Type II Parametric Downconversion in a Poled Fiber

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Abstract: We report photon-pair generation at the 1.5-μm telecom band via continuous-wave type-II parametric downconversion in a birefringent periodically-poled silica fiber. The time- and polarization-correlations of the downconverted light are examined.

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1. Introduction

Single photon and correlated photon-pair sources are required for many applications in quantum information. An experimental realization of correlated photon pair generation can be found through the nonlinear optical process of spontaneous parametric down-conversion (SPDC). Conventional optical fiber composed of fused silica, however, does not possess the second-order optical nonlinearity ($\chi^{(2)}$) required for SPDC. It is still possible to generate photon pairs in fiber with spontaneous four-wave-mixing, a third-order process, but the presence of spontaneous Raman scattering requires that the signal and idler be greatly separated in wavelength [1] or that the fiber be cryogenically cooled [2]. Such problems can be alleviated if the second-order nonlinearity were present in fused silica.

One can induce a non-zero $\chi^{(2)}$ in optical fiber through thermal poling [3]. The process is performed with specialty twin-hole fiber (a cross-section of which is shown in Fig. 1a inset), in which two large air-holes sandwich the core. The induced $\chi^{(2)}$ arises from a frozen-in DC field E_x^{DC} – present in the core region of the fiber after poling – and the Kerr nonlinearity: $\chi^{(2)}_{ijk} = 3\chi^{(3)}_{ijkx}E_x^{DC}$. The DC field is taken by convention to be in the x direction. This model gives rise to the following relation between the $\chi^{(2)}$ tensor elements, which have been found to be experimentally valid for our fiber [4]: $\chi^{(2)}_{xxx} = 3\chi^{(2)}_{xyy} = 3\chi^{(2)}_{yxy} = 3\chi^{(2)}_{yyx}$.

Our poled fiber is quasi-phase-matched (or periodically-poled) [3] for the second-harmonic generation (SHG) of $\lambda_{SH} \approx 775$ nm light in the LP_{01} mode. The four non-zero elements of the $\chi^{(2)}$ tensor result in the presence of three distinct SHG signals ($y + y \to x$, $x + x \to x$, $y + x \to y$) (Fig. 1a). The fiber birefringence, which we attribute to the fiber geometry (Fig. 1a inset), allows for the spectral separation of the three phase-matchings.

From Fig. 1a, we find that the type-II SPDC phase-matching ($y \to x+y$) is perfectly quasi-phase-matched when y-polarized CW pump light of wavelength $\lambda_P \approx 774.7$ nm is launched into the fiber. At this pump wavelength, however, the signal and idler are degenerate (Fig. 1b); by detuning λ_P to 774.9 nm, it is possible to deterministically separate the signal and idler in wavelength using a C- and L-Band wavelength-division multiplexer (WDM).

In this work, we observe the time- and polarization-correlated nature of the downconverted type-II photon pairs in a 20-cm long periodically-poled silica fiber (PPSF). Previous work [5] utilized lower-efficiency poled fibers with poorer coincidence-to-accidental ratios, where fiber birefringence was (presumably) not present to allow for the observation of polarization correlation.

2. Experiment

A Ti:Sapph laser (Fig. 1c) is used as the CW pump, with its wavelength λ_P tuned to 774.88±0.05 nm. The pump polarization is adjusted with a polarizer (Pol. P), quarter-, and half-waveplates (QWP, HWP) before being launched into an objective lens (OBJ) and coupled into a single-mode telecom fiber (SMF-28) pigtail that is fusion-spliced to the PPSF. The pump power within the PPSF is approximately 50 mW (not all of which is in the LP_{01} mode, as the fiber is multi-mode at λ_P). At the output end of the PPSF, the downconverted light is filtered out from the 775-nm pump using three cascaded 1550/775 nm WDMs, allowing for greater than 110 dB pump suppression. The pump power and wavelength are monitored with a power meter and optical spectrum analyzer (respectively). The signal and idler are then deterministically split in wavelength using a C-/L-Band WDM. The total insertion loss at 1.5-μm for the system is 6.5 dB per leg, and quantum efficiencies of the single-photon detectors (SPDs) are 10 % (C-Band) and 6 % (L-Band). On the C-Band leg, a fiber-polarization controller (FPC1) and fiber-based polarizer (Pol. 1) ensure that only x-polarized ($\theta_1 = 0$) light enters the SPD. On the L-Band leg, FPC2 and a free-space polarizer (θ_2) allow us to vary the polarization monitored, from x to y and all other linear polarizations in between; it is initially set to y ($\theta_2 = 90^0$).

