

MHz rate and efficient synchronous heralding of single photons at telecom wavelengths

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Abstract: We report on the realization of a synchronous source of heralded single photons at telecom wavelengths with MHz heralding rates and high heralding efficiency. This source is based on the generation of photon pairs at 810 and 1550 nm via Spontaneous Parametric Down Conversion (SPDC) in a 1 cm periodically poled lithium niobate (PPLN) crystal pumped by a 532 nm pulsed laser. As high rates are fundamental for multi-photon experiments, we show that single telecom photons can be announced at 4.4 MHz rate with 45% heralding efficiency. When we focus only on the optimization of the coupling of the heralded photon, the heralding efficiency can be increased up to 80%. Furthermore, we experimentally observe that group velocity mismatch inside long crystals pumped in a pulsed mode affects the spectrum of the emitted photons and their fibre coupling efficiency. The length of the crystal in this source has been chosen as a trade off between high brightness and high coupling efficiency.

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1. Introduction

In recent years, the generation of single photon Fock states has seen a significant increase in interest, not only from a fundamental perspective, but also for their key role in many quantum information applications [1, 2], such as linear-optics quantum computing [3] and single-photon

detectors calibration [4]. In the context of quantum communication [5], heralded single photon (HSP) sources could be adopted for a wide range of tasks, like device independent Quantum Key Distribution (QKD) [6] or distribution of entangled photons at a distance via quantum repeaters [7, 8].

The idea of a HSP source was introduced for the first time in 1986, when Hong and Mandel [9] showed that a localized one-photon Fock state can be achieved by exploiting the temporal correlation of the photon pairs generated by Spontaneous Parametric Down Conversion (SPDC): one photon can be heralded by the detection of its twin. Due to the probabilistic nature of SPDC, single photons cannot be generated on demand. However, upon detection of one of the twin photons at a heralding rate R^H , one can define the heralding efficiency η^H , i.e. the probability of finding a photon in a single mode fibre given the trigger signal. Thus far, significant theoretical and experimental efforts have been made to efficiently couple into fibre single photons generated via SPDC in bulk [10–12] or periodically poled crystals [13, 14], and in nonlinear waveguides [15].

In the last two decades, a variety of HSP sources based on SPDC has been realized in an asynchronous configuration, via a CW pump [16–19] and synchronously with a pulsed pump [20–25]. Recently, promising all-fibre synchronous HSP sources based on Four Wave Mixing (FWM) have also been reported [26–29]. However, only some of these HSP sources are suited to quantum communication applications, where it is necessary to herald with high probability, and rate, the presence of photons at telecom wavelengths into a single mode fibre. The majority of the HSP sources at telecom wavelengths based on SPDC operate in an asynchronous way [16–19]. To the best of our knowledge, the only HSP sources based on pulsed SPDC are reported in [23, 24], but suffer from poor heralding efficiencies.

Nonetheless, the pulsed pumping regime is more advantageous than the CW one in some quantum communication applications. For example, in QKD the pulsed mode can make the synchronization of multiple communicating parties easier with respect to the CW mode. Some other challenging multi-photon quantum information experiments can take advantage of the pulsed pumping configuration. In particular, our study is motivated by the requirements of a recent proposal to use Sum Frequency Generation (SFG) between single photons belonging to two distinct entangled photon pairs in order to faithfully herald entanglement at a distance [30]. The pulsed pumping configuration, with respect to the CW one, allows one to synchronize the arrival of the two single photons in the nonlinear crystal performing the SFG. For this experiment to be feasible, despite the low efficiency of the nonlinear interaction between single photons, high repetition rates and efficient coupling are required.

However, the coupling efficiency of pulsed SPDC sources is usually limited by the group velocity mismatch between the generated photons and the pump pulses inside the nonlinear crystal. Indeed, because of the dispersive properties of the crystal, the SPDC generated photons can acquire a temporal delay with respect to the pump, which can be larger than the pump pulses' coherence time. Under these conditions, the coherence of the photons emitted from different longitudinal positions within the crystal is lost, resulting in a spatial multimode emission and in a reduction of the fibre coupling. These effects can be limited by reducing the length of the crystal, which, in turn, causes a decrease of the source brightness.

