Packaged integrated SPDC photon pair source with polarisation splitter.

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Abstract

The development of a packaged integrated optic photon pair source based on spontaneous parametric down-conversion (SPDC) is reported. The source consists of a periodically poled Ti:$LiNbO_3$ waveguide combined with a polarisation splitter on the same substrate. A dielectric end face mirror results in a first pump suppression by -17 dB. Single mode fibre pigtails at input and output waveguides result in a stable operation. A domain periodicity of 9.1 µm was chosen to obtain (type-II) quasi phase matched SPDC with orthogonally polarised photon pairs around 1560 nm wavelength. The photon bandwidth is estimated to be 400 pm.

Introduction

Photon pair sources based on quasi phase matched (QPM) spontaneous parametric down-conversion (SPDC) in nonlinear crystals proved to be essential devices for reliable Quantum Key Distribution (QKD) systems[1]. In integrated optical sources using e.g. waveguides in periodically poled lithium niobate (PPLN)[2] a high efficiency and brightness can be obtained. Up to now, mainly type-I phase matched devices have been used in system applications. Type-II devices, which inherently yield orthogonally polarised photons of much smaller spectral bandwidth, have recently been demonstrated[3,4]. They consist of a Ti:PPLN waveguide; spatial photon separation and pump suppression are done externally using bulk or fibre optics. In our contribution a type-II photon pair source is presented which combines for the first time a polarisation splitter and a pump reflector on the same substrate. Moreover, it is fibre coupled on both, input and output sides.

Design and fabrication

A schematic drawing of the integrated photon pair source is shown in Fig. 1. The pump light (λ_p ~ 780 nm) is coupled into the waveguide using a polarisation maintaining single mode fibre (PMF). Both, fibre and waveguide end faces are angle-polished to avoid back-reflections into the fibre. The input coupling is optimised for TE-polarisation. The single mode waveguide structure was fabricated by in-diffusion of photolithographically defined 7 µm wide, 80 nm thick Titanium stripes for 9 hours at 1060°C. Afterwards, a waveguide section of 66 mm length was periodically poled with a periodicity of 9.1 µm to obtain (type-II) quasi phase matched SPDC with signal and idler wavelengths around 1560 nm (waveguide temperature ~ 50°C). The orthogonally polarised signal and idler photons generated in the Ti:PPLN waveguide are separated by a specially designed directional coupler operating as polarisation splitter. On the waveguide end face a dielectric mirror is deposited to reflect the residual pump. The spatially separated photons are butt-coupled to standard single mode fibres embedded in a dual core glass ferrule. The integrated photon pair source is packaged as a whole in an Al-housing, which also allows stabilising the substrate temperature.

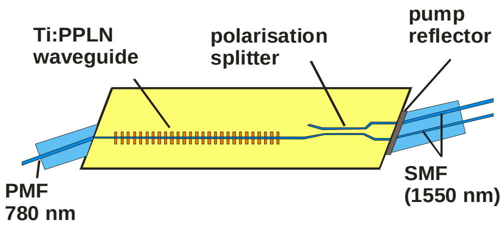

Figure 1: Scheme of the integrated photon pair source with fibre pigtails.

Waveguide components and pump reflector

The ***Ti:PPLN waveguide*** was characterized by an investigation of second harmonic generation (SHG) and of spontaneous parametric fluorescence (SPF). Measured SPF-spectra for different pump wavelengths are shown in Fig. 2. They were obtained before fibre pigtailing from a waveguide without subsequent polarisation splitter fabricated as control guide on the same sample with identical parameters. Thus, TM- and TE-polarized SPF was emitted by the same waveguide and could be measured in a single run of the spectrometer. The TM-emission was consistently lower than the TE-emission at all pump wavelengths; this is mainly attributed to the higher TM-propagation loss in the waveguide and to the polarisation dependent transmission of the spectrometer. The half-widths of the SPF-peaks are 2.3 nm determined by resolution of the spectrometer.

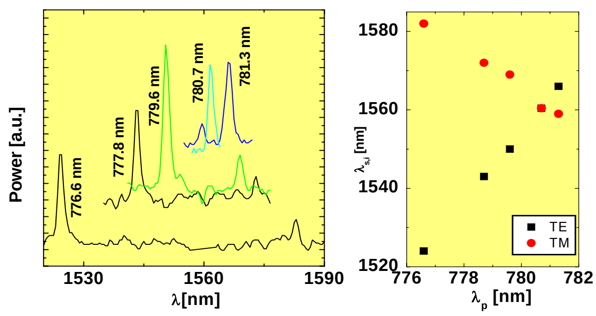

Figure 2: SPF-spectra (left); parameter is the pump wavelength λ_p. Signal and idler wavelengths versus pump wavelength (right).

