Ultratunable Quantum Frequency Conversion in Photonic Crystal Fiber

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Abstract: We achieve ultrabroad quantum frequency conversion in a photonic crystal fiber, converting a 1,551 nm heralded single photon to one with wavelengths spanning the range 1,226 - 1,483 nm. We confirm non-classical timing correlations with the herald photon, and for conversion to 1,300 nm we measure a $g^{(2)}(0)_{\mu,\tau} = 0.25(6)$. © 2023 The Author(s)

OCIS codes:

Manipulating the spectral properties of single photons is essential for a wide array of quantum optical technologies spanning quantum sensing [1], quantum communication [2], and quantum computing [3]. Crucial components for these technologies include single-photon sources [4], quantum memories [5], waveguides [6], and detectors [7], which often operate at disparate wavelengths. Quantum frequency conversion is a key enabler for the hybridization of these components, and is itself an emerging platform for quantum optical processing. Photonic crystal fibers (PCF) are an excellent platform for frequency conversion since they can offer high optical non-linearities and guide a broad range of wavelengths in a single spatial mode.

In this work [8], we use a PCF engineered [9, 10] to have a highly symmetric group velocity profile, extending over 1 PHz about its zero-dispersion frequency ($v_0 \sim c/1,040$ nm). This allows us to keep one pump wavelength, $\lambda_p$, group velocity matched with the signal $\lambda_s = 1,551$ nm) fixed while tuning the second pump wavelength, $\lambda_q$, to choose the converted target photon wavelength $\lambda_t$. By tuning $\lambda_q$ between 820 nm and 910 nm, we convert photons over the range of 1,226 nm - 1,408 nm. Small shifts in $\lambda_p$ extend this range to 1,483 nm. This covers the entire o- and e-telecom bands.

Pump pulses $p$ and $q$ are generated in two OPOs pumped with 532 nm laser pulses, 10 ps in duration. Additional 532 nm laser light pumps spontaneous parametric downconversion (SPDC) in a periodically-poled Lithium Niobate (PPLN) crystal producing signal (herald) photons near 1,550 nm (810 nm). Signal ($s$) photons are combined with $p$ and $q$ pulses on dichroic mirrors and coupled into a 10 cm PCF. After filtering out the pump wavelengths, we measure the converted photon $t$ on a superconducting nanowire single-photon detector (SNSPD). We find a 12% conversion efficiency of the signal to the new wavelength $\lambda_t$. Fixing $\lambda_q = 872.8$ nm, giving $\lambda_t = 1300$ nm, we measure a heralded auto-correlation of $g^{(2)}_{\mu} (0) = 0.25(6)$ for the converted mode, well-below the classical threshold of 1. For the input, we measured $g^{(2)}_{\mu,s} (0) = 0.034(8)$.

We have realized quantum frequency conversion in a novel PCF over an ultrabroadband range. In this configuration we converted single photons in the telecom c-band to any wavelength in the o- or e-bands. By changing the wavelength configuration, we could convert single photons at 1550 nm to NIR wavelengths, or convert photons between two NIR wavelengths. Such a device is a vital component to building a hybrid quantum network with single photons.
Fig. 1. (a) Four-wave mixing level diagram. (b) Group velocity curve, symmetric about zero dispersion for an ultrabroad range for the PCF (cross section shown in (c)). (d) Coincidence-to-accidental ratio $R_{CA}$ for converted light at points between 1,226 – 1,483 nm with a herald photon. The converted range includes the entire o- and e-bands. The $R_{CA}$ between 1,551 nm input and 810 nm herald photons was 63.

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