In this paper, we choose the length of the crystal in order to achieve a trade off between high brightness and high coupling efficiency. Indeed, we experimentally demonstrate the realization of a synchronous HSP source at telecom wavelengths, based on pulsed SPDC in a 1 cm bulk PPLN crystal, with which telecom photons can be heralded at 4.4 MHz rate with 45% heralding efficiency. To the best of our knowledge, this is the most efficient high rate HSP source based on pulsed SPDC ever reported. We measure a 80% efficiency of announcing a telecom photon, when we concentrate only on the coupling of the heralded photon. Furthermore, by testing a

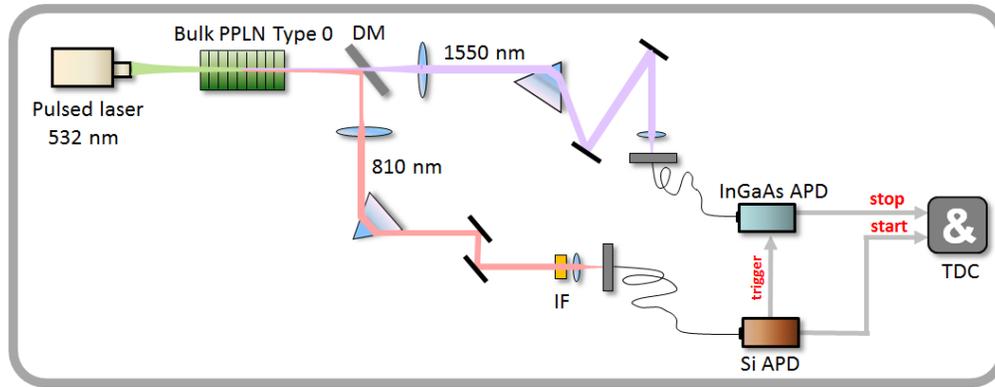


Fig. 1. Setup of the source. DM: dichroic mirror; IF: interference filter.

4 cm crystal in a pulsed and CW pumping configuration, we experimentally investigate how the group velocity mismatch in longer crystals affect the spectrum and the coupling efficiency of the emitted photons.

2. The source

A 430 MHz passively mode-locked laser (Time-bandwidth GE-100-VAN-HP-SHG-430) producing pulses of 8 ps at 532 nm, pumps a 1 cm Type 0 (e,e,e) PPLN bulk crystal (Covesion SFG2) with a $7.10\mu\text{m}$ poling period which gives the phasematching conditions necessary to produce photon pairs at 810 nm and 1550 nm via SPCD at a temperature of 180 C. This crystal has a clear aperture of $0.5\text{ mm}\times 0.5\text{ mm}$ and is anti-reflection coated on both sides for the pump, signal and idler wavelengths (see Fig. 1). The pump laser is coupled into a polarization maintaining fibre to select a single spatial mode and focused on the crystal with an aspheric lens (Geltech 352110) with focal length $f=6.24\text{ mm}$, which yields a $40\mu\text{m}$ waist within the crystal.

The generated signal (810 nm) and idler (1550 nm) photons are separated by a dichroic mirror and collimated using $f=150\text{ mm}$ achromatic lenses (Thorlabs AC254-150-B/C). The pump light is removed using equilateral prisms (Schott F2 glass) at the Brewster angle. The photons are then coupled into fibres using aspheric lenses (Geltech 352220-B for the idler with $f=11\text{ mm}$ and Geltech 350260-C for the signal with $f=15.36\text{ mm}$). Injecting light backwards through the fibres allows one to check for the correct alignment, for the size of the waists in the crystal and for the transmission in the optical path. On the 810 nm arm, we use an interference filter centered at 810 nm, with a 10 nm bandwidth and 55% transmission, to further remove the pump light.

The heralding photon at 810 nm is detected by a free running Silicon Avalanche PhotoDiode (Si-APD) (Laser Components 'Count') with $\eta_{810}=50\%$ efficiency at 810 nm, 5 Hz dark counts and 110 ns dead time. The telecom photon is detected by an InGaAs APD (ID201, IDQuantique) in gated mode with $\eta_{1550}=10\%$ efficiency and $10\mu\text{s}$ dead time in order to reduce after-pulsing. We measured the dark count probability of this detector at 10 kHz triggering rate to be $8\cdot 10^{-6}$ per ns.

