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Noise Reduction of a Fiber-memory Photon Source for Temporal Multiplexing

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Abstract: Multiplexing nonlinear photon pair sources provides a path towards a near-deterministic photon source. Here we present a significant noise reduction in a fiber-cavity integrated spontaneous four-wave-mixing source, designed for temporal multiplexing.

1. Introduction

Temporal multiplexing [1] enables brightness enhancement of heralded single photon sources, while maintaining their non-classical properties. Promising results have been obtained with table-top, free-space cavities combined with an external downconversion source, for example [2]. Quantum memories have long been recognized as powerful tools for temporal multiplexing [3]. To this end, we developed the fiber-cavity storage with intracavity frequency translation (FC SWIFT) protocol [4]. A key benefit of this scheme is that signal-herald photon pairs are generated inside the fiber cavity by spontaneous four-wave mixing (SFWM), but without the insertion of additional (lossy) optical elements [5]. However, $\chi^{(3)}$ photon sources in fiber typically suffer from significant Raman scattering noise [6]. Here we demonstrate significant noise reductions in our scheme, an important step towards active temporal multiplexing.

2. Scheme

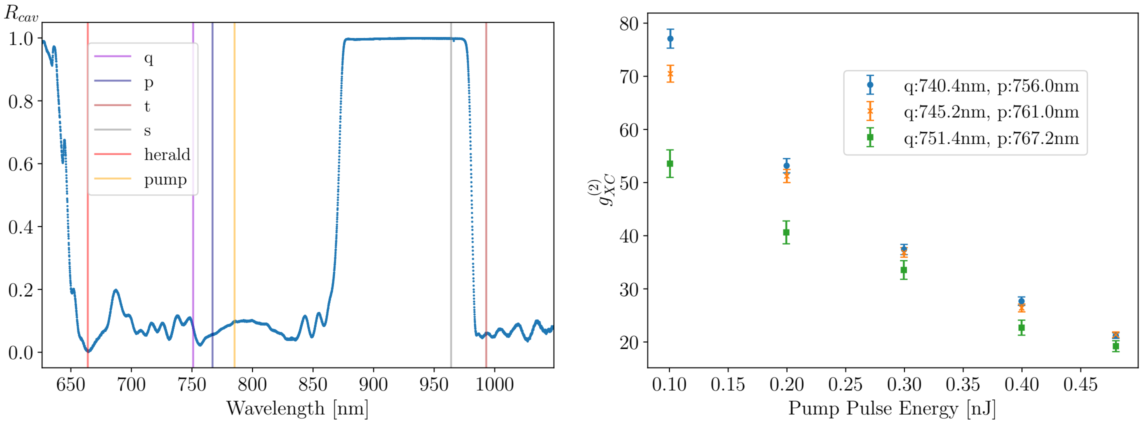
A strong pump ($\lambda_{pump} = 785.2\,\text{nm}$) undergoes SFWM in a birefringent fiber (HB800) to generate signal (s) and herald photons at 964 nm and 664 nm respectively. The pump is aligned to the slow axis of the fiber while the photons are generated on the fast axis. Each end facet of the HB800 fiber is coated with a custom dielectric coating that is transmissive for the pump pulse and herald photon, but highly reflective $> 99\%$ for the signal photons. Figure 1a shows the reflectivity of the coating as a function of wavelength. The herald photon is collected and detected by a single photon avalanche photodiode. The signal photon is reflected by the custom dielectric coating and thus temporarily stored in the fiber-cavity until the readout procedure is initiated. The fiber-cavity cycle time for the stored signal (25 ns) is designed to match an integer multiple of the cavity cycle time of the pump and control lasers, facilitating pulse picking.

The readout is conducted by frequency shifting the signal photon to a region where the dielectric coating is transmissive, ideally $> 95\%$. This is done by performing Bragg scattering four-wave mixing (BSFWM) using two bright control pulses (p: slow axis; q: fast axis) that temporally overlap with the stored signal pulse (s). The BSFWM converts the signal photon at 964 nm on the fast axis to 993 nm on the slow axis. The output signal (t) is then transmitted with high efficiency by the fiber's dielectric coating, where it can be detected or used as a resource.

For temporal multiplexing of the SFWM source, we direct a train of pump pulses, into the fiber cavity. When a herald photon is detected at the cavity exit, we rapidly switch a Pockels cell to reject additional pump pulses before they enter the fiber and create additional pairs. After a user-chosen delay, we apply the control pulses to read out the stored signal photon.

3. Results and Discussion

Figure 1b shows the two-mode cross-correlation ($g^{(2)}_{XC}$) between the retrieved signal and herald photon at various pump pulse energies. As the control wavelengths are blue-detuned further from the signal wavelengths, the $g^{(2)}_{XC}$ increases, indicating that there is a reduction in the noise. Although the noise is reduced by moving the controls further from the signal wavelengths, the OPO system has a reduced output power for $\lambda < 750\,\text{nm}$. The loss in peak power of the controls reduces the efficiency of the BSFWM and consequently the overall readout probability.



(a) (b)

Fig. 1: (a) Reflectivity of the coating. (b) Cross-correlation.

Shorter control wavelengths combinations suffered further conversion efficiency losses, i.e. the conversion efficiency from the s to t mode is $\eta_{conv} = 0.81(1)$ for $\lambda_q = 748.2$ nm and $\lambda_p = 765.7$ nm compared to $\eta_{conv} = 0.90(1)$ for $\lambda_q = 751.1$ nm and $\lambda_p = 767.3$ nm. Thus a compromise was made and control wavelengths of $\lambda_q = 748.2$ nm and $\lambda_p = 765.7$ nm were selected in order to optimize for reduced noise and an acceptable conversion efficiency. We performed a heralded auto-correlation ($g^{(2)}_{AC}(t_1,t_2|h)$) of the output signal to validate the non-classical properties of the output state. For our noise-reduced scheme we obtained an auto-correlation of $g^{(2)}_{AC}(t_1,t_2|h) = 0.066(13)$ after six cavity cavity cycles. We compare this result with that of the fiber-cavity presented in ref [7] which obtained a $g^{(2)}_{AC}(t_1,t_2|h) = 0.264(7)$ after two cavity cycles when using a single wavelength as both the pump and p-control pulses. This significant reduction in noise is a key enabling step towards brightness-enhanced generation of high quality single photons.

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