

Integrated optical source of polarization entangled photons at 1310 nm

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Abstract

We report the realization of a new polarization entangled photon-pair source based on a Titanium indiffused waveguide integrated on PPLN. We show that the paired photons are emitted at 1310 nm within a bandwidth of less than 1 nm. The quantum properties of the pairs are demonstrated to be of high quality using a Hong, Ou, and Mandel type experiment.

Introduction

Quantum key distribution (QKD) often relies on single or entangled pairs of photons [1]. Here quantum information is encoded on their quantum properties, such as polarization [2]. Spontaneous parametric down conversion (SPDC) in non-linear crystals is a common way to produce such entangled pairs [2,3]. However, proof of principle experiments are over now and today's QKD realizations are more and more market-oriented where miniaturization and reliability are essential features. For instance, efforts are spent on developing more efficient and compact photon-pair sources. In addition, as soon as long-distance QKD is concerned, the paired photons have to be emitted within one of the telecom windows together with narrow bandwidths [4].

In this context, the aim of this work is to gather all of the above mentioned features in a single source based on a Titanium (Ti) indiffused PPLN waveguide. We report for the first time the efficient emission of narrowband polarization entangled photons at 1310 nm, showing the highest quality of two-photon interference (coalescence) ever reported in a similar configuration [5,6].

Principle of the source

The principle of our new source is sketched in Fig.1. Ti-indiffusion technology has been employed for waveguide fabrication in order the device supports both vertical (V) and horizontal (H) polarization modes. A type-II SPDC process can therefore take place, exploiting the d_{24} non-linear coefficient of the material [5]. In this case, starting from H-polarized pump photons at 655 nm this quasi-phased matched process leads to the generation of paired photons at 1310 nm, having strictly identical properties, but with orthogonal polarizations.

After filtering out the remaining pump photons, they can be separated using a 50/50 beam-splitter (BS) whose outputs are labelled a and b. In average, the separation occurs with a probability of 1/2, but when successful, the two possible output states, $H_a V_b$ and

$V_a H_b$, have equal probabilities so that the related two-photon state corresponds to the entangled state

$$\frac{1}{\sqrt{2}} \left[|H_a V_b\rangle + |V_a H_b\rangle \right]$$

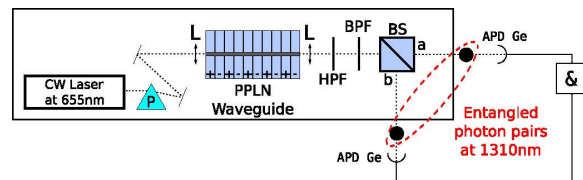


Fig. 1: Schematic of the polarization entangled photon-pair source at 1310 nm. An external cavity diode laser at 655 nm is employed to pump a Ti-indiffused PPLN waveguide in the CW regime; A prism (P) is used to remove the infrared light coming from the laser. A set of lenses (L) are used to couple light in and out of the waveguide. The association of a high-pass filter (HPF, cut-off at 1000 nm, $T=90\%$) and a bandpass filter (BPF, 1310 nm, $\Delta\lambda= 10\text{nm}$, $T=70\%$) allows removing the residual pump photons. Finally, a 50/50 beam-splitter (BS) enables separating the paired photons, revealing entanglement in the coincidence basis. For characterization, we use two passively-quenched Ge-APDs connected to an AND-gate (&) for coincidence counting.

Characterization and results

The classical characterization of a 3.6 cm-long waveguide has shown the bright emission of cross-polarized photons at the degenerate wavelength of 1310 nm within a bandwidth of 0.7 nm. This was obtained from a waveguide featuring a width of 7 μm and a periodic poling of 6.6 μm . The commonly accepted brightness unit is defined as the number of pairs produced per second, per GHz of bandwidth, and per mW of pump power. We calculated a normalized production rate of $10^5 \text{ s}^{-1} \cdot \text{GHz}^{-1} \cdot \text{mW}^{-1}$ which is among the best ever reported for similar configurations [5,6].