Note that we assume a 10% relative uncertainty in the calibration of the detectors efficiency, which produces a similar error in the coupling efficiencies reported in this paper. In order to characterize the source, we measure via a Time to Digital Converter (TDC) (Agilent Acqiris TC890) the coincidences between the detections of the InGaAs and the Si detectors as a func-

tion of their time difference.

In order to study effects due to the group velocity mismatch in the presence of a pulsed pump, we also test a 4 cm PPLN bulk crystal. In this case, an aspheric lens (Geltech 350280-C) with $f=18.40$ mm is used for fibre coupling the telecom photon and the distance between the optical elements is set in order to provide the optimal beam waists inside the longer crystal. For further characterization of the source, a CW laser at 532 nm (Laser Quantum Torus) is also used.

2.1. Photon coupling optimization

The coupling efficiency of a single photon (or photon pair) source is a critical parameter, especially in multi-photon experiments where the probability of success decreases with the photon losses to the power of the number of photons involved in the experiment. In [13] it is theoretically shown that by properly focusing the pump onto a bulk crystal, one can attain SPDC photon emission very close to the single mode of optical fibres, independently of the crystal length. For a monochromatic pump with a specific waist, it is possible to calculate the density matrix of the emitted SPDC two-photon state, which is constrained by phase-matching conditions, in terms of angular and frequency distribution, as described in [13]. Due to the high dimensionality of the problem, the calculation can be numerically intensive but gives access to the full information about the state, including spatial and spectral correlations. In our case, we use this information for optimizing the pump focusing in order to maximize the fibre coupling.

We calculate with this model that with a beam waist inside the 1 cm crystal of $40\ \mu\text{m}$ for the pump and of $30\ \mu\text{m}$ for the idler and signal beams collected by the corresponding fibres, the photons generated by SPDC in the crystal are emitted with a spatial distribution which has a 96% overlap with a single gaussian mode. Beam waists of $80\ \mu\text{m}$, $60\ \mu\text{m}$, $60\ \mu\text{m}$ for the pump, signal and idler respectively are calculated for the 4 cm crystal.

Although there are optimal beam waists, the overlap between the pump and the generated photons can be better than 90% over nearly one order of magnitude in waist size, provided that the collecting optics is chosen accordingly. In order to accurately plan the beam paths and to avoid optics or alignments which could introduce aberrations, we simulated the beams propagation using the optical modeling software “Code V”. All alignment takes advantage of CCD cameras to ensure that the beam profile is of the desired size, to guarantee overlap between the different modes and to avoid the aberrations which can arise if the lenses are not exactly on axis, or if the prism is not at the Brewster-angle.

3. Characterization of a HSP source

Different parameters can be adopted for characterizing a HSP source. Here, we focus on the heralding efficiency and on the conditional autocorrelation function.

3.1. Heralding efficiency

The heralding efficiency η^H is the probability of finding the signal photon (1550 nm) in the single mode fibre once the idler (810 nm) is detected. In our case, η^H is equivalent to the overall transmission of the telecom photon, from the nonlinear crystal to the InGaAs detector. A first and simple way to estimate η^H is to measure the coincidences with the TDC between the InGaAs and the Si-APD detections, with the InGaAs detector triggered by the signal provided by the Si-APD. Indeed, in this situation the overall transmission of the telecom photon is given by:

$$t_{1550} = \eta^H = \frac{C}{S_{810}\eta_{1550}}, \quad (1)$$

where C is the coincidence count rate and S_{810} the singles on the Si-APD. Accidental coincidences and dark counts of the Si-APD are subtracted from the value of C and S_{810} respectively.

It is desirable to perform the measurement of t_{1550} at a low pumping regime, in order to make the emission of multiple photon pairs negligible.

