Broadband Polarization-Entanglement in a Poled Fiber

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Abstract: Broadband polarization-entanglement over 100 nm is demonstrated in a poled fiber phase-matched for type-II downconversion in the 1.5-μm telecom-band. Two-photon interference and Hong-Ou-Mandel interference are used experimentally to confirm the broadband nature of the entanglement.

OCIS codes: (270.0270) Quantum optics; (190.4370) Nonlinear optics, fibers

1. Introduction

Entangled photons are a fundamental resource in quantum optics and quantum information [1]. Fiber-based sources of entangled photon pairs are especially sought-after for their ease of integration with current telecom infrastructure. While spontaneous parametric downconversion (SPDC) has historically been used to generate such entangled photons in bulk crystals, the inversion symmetry of fused silica prevents SPDC (and other second-order parametric processes) from occurring in conventional fiber. However, optical fibers subjected to thermal poling and quasi-phase-matching have been found to allow for second-harmonic generation [2] and type-II SPDC. Exploiting this type-II SPDC allows for the direct generation of polarization-entangled photon pairs in a poled fiber at 1.5-micron, which was recently demonstrated [3].

Here we demonstrate that the polarization entanglement is in fact broadband, by using coarse wavelength division multiplexers (WDMs) to divide the downconverted light into three frequency-conjugate sets. A Hong-Ou-Mandel (HOM) interference experiment is also carried out (without filters) to show that the downconverted photons are broadband.

2. Experiment

The fiber used is a step-index fiber with core radius $a = 2.0$ μm, and numerical aperature 0.20. Thermal poling is applied to induce a uniform second-order nonlinearity along the length (17 cm) of the fiber. Periodic UV erasure of the nonlinearity allows for the quasi-phase-matched second-harmonic generation (SHG) of 775 nm light in the LP_{01} transverse mode (the fiber is multimode at this wavelength). Three spectrally-separated phase-matched (type-0, I, and II) SHG signals [4] are present due to the form birefringence in the fiber. The type-II signal is exploited to generate polarization-entangled photon pairs when the fiber is pumped at 774.6 nm. The extremely low walkoff (60 fs/m) between the two principal polarizations (H, V) of the poled fiber results in a compensation-free source of polarization-entangled photon pairs.

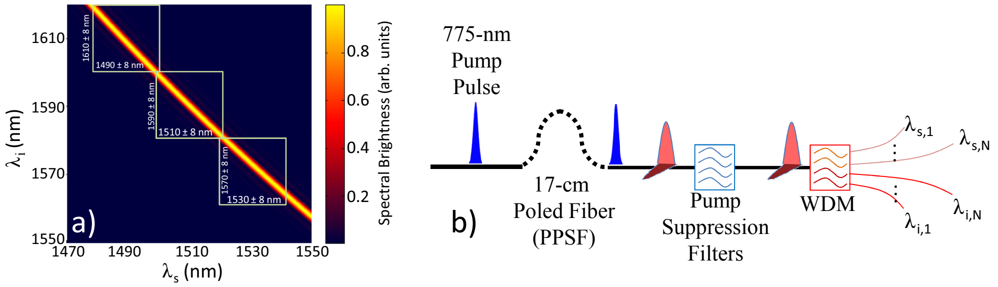
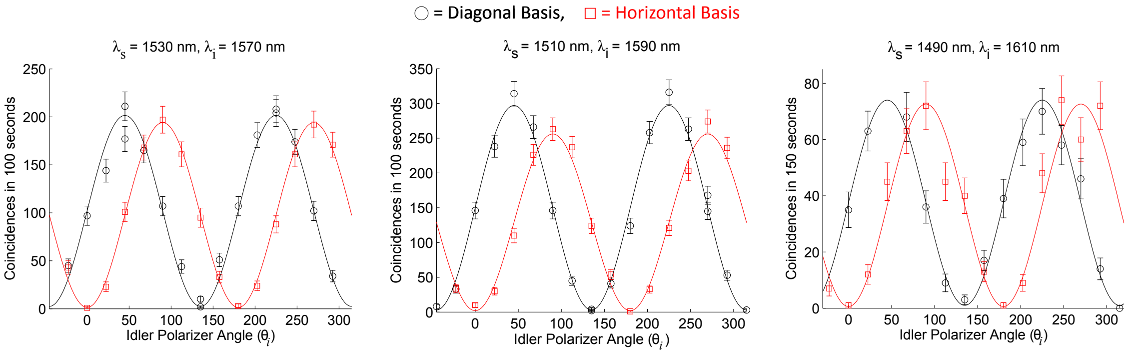


Fig. 1. a) The computed joint-spectral amplitude of the downconverted type-II photons generated in the poled fiber. b) The spectrally-entangled nature of the biphoton allows us to carve up the spectrum into separate frequency-conjugate pairs (λ_s, λ_i) using WDM filters.

