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High-Efficiency, Ultra-Broadband, and Low-Noise Quantum Memory in Atomic Barium Vapor

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Introduction.—Optical quantum memory describes the process of on-demand storage and retrieval of single-photon-level quantum states, and is a critical enabling technology for many quantum applications. Memory bandwidth plays an important role in these applications, as it determines the pulse durations compatible with the memory and places an upper bound on the clock rate and processing speed of a quantum device. Here we present experimental results of an atomic barium quantum memory that enables storage and retrieval of ultra-broadband (>800 GHz) signal photons with high storage efficiency [95.6(3)%] and low noise [$3.8(6)\times10^{-5}$ noise photons].
Experimental Results.—The quantum memory operation is based on the ground ($6s^2\ {}^1S_0$), excited ($6s6p\ {}^1P_1$), and metastable ($6s5d\ {}^1D_2$) orbital states of atomic barium in a Λ-type configuration. The barium vapor is created in an 800-900 °C barium heat pipe oven with 0-1000 torr tunable argon buffer gas pressure. The ground-excited transition at 553.5 nm features large and tunable homogeneous collisional broadening due to the argon buffer gas and a peak optical depth of $d = 50$. The memory operates in the so-called absorb-then-transfer (ATT) regime, in which the signal field is linearly absorbed along the ground-excited transition, whose collisionally broadened lineshape enables efficient absorption of ultra-broadband photons; the resulting atomic polarization is transferred into a so-called spin wave by application of a strong [O(10 uJ), 100 fs] control pulse along the excited-metastable transition at 1500 nm. The storage state has a $O(0.1)$ second coherence lifetime in the bare atom [1], but this is reduced to the O(ns) level due to motional dephasing [0.49(1) ns measured memory lifetime]. The memory experiment is repeated at a repetition rate of 1 kHz. The total end-to-end efficiency of the memory at 900 °C is 31(1)%, which is limited by available control field power.

Fig. 1(a) shows a comparison of our memory's storage efficiency and bandwidth relative to the rest of the atomic ensemble quantum memory literature, demonstrating that our memory is unique in its high efficiency and simultaneously broad bandwidth. Fig. 1(b) demonstrates an effect of fundamental physical interest, where the largest total memory efficiency is observed at small, non-zero two-photon detuning. We call this effect near-off-resonant memory (or NORM) operation, which we believe balances resonant reabsorption loss and finite available control field power. Detailed theoretical study of NORM operation is ongoing. Fig. 1(c) shows the noise performance of our memory, where we plot the measured signal-to-noise ratio of the photons retrieved from the memory as a function of the average input photon number of a weak coherent state. This noise performance is comparable to state-of-the-art noise measurements in ladder-type atomic systems [2].

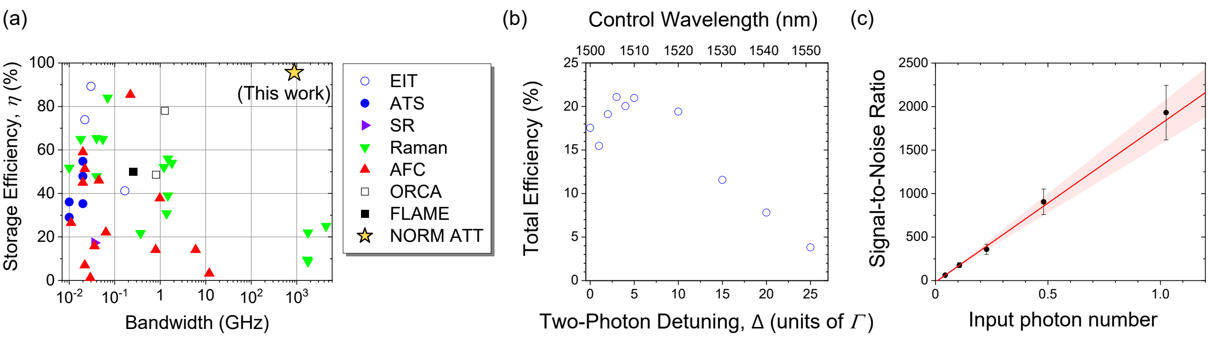

Fig. 1 (a) Comparison of the present quantum memory storage efficiency and bandwidth with the rest of the atomic ensemble quantum memory literature (citations for each data point given in Ref. [2]]). (b) Near-off-resonant memory (NORM) operation; total memory efficiency at 800 °C measured as a function of two-photon detuning, showing optimal memory efficiency at finite, near-resonant detuning. (c) Signal-to-noise ratio of our memory measured as a function of input photon number, demonstrating low-noise performance.

References

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