On the right also the tuning characteristics of the SPF is given extracted from the spectra on the left.

The special directional coupler to be used as ***integrated polarisation*** splitter was tested separately investigating devices of different coupling length. A polarisation splitting ratio of more than 20 dB for both polarisations could be obtained. Unfortunately, the coupler combined with the Ti:PPLN waveguide in the photon pair source has a length of 515 µm which is slightly larger than optimum; therefore, the splitting ratio was only 15 dB for both polarisations.

A ***dielectric mirror*** deposited on the waveguide end faces to reflect the pump radiation consists of 12 alternating layers of TiO_2 and SiO_2. The thickness of each layer was optimised by a Monte-Carlo simulation. The criteria for optimisation were high transmission for down-converted photons and high reflectivity for pump photons. A pump suppression of about -17 dB was achieved, whereas the transmission losses for signal and idler photons could be kept very small (-0.2 dB).

The ***waveguide-to-fiber couplers*** consist of angle-polished (polarisation maintaining) single mode fibres embedded in glass ferrules glued to the waveguide end faces. The waveguide-to-fibre-transmission was monitored during pigtailing (@ λ = 1550 nm). As result, an output coupling loss of -2 dB was observed.

Characterization of the packaged source

The integrated photon pair source is operated with an extended cavity semiconductor laser (ECL) as tuneable pump. At a substrate temperature of 50°C, degenerate operation is achieved at λ_p = 778.5 nm yielding signal and idler wavelengths at 1557 nm.

At first, the packaged photon pair source was tested by ***SHG in backward direction.*** The radiation of a tuneable ECL (λ ~ 1556 nm) was polarisation-splitted and coupled via the two output fibres into the output guides of the integrated source to equally excite TM- and TE-modes. Both are combined via the polarisation splitter and generate a TE-polarised SH-wave in the Ti:PPLN waveguide. This light is emitted via the PMF in backward direction (Fig. 3).

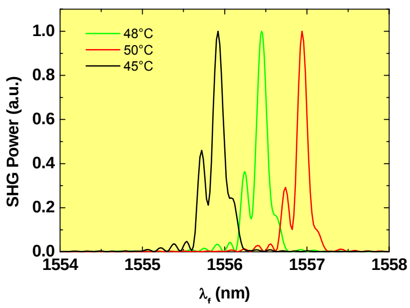

Figure 3: SHG measured in backward direction at different temperatures after packaging. The phase matching bandwidth is ~ 100pm only.

The measured SHG-efficiency is ~ 0.1 %/Watt, about one order of magnitude smaller than expected from theory, if coupling losses are neglected. A phase match bandwidth of only 100 pm was observed confirming a good homogeneity of the 66 mm long Ti:PPLN waveguide. A 400 pm bandwidth can be expected for the correlated photon pairs.

The emission of single photon pairs was analysed by single photon (InGaAs) avalanche diodes connected to both output fibres. Additional fibre-optic isolators (absorbing around λ_p) were inserted to improve the suppression of the pump by another -30 dB. Both detectors were triggered at the same time with a 13 kHz repetition frequency; they measure the delay time till a photon is detected. A computer determines the coincidence counts as function of the photon arrival time differences. A result of such a ***coincidence measurement*** at degeneracy, obtained with an input pump power of 2 mW, is shown in Fig. 4.

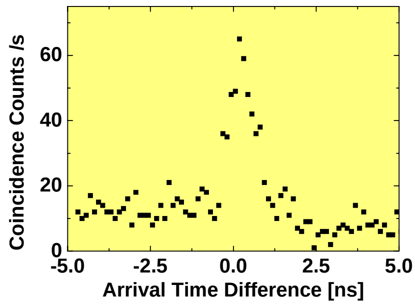

Figure 4: Coincidence counts of detected single photon counts versus the arrival time difference.

Conclusions

A fully packaged integrated SPDC photon pair source has been developed. It emits photons of a spectral bandwidth of only ~400 pm. There is still a large potential to improve the source: in particular, coupling losses can be substantially reduced resulting in a higher efficiency. A polarisation splitter of higher splitting ratio would suppress most of the photons of unwanted polarisation. Also the pump suppression at both outputs can be further improved e.g. by inserting fibre optical band-pass filters.

References

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