A pulsed source (mode-locked Ti:Sapph) with central wavelength 774.6 nm is used as the pump for the poled fiber. The joint-spectral amplitude shown in Fig. 1a is characteristic of an entangled state with a large ($\gg 1$) Schmidt number. Exploiting this spectral entanglement, we use coarse WDM filters (Fig. 1b) to separate the biphoton into three frequency-conjugate parts [5], each of which can be treated as a polarization-entangled state $(|HV\rangle + |VH\rangle)$ for the experiments presented here; central wavelengths for the signal (idler) filters are 1530 nm (1570 nm), 1510 nm (1590 nm), and 1490 nm (1610 nm), with each filter having a 3 dB bandwidth of 16 nm.

At the output of each set of frequency-conjugate filters, polarization analyzers (consisting of a half-wave and quarter-wave plate, and polarizer), followed by gated Geiger-mode single photon detectors (SPDs), are used to detect the photons. A time-interval analyzer (TIA) checks the arrival times of the photons to determine accidental and coincidence counts. Two-photon interference results are shown in Fig. 2. The visibilities for the diagonal basis are found to exceed 97% for all three frequency-conjugate sets, demonstrating broadband polarization-entanglement.



Visibility = 97.5 ± 1.2 %

Visibility = 98.0 ± 0.3 %

Visibility = 97.3 ± 1.7 %

Fig. 2. Results of the two-photon interference measurements for the three frequency-conjugate pairs. The diagonal-basis visibilities are written below each plot.

Finally, a HOM experiment is used to determine the temporal extent of the biphoton wavepacket, and thus the bandwidth of the downconverted light. Fig. 3a gives the experimental setup; this Mach-Zehnder interferometer (MZI) replaces the WDMs in Fig. 1b. A polarizing beam splitter (PBS) splits the type-II photons deterministically, with the $V-$ and $H-$polarized photons going into separate legs of the interferometer; a variable optical delay (VOD) line compensates for the path length difference of the MZI. Fiber-based polarization controllers (FPC2, FPC3) change the polarizations of the photons to be the same when they meet at the beam splitter (BS). SPDs are placed at the output of the BS and coincidence measurements are made. Fig. 3b shows the experimental results, demonstrating a high-visibility dip of width 43 fs, which is equivalent to an SPDC bandwidth of more than 100 nm at 1.5 microns.

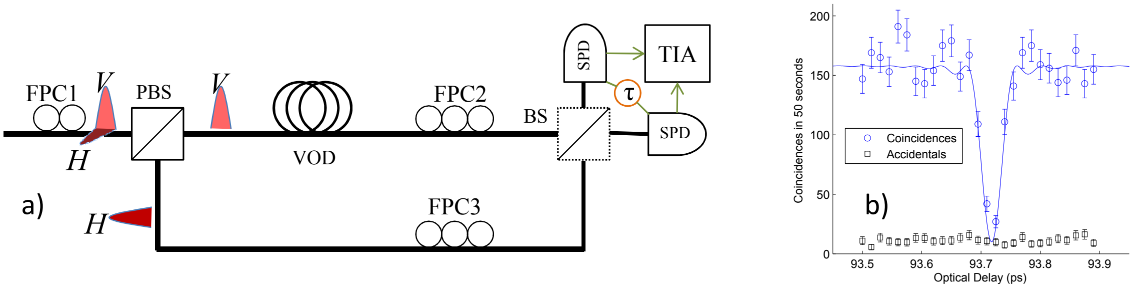


Fig. 3. a) Experimental setup for the Hong-Ou-Mandel (HOM) experiment. b) Results of the HOM experiment, with a full-width at half-maximum dipwidth of 43 fs; this corresponds to a more-than 100 nm bandwidth for the downconverted 1.5-micron biphotons.

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