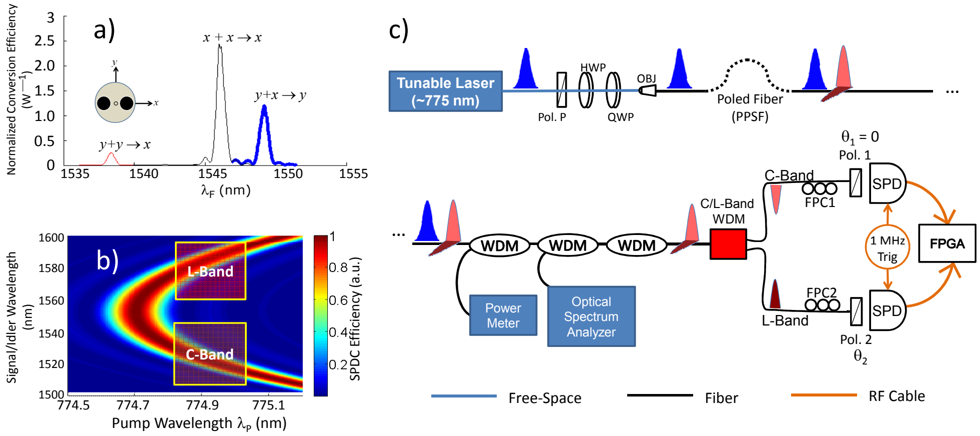

Fig. 1. a) Experimental SHG spectrum for our poled fiber. The inset shows the fiber cross-section of the poled fiber; note that the DC-field $E_x^{(DC)}$ is aligned to one of the fiber's principal axes (x). b) Theoretical SPDC tuning curve for the type-II phase-matching; detuning λ_P to the red results in spectral separation of the downconverted light. c) Experimental setup for measuring the time- and polarization-correlations of the photon pairs; the blue 'pulse' represents the pump light (which is actually CW), and the red/magenta pulses represent the downconverted signal and idler.

The coincidence measurement involves triggering both the SPDs synchronously at $f = 1$ MHz. A relative electronic delay between the trigger signals is implemented for the time-correlation measurement. Due to the narrow optical gates (400 ps) of the SPDs, the relative delay resolution must be small (100 ps). A field-programmable gate array (FPGA) is used as coincidence counter; a coincidence is counted when the SPDs both fire within 50 ns of each other. As the downconverted signal and idler photons are generated simultaneously, the arrival times at their respective SPDs should be correlated, and the coincidence counts should peak for a specific relative delay. Here (Fig. 2a), we find that the relative delay is 10.1 ns, and that the coincidence-to-accidental ratio (CAR) is on the order of 30:1 (when the C-Band leg is x-polarized, and L-Band leg y-polarized). The integration time for each delay value is 200 seconds.

For polarization-correlation, the polarizer angle (θ_2) on the L-Band leg (Fig. 1c) is allowed to vary from 0^o to 180^o, and coincidences are measured for various angles. The C-Band leg, meanwhile, is fixed to the x-polarization. The relative trigger delay is set to 10.1 ns to optimize coincidence counts, and an integration time of 200 s is used for each value of θ_2. We observe clearly (Fig. 2b) that the coincidence counts are maximized when the L-Band leg is y-polarized ($\theta_2 \approx 90^o$), and minimized when it is x-polarized ($\theta_2 \approx 0^o, 180^o$). These results are consistent with the type-II SPDC phase-matching $y \rightarrow x + y$.

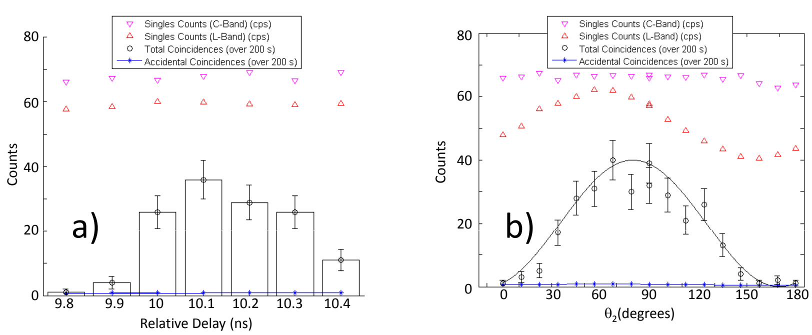

Fig. 2. a) Results of the time-correlation experiment show that the coincidence-to-accidental ratio (CAR) exceeds 30:1, and that coincidences are maximized when the relative trigger delay is 10.1 ns. The C-Band polarizer is set to x, while the L-Band is y-polarized. b) Polarization-correlation measurements show that when the C-Band leg is x-polarized ($\theta_1 = 0^0$), the coincidence measurements are maximized when the L-Band leg is y-polarized ($\theta_2 \approx 90^o$), as expected for type-II downconversion. Singles counts are measured in counts per second (cps), and the accidental coincidences (Acc) are calculated using the singles counts (s_C, s_L) and trigger rate f (= 1 MHz) of the SPDs: $Acc = s_C \times s_L/f$.

3. Conclusion

We have demonstrated time- and polarization-correlations in the SPDC pairs produced by type-II quasi-phase-matching in a birefringent PPSF. Future work will include observation of polarization entanglement from the source.

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