The transmission of the photon at 810 nm, can also provide other useful information about the source. It can be estimated by measuring the coincidences with the InGaAs APD in gated mode but not triggered by the Si detector. Indeed, in this situation the transmission of the idler photon is given by

$$t_{810} = \frac{C'}{S_{1550}\eta_{810}}. \quad (2)$$

where C' are the net coincidence counts in this configuration and S_{1550} the singles on the InGaAs-APD. Even in this case, we subtract accidental coincidences from the value of C' . We subtract from S_{1550} a value of dark counts corresponding to a triggering rate equal to the value of S_{1550} itself. Notice that Eq. (1) and (2) are valid in a regime where the detectors are not in a saturated condition.

Once the overall transmission of the two photons is determined, together with the knowledge of the detectors' efficiency, one can calculate the number of photon pairs generated per pulse p . This quantity can be also measured by adopting an alternative method [31]: the detection of the twin SPDC photons produces the appearance of a coincidence peak in the distribution of the coincidences measured by the TDC with respect to the time delay between the idler and the signal photon. However, for a pulsed source, because of inefficient detection, side peaks, corresponding to coincidences between not correlated photons, are also present. The value of p can also be determined by measuring the ratio between the counts in one side peak and the counts in the main peak.

3.2. Conditional autocorrelation function

The conditional autocorrelation function $g_{a|b}^{(2)}(0)$ of the state of the heralded photon a , given a detection of the heralding photon b , is often adopted as a figure of merit for evaluating the single photon emission of a HSP source. In our case, the photons a and b are the idler at 1550 nm and the signal at 810 nm respectively. For a SPDC source, the $g_{a|b}^{(2)}(0)$ can be calculated exactly using Eq. (24) in [34], that can be written in the case of low values of p ($p \ll 1$) and no detector noise as

$$g_{a|b}^{(2)}(0) = f_N(2 - \eta_b)p + O(p^2), \quad (3)$$

where $f_N = 1 + \frac{1}{N}$ is a factor depending on N , i.e. the number of modes characterizing the state of the heralded photon, and η_b is the overall detection efficiency of the triggering (heralding) photon b , which in our case can be expressed as $\eta_b = t_{810}\eta_{810}$. The factor f_N has a value of 2 in the single mode case ($N = 1$), while it is equal to 1 in the fully multimode configuration. Notice that f_N drops quickly to 1 for increasing N .

The $g_{a|b}^{(2)}(0)$ also depends, to a first approximation, on the detection and coupling efficiency of the heralding photon η_b . In particular, $g_{a|b}^{(2)}(0)$ increases for lower values of η_b . In [34] the authors take into account a non unit efficiency and non photon number resolving detector.

From Eq. (3), we see that $g_{a|b}^{(2)}(0)$ is proportional, to a first approximation, to the pair generation probability of the source p . Since p represents the main factor on which $g_{a|b}^{(2)}(0)$ depends, it is sufficient to measure p in order to have a good estimation of the autocorrelation function $g_{a|b}^{(2)}(0)$. The autocorrelation function $g_{a|b}^{(2)}(0)$ goes to zero for low values of p . However, for practical applications, a tradeoff between a low $g_{a|b}^{(2)}(0)$ and a high photon generation rate must be found. A pulsed laser with high repetition rate, such as the one used in our experiment, allows one to have high production rates even at relatively low p [32].

4. Experimental results

4.1. High heralding rate

We first show that with our source one can herald single telecom photons efficiently even at high heralding rates. High heralding rates are allowed by the high repetition rate (430 MHz) of our pump laser. Moreover, they can be achieved with high detection and fibre coupling efficiency of the heralding photon at 810 nm. Therefore, we optimize the fibre coupling of both photons by maximizing the coincidence rate.

