

OPTICAL QUANTUM MEMORY IN ATOMIC BARIUM WITH 880 GHZ BANDWIDTH AND 95% STORAGE EFFICIENCY

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Abstract—We demonstrate quantum memory of single-photon-level coherent pulses of 880 GHz bandwidth with 95.6(3)% storage efficiency in collisionally broadened barium vapor. We measure 26(1)% total efficiency, limited by control field power; 0.49(1) ns memory lifetime, limited by motional dephasing; and a signal-to-noise ratio of $O(10^3)$, limited by two-photon control field scattering. To the best of the authors' knowledge, this represents the best efficiency, lifetime, and noise performance of atomic quantum memories in the ultrabroadband regime (>100 GHz bandwidth) to date.

I. INTRODUCTION

An optical quantum memory is a device capable of on-demand storage and retrieval of single-photon-level quantum states, and it is a critical enabling technology for many quantum applications such as Bell state measurements [1], entanglement swapping [2], quantum teleportation [3]. Memory bandwidth is crucial, as it determines the compatibility of the memory with short-duration pulses and places an upper bound on the processing speed of applications such as quantum networks.

II. EXPERIMENTAL SPECIFICATIONS

Here we describe a Λ -type quantum memory experiment that is compatible with 880 GHz bandwidth, or 500 fs duration, signal photons based on an 800-900 °C atomic barium vapor in the presence of argon buffer gas. The signal photon is tuned near resonance with the ground ($6s^2\ ^1S_0$) to excited state ($6s6p\ ^1P_1$) transition at 553.5 nm. After linear absorption along this transition, the resulting atomic polarization is transferred into a so-called spin wave by application of a strong [$O(10\text{ uJ})$, 100 fs] control field laser pulse tuned near resonance with the excited to storage state ($6s5d\ ^1D_2$) transition at 1500 nm.

III. HIGH-EFFICIENCY, ULTRA-BROADBAND, AND LOW-NOISE MEMORY OPERATION

At an argon pressure of 200 torr and a temperature of 900 °C, we send single-photon-level attenuated coherent states into our memory along with two control field pulses separated by 20 ps. By spectrally-resolved measurement of the signal field with the control field 'on' and 'off,' we measure the storage efficiency of our memory to be

95.6(3)%, the highest efficiency of any atomic quantum memory in the ultrabroadband regime. By unblocking the retrieval control field, we further measure the total end-to-end efficiency of our memory to be 26(1)%. The high efficiency is due primarily to argon buffer gas producing large and tunable collisional broadening in the excited state, which allows us to better match the excited state linewidth to the bandwidth of the signal photons. Another effect that we call near-off-resonant memory (or NORM) operation, in which the largest total efficiency occurs at a small, non-zero two-photon detuning, also contributes to our high efficiencies.

The lifetime and noise performance of this memory are noteworthy. By measuring our memory's total efficiency as a function of storage time at 900 °C and 3.0 torr argon, which we fit to a Gaussian decay model indicative of the expected motional dephasing at this temperature and argon pressure, we obtain a 1/e memory lifetime of 0.49(1) ns, the longest memory lifetime for any atomic memory in the ultrabroadband regime. By plotting the signal-to-noise ratio of photons retrieved from the memory as a function of average input photon number, which we perform a linear fit on, we extract a signal-to-noise ratio at 1 input photon per pulse of $8(1) \times 10^3$, an average number of noise photons per pulse of $3.8(6) \times 10^{-5}$, and a single-photon fidelity of 0.99988(2). To the best of the authors' knowledge, this represents the lowest noise memory operation of any atomic memory in the ultrabroadband regime and is a result of the control field frequency being insufficient to excite four-wave mixing noise, the dominant noise contribution in most broadband Λ -type memories.

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