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 done to develop 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. Moreover, a narrow bandwidth is required [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 in-diffused periodically poled lithium niobate (Ti:PPLN) waveguide. We report for the first time the efficient emission of narrowband polarization entangled photons at 1310 nm wavelength, showing the highest quality of two-photon interference (coalescence) ever reported in a similar configuration [5,6].

Principle of the source

The principle setup of the new source is sketched in Fig. 1. Ti-indiffusion technology has been used to fabricate a 3.6 cm long waveguide of 7 µm width in a PPLN substrate of 6.6 µm periodicity. The Ti:PPLN waveguide 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, the 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, the generated pairs can be separated using a 50/50 beam-splitter (BS) with outputs labelled a and b. On average, the separation occurs with a probability of 1/2, but when successful, the two possible output states, H_aV_b and V_aH_b, have equal probabilities so that the related two-photon state corresponds to the entangled state $\frac{1}{\sqrt{2}}\left[|H_a, V_b\rangle + |V_a, H_b\rangle\right]$.

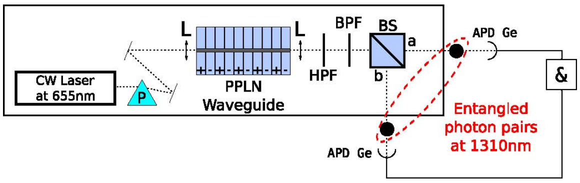

Figure 1: Schematic of the polarization entangled photon-pair source at 1310 nm. An external cavity diode laser at 655 nm is employed to pump a Ti-indiffused PPLN waveguide in the cw regime. A prism (P) is used to remove the infrared light coming from the laser. A set of lenses (L) is used to couple light in and out of the waveguide. The combination of high-pass (HPF, cut-off at 1000 nm, T=90%) and band-pass filter (BPF, 1310 nm, $\Delta\lambda$= 10nm, 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 the Ti:PPLN waveguide gave a bright emission of cross-polarized photons at the degenerate wavelength of 1310 nm within a bandwidth of 0.7 nm. The accepted brightness unit is defined as the number of pairs produced per second, per GHz of bandwidth, and per mW of pump power. From our experimental data a brightness of 10^5 $s^{-1}GHz^{-1}mW^{-1}$ was calculated, which is among the best results 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 port. 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) of the dip, 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. On the other hand, the width of the dip is directly related to the coherence time of the single photons [7].

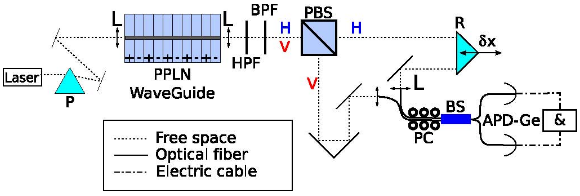

Figure 2: Two-photon interference experiment. The two polarization modes are first separated using a polarization beam-splitter (PBS). A retro-reflector (R) placed in one arm is employed to adjust the relative delay of the two photons. After being coupled into single mode optical fibres, these photons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

Fig. 3 shows the coincidence rate as a function of the path length difference between the two arms; it 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.

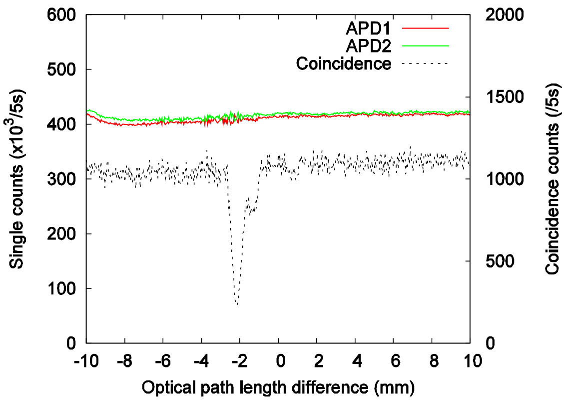

Figure 3: Net coincidence and single counting rates at the output of the 50/50 beam-splitter as function of the relative length of the two arms. The position of the dip is linked to the relative separation experienced by the H and V photons in the generator due to their different group velocities. The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

Conclusions

Exploiting type-II SPDC in a Ti:PPLN waveguide, we have demonstrated a narrowband and bright source of cross-polarized paired photons emitted, for the first time, at 1310 nm within a bandwidth of 0.7 nm. The brightness of the source is on the order of 10^5 $s^{-1}GHz^{-1}mW^{-1}$. 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 similar configurations, together with the compactness and reliability of the source, make it a high-quality generator of polarization entangled photon pairs. This work clearly highlights the potential of integrated optical devices to serve as key elements for long-distance QKD.

References

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