Generation of Narrow Bandwidth Paired Photons: Use of a single driving laser

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Abstract: We use a single Ti:Saphire laser to cool, pump, and to render transparent a cloud of $^{87}$Rb atoms. Paired photons are generated into opposing single-mode fibers at a rate of 750 counts per second.

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It is an objective of workers in quantum optics to develop generators of single photons and of correlated and entangled paired photons, both with controllable waveforms. A major step was made by the groups of Lukin and Kimble who demonstrated the use of electromagnetically induced transparency (EIT) to generate single photons on demand and to show non-classical correlations of paired photons [1, 2]. More recently, Balic et al demonstrated generation and rudimentary waveform shaping of narrow-band biphotons [3].

This paper describes a useful simplification of the Balic technique: We replace the three driving lasers (trapping, pump, and coupling) of the earlier experiment with a single (Ti:Saphire) laser. This laser is tuned to the $|2\rangle \rightarrow |3\rangle$ transition and is therefore detuned by 6.8 GHz from the $|1\rangle \rightarrow |3\rangle$ transition (Fig. 1). It therefore serves to create transparency (and slow light) at the anti-Stokes frequency, and also, at the same time, it serves as a pump for the four frequency parametric process that generates the paired photons. Two AOMs are used to generate and control both trapping and pump frequencies from the single laser. This is done periodically at a duty cycle of 10% with the MOT on for 4.5 ms, followed by an experimental window of 500 µs.

We work with a right angle geometry that because of the driving polarization allows, in essence, complete suppression of Rayleigh scatter of the strong pump into the opposing optical fibers. In particular, we find that there is no need for additional optical filters.

The principal experimental results are shown in Fig. 2 where we plot coincidence counts versus delay time both on resonance with the $|2\rangle \rightarrow |3\rangle$ transition and when off resonance. In Fig. 2a, we obtain a violation of the Cauchy-Schwartz inequality of $>1600$. Fig. 2b shows how by varying the detuning and power, the correlation time, and by implication, the paired source line width can be varied. With the maximum power of 160 mW, the observed paired photon generation rate is about 12 s$^{-1}$. Allowing for an efficiency of each photodetector of 40% and a duty cycle of 10% this corresponds to a generation rate of 750 s$^{-1}$. 

![Fig.1. In presence of a strong pump laser, counter propagating Stokes and anti-Stokes photon pairs are generated into a pair of single-mode fibers (SMF) perpendicular to the pump beam direction and are detected by two single-photon-counting modules (SPCM). The pump laser, with a beam diameter of 1.2 mm, retro reflected by a mirror (M), is linearly polarized along the Stokes-anti-Stokes direction. The optical depth on the anti-Stokes path is 7.3.](image-url)
Many years ago [4, 5], it was shown that two-state atoms could be used to produce correlated photons. In order to normalize the present results and to verify the importance of the use of EIT, we use the same MOT to measure the coincidence count rate of the two state |5S 1/2, F=2> → |5P3/2, F=3> system when operating in a near collinear (2°) backward wave geometry. Coincidence counts versus delay time are shown in Fig. 3, where the peak value of the intensity correlation $g^{(2)}(\tau)$ of the forward and backward beams is 1.79. Using a fiber beam splitter we also measure (not shown) the peak value of the autocorrelation function of each beam $g^{(2)}(0) = 1.80$. Therefore, in the two-state system, the Cauchy-Schwartz inequality $[ |g^{(2)}(\tau)|^2 / (g^{(2)}(0)g^{(2)}(0)) \leq 1]$ is not violated.

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