 line by 15 GHz. We demonstrate, for the first time, cavity-enhanced Raman storage and retrieval of sub-ns coherent states. Finally we present the noise characteristics of the cavity memory, and discuss routes towards an optimised design.

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