We initially characterize the source at low pump power, in order to avoid the saturation of the detectors and to measure more accurately the overall transmission of the photons. At an average pump power of $45 \mu\text{W}$, we measure 49 kHz of counts of the Si-APD and 2.2 kHz of coincidences with the InGaAs detector triggered by the Si-APD. Using Eq. (1), we calculate a overall coupling, or heralding efficiency, of the telecom photon of 45%. We measure a 80% transmission through the optical elements on the telecom arm of the source. On the 810 nm arm, we measure instead a overall coupling of 39%. Notice that the lower coupling efficiency at 810 nm is partly due to the presence of additional filtering losses in the 810 nm arm, and to the fact that the collecting single mode fibre, unlike the 1550 nm one, is not anti-reflection coated. With the values mentioned above, we estimate to have generated a number of photon pairs per pulse of $p = 6 \cdot 10^{-4}$. This value is confirmed by the alternative measurement method described in 3.1. At this point, we increase the average pump power to 7.5 mW, corresponding to $p = 0.1$, and we measure 4.4 MHz rate on the Si-APD. At 0.1 photons per pulse the expected number of coupled 810 nm photons per second is 16.8×10^6 . At these high rates the deadtime of the detector (110 ± 10 ns) has a strong influence on its effective efficiency, reducing it from 50% to 29% [36]. We would therefore expect a 4.8 MHz heralding rate instead of the measured 4.4 MHz. This small discrepancy is not due to multi-photon terms which remain negligible even at these rates, but rather to the uncertainty in the measurement of the dead time of the detector.

By using the Eq. (3) in the multimode case, we calculate in this regime for the conditional autocorrelation function $g_{ab}^{(2)}(0)$ a value of 0.18. This confirms that with our source it is possible to herald single telecom photons even at high heralding rates.

4.2. High heralding efficiency

We now show that very high heralding efficiencies of the telecom photon can also be achieved with our source. Changing the position of the two lenses along the propagation axis of each photon it is possible to mode-match the fiber mode to the mode of the generated photons. Doing so we can choose whether to optimize for heralding efficiency of the 1550 nm photon or for pair coupling efficiency (maximizing the coincidence rate). This arises from the fact that it is possible to align the 810 nm collection optics to match the mode most correlated to the actually collected 1550 nm photons. This effect is predicted in [13]. We measure the heralding efficiency at rates which are high enough to reduce the effect of dark counts but low enough to avoid detector saturation. At an average pump power of $68 \mu\text{W}$, we measure 94 kHz of counts of the Si-APD and 7.5 kHz of coincidences with the InGaAs detector triggered by the Si-APD. Using Eq. (1), we calculate a 80% heralding efficiency of the telecom photon. The photon at 810 nm has an overall transmission of 5%. With the values mentioned above, we calculate $p = 0.009$.

Using Eq. (3), we find a value for the autocorrelation function $g_{ab}^{(2)}(0)$ of 0.018. In this regime, corresponding to low values of p and 100 kHz heralding rate, the heralded state corresponds of a single telecom photon of good quality, in the sense that it has a negligible multi-photon component.

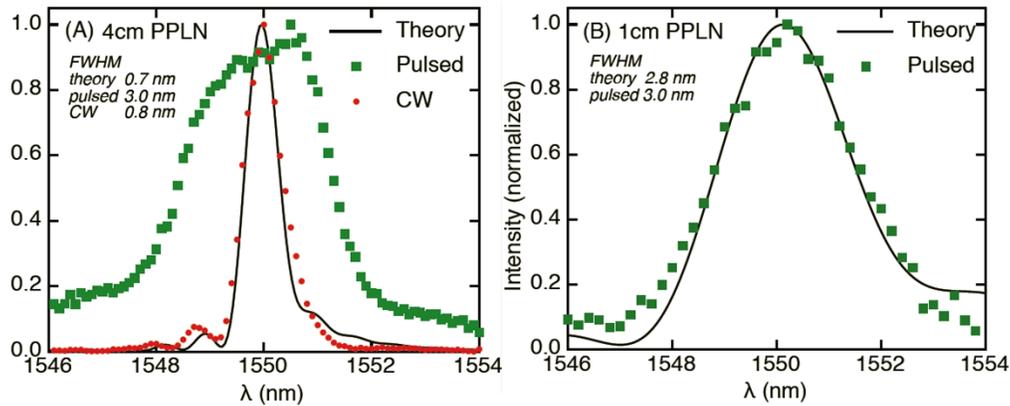


Fig. 2. a) Measured spectrum of the heralded photons in the pulsed and CW pumping configuration for a PPLN bulk crystal of 4 cm of length. The calculated spectrum is also reported. b) Measured spectrum for a PPLN bulk crystal of 1 cm of length in the pulsed regime compared with the theoretical curve.

4.3. Group velocity mismatch in longer crystals

In order