Efficient generation of polarization-entangled photon pairs at 795 and 1610 nm

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Abstract: We obtain efficient generation of tunable single-mode fiber-coupled polarization-entangled photon pairs from a dual pumped parametric downconverter. The outputs from the bidirectionally pumped downconverter are combined to form polarization entangled pairs with a production rate of 15000/s/mW. Quantum interference with a visibility $> 90\%$ was observed and used to determine the photon bandwidth of 60 GHz.

Distribution and storage of entanglement over long distances are necessary in many applications in quantum communications, such as long distance teleportation [1]. For example, Rb-based quantum memories require photon pairs with one wavelength at the Rb transition of 795 nm, and the conjugate wavelength in the telecommunication band of ~1550 nm for long-distance transport and subsequent frequency translation to 795 nm [1, 2]. We have demonstrated a source of polarization-entangled photon pairs based on periodically poled lithium niobate (PPLN) parametric downconversion that is suitable for coupling into a Rb quantum memory unit. In particular, the high degree of spatial and spectral correlation in the spontaneous emission output permitted us to obtain a single-mode flux of $\sim$ 10 pairs/s/mW of pump power in a bandwidth of 30 MHz that is expected for the Rb quantum memory.

Periodically poled materials allow the wavelengths of the photons to be chosen anywhere within their transparency windows. We used a 2-cm PPLN crystal with a grating period of 21.6 μm for third-order type-I quasi-phase matched downconversion of a 532-nm pump photon into a 795-nm signal and a 1610-nm idler photon. The pump was weakly focused inside the crystal with a confocal parameter of 20 cm, and the signal and idler frequencies were temperature tunable over 100 K at a rate of 150 GHz/K [3]. Temperature tuning also allows the emission angle to be finely adjusted for a given emission wavelength. Figure 1 shows CCD

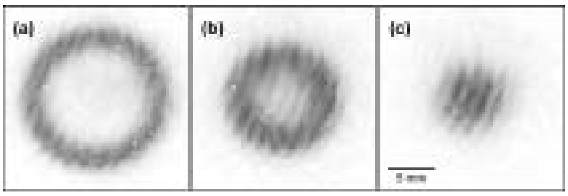

Fig. 1. Far-field images of spontaneously downconverted light at 795-nm for PPLN temperatures of (a) 177.6°C, half cone angle of 17.0 mrad (b) 180.6°C, half angle of 10.3 mrad, and (c) 183.6°C, collinear. Fringing is due to camera etalon effects.

camera images of the spontaneously downconverted light through a 1-nm interference filter at three different temperatures. We have found that the temperature dependence of the 795-nm signal emission angles agrees well with predictions obtained from the Sellmeier equations for $LiNbO_3$, which facilitates coupling of the spontaneously emitted outputs into their respective single-mode fibers. We have obtained a single-mode coupling efficiency of ~18% for the signal beam with a 0.11-nm interference filter centered at 795 nm. Without the filter, the full output bandwidth could not be efficiently coupled and the coupling decreases to a few percent.

We measured the pair coincidences by also coupling the idler photons into a single-mode fiber, and detecting them with an InGaAs Geiger-mode avalanche photodiode that was triggered by a signal count at the Si photon counter [3]. We note that the idler divergence angle is twice that of the signal beam because of their wavelength difference. Corrected just for the detector quantum efficiencies (20% and 50% for the InGaAs and Si counter, respectively), we obtained a coincidence rate of 4100/s/mW with the 0.11-nm interference filter. The highest signal-conditioned idler detection probability was 9.4%, limited by our 20% efficient InGaAs

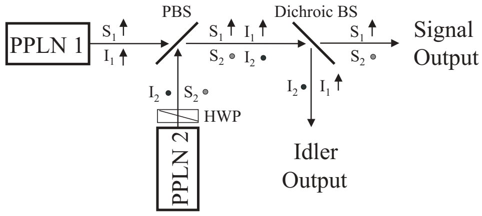

Fig. 2. Conceptual scheme for the generation of polarization-entangled photon pairs from two downconverters. PBS: polarizing beam splitter. HWP: Half wave plate.

counter, propagation and coupling losses. Without the interference filter, overall signal losses were less and the coincidence rate increased to 16000/s/mW. However, the signal-conditioned idler detection probability dropped to 5.2% because the fiber coupling was no longer optimal.

The outputs of two identical parametric downconverters can be combined to generate polarization entanglement, as shown schematically in Fig. 2. Experimentally, our PPLN crystal was pumped coherently in both directions and the pairs were extracted using dichroic mirrors and prisms. The two signal and two idler fields were combined at their respective polarizing beamsplitters, and coupled into single-mode fibers. Polarization entanglement arises because of quantum interference between the signal and idler fields. The phase of this quantum interference determines the state of the polarization entanglement (singlet or triplet, for example), and is set by the path length difference between the two signal fields and that of the two idler fields. In the experiment, we set the signal and idler polarizing beam splitters (PBS) at 45°, and swept the path length of one of the idler fields with a piezoelectric transducer. Figure 3 shows the expected enhancement and suppression of coincidences as the state of the polarization entanglement was swept from singlet to triplet. After subtracting accidental coincidences, we obtain a visibility greater than 90%. We note that the setup exhibited no visible phase shift over 5 minutes without active stabilization of the optical path lengths.

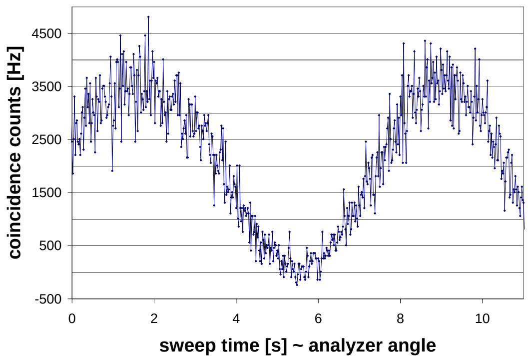

Fig. 3. Quantum interference signature of polarization entanglement. The signal and idler photons were both analyzed at 45°, as one of the idler path length was slowly swept.

We were able to infer from the quantum interference measurements the length of the photons. Without the interference filter we recorded the visibility as the path lengths of the interferometer was gradually unbalanced. We observed that at a delay of 2.3 mm the visibility dropped by 50%. This corresponds to a photon length of 7.5 ps and a bandwidth of 60 GHz if we assume a Gaussian envelope. The reduction in bandwidth is a result of the strong correlations between spectral and spatial modes and the fiber coupling. The photon bandwidth of 60 GHz, however, is still 4 orders of magnitude larger than the expected trapped-Rb cavity linewidth of 30 MHz. However, we estimate our source generated a flux of ∼10 pairs/s/mW of pump within the 30-MHz bandwidth. By pumping with several hundred mW of power and by using a first-order grating a flux of over 1000/s can be obtained, which should be sufficient for testing some aspects of the long-distance teleportation protocol [1].

References

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