The quantum characterization is based on a Hong, Ou, and Mandel (HOM) setup from which it is possible to infer the potential amount of entanglement of the produced pairs [7]. In this experiment (see Fig.2), if two identical photons enter the BS through

different inputs at the same time, a destructive interference occurs and makes them exit the device through the same output. This is known as the coalescence effect. Consequently, a dip in the coincidence detection rate is expected as a function of the temporal overlap between the two photons. Here, two parameters are of interest. On the one hand, the visibility (or depth), which depends on any experimental distinguishability, is the figure of merit which is linked to the quality of the entangled state produced by the source of Fig.1. On the other hand, the width of the dip is directly related to the coherence time of the single photons [7].

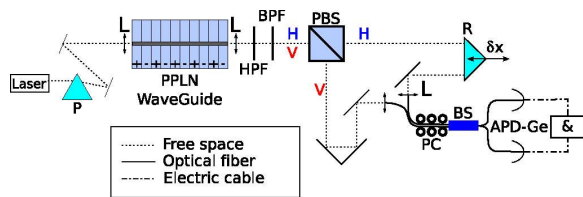


Fig. 2 : Two-photon interference experiment. The two polarization modes are first separated using a polarization beam-splitter (PBS). A retroreflector (R) placed in one arm is employed to adjust the relative delay of the two photons. After being coupled into single mode optical fibers, these photons are recombined at a 50/50 coupler (BS) where quantum interference occurs. Note that both polarization modes are adjusted to be identical using fiber-optics polarization controllers (PC) in front of the coupler. The overall losses of the interferometer were estimated to be of 5.5 dB.

Fig.3 exhibits the coincidence rate as a function of the path length difference between the two arms and clearly shows a HOM interference while single photon detection remains constant in both APDs. The net visibility, i.e. when noise is discarded, is of about 85% which is the best ever reported for similar configurations. We can also see in Fig.3 that the dip is noticeably distorted. We identify that the phase-matching condition in our waveguide gives rise to a state that partially overlaps with the Ψ^- state for the energy-time observable. It is the only state that gives rise to a coincidence peak when submitted to a HOM experiment due to symmetry considerations.

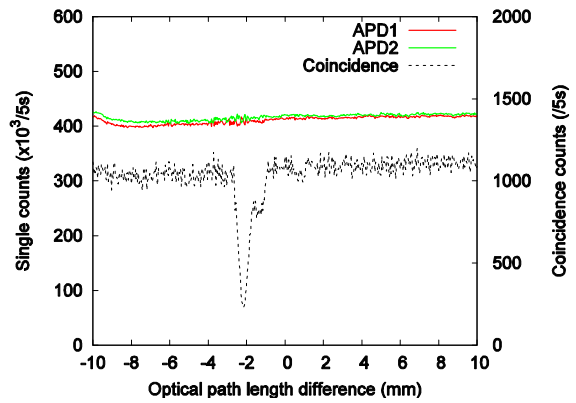


Fig. 3 : Net coincidence and single counting rates at the output of the 50/50 beam-splitter as function of the relative length of the two arms. Here the position of dip is linked to the relative separation experienced by the H and V photons in the generator due to their different group velocities. The dip exhibits a net visibility of 85% and a width of 1.5 mm FWHM for a temperature of 71.64° C.

Conclusion

Using a type-II PPLN waveguide, we have demonstrated a narrowband and bright source of cross-polarized paired photons emitted at 1310 nm within a bandwidth of 0.7 nm, and with a production rate to be on the order of $10^5 \text{ s}^{-1} \cdot \text{GHz}^{-1} \cdot \text{mW}^{-1}$. Furthermore, using a HOM-type setup, we obtained an anti-coincidence visibility of 85% indicating a high level of photon indistinguishability. These results, to our knowledge the best ever reported for the similar configurations, together with the compactness and reliability of the source, make it a high-quality generator of polarization entangled photon-pairs for the first time at 1310 nm. This work clearly highlights the potential of integrated optics to serve as key elements for long-distance QKD.

References

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