Single photon generation “on demand” from a single trapped atom strongly coupled to an optical cavity

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Abstract: Optically trapped atoms in the strong coupling regime of cavity QED have been used to generate single photons deterministically. Referenced to the total cavity output, the generation efficiency for polarized photons is 16%.

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OCIS Codes: (270.5580) Quantum electrodynamics; (270.5290) Photon statistics.

A source of single photons which allows the user to control the emission time of a photon pulse into a well-defined mode of the electromagnetic field is a crucial building-block in quantum information science. For example, the implementation of a distributed quantum network using optical communication between its nodes relies on this capability. In this contribution we report the experimental realization of such a device, using single cesium atoms strongly coupled to an optical cavity. Significantly, intracavity trapping times are typically 70 ms, much longer than the repetition rate for photon generation (10 μ s).

Our atom-cavity system has parameters $(g, \gamma, \kappa) = 2\pi \times (17, 2.6, 4)$ MHz, where g is the rate of coherent coupling, and γ and κ are the rates for atomic spontaneous emission and cavity decay, respectively [1]. The cavity length is tuned to be resonant with the $(6S_{1/2}, F=4) \rightarrow (6P_{3/2}, F'=3')$ in cesium, with wavelength 852.4 nm. An atom is trapped inside the cavity using a standing wave far-off-resonance-trap (FORT) along the cavity axis. After an atom is loaded into the intracavity FORT, it is illuminated by a sequence of laser pulses. The first pulse, near resonant with $F=3 \rightarrow F'=3'$, pumps the atom to the strongly coupled excited state thereby enabling the emission of a single photon into the cavity mode via $F'=3' \rightarrow F=4$. The next pulse, which drives the $F=4 \rightarrow F'=4'$ transition, recycles the atom back to the $F=3$ ground state. The pulse durations used in preliminary experiments have been $T_P=1 \mu$ s and $T_R=5 \mu$ s for the pumping and recycling pulses, respectively, with an overall repetition period of $T=10 \mu$ s (although it should be possible to reduce these times significantly with small degradation of performance). The Gaussian beam from the cavity is directed to a beamsplitter and then to photon-counting detectors (D_A, D_B), whose output pulses are recorded by a time-interval analyzer with $\delta=2$ ns resolution.

Fig. 1. Correlation data $n(\tau)$ for single photon generation from single trapped atoms in an optical cavity (convolved with a 40 ns Gaussian for smoothing). The reduction of the peak height around $\tau=0$ results from the suppression of the two-photon probability relative to a Poissonian (classical) source.

In order to quantify the photon statistics of the output pulses, we compute a cross-correlation function $n(\tau)$ in which we bin coincidence counts as a function of delay between photodetection events at D_A and D_B . Sub-Poissonian photon statistics are plainly evidenced in Fig. 1, with the likelihood of two photons being detected within one trial strongly suppressed relative to that for detection events in different trials. In quantitative terms, the average of N_j for $j \neq 0$ exceeds N_0 by a factor of 6.1, where

$$N_j = \int_{jT-T_p/2}^{jT+T_p/2} n(\tau) d\tau,$$

whereas for a coherent state, $N_j/N_0 = 1$.

In conclusion, we have produced single photons on demand using single trapped atoms strongly coupled to a high finesse optical cavity. Polarized photons from our two-sided cavity are generated with an inferred probability 16%, which yields a Mandel Q parameter $Q = -0.13$, where $Q = 0$ for a coherent state.

[1] J. McKeever *et al*, "Experimental Realization of a One-Atom Laser in the Regime of Strong Coupling," *Nature* **425**, 268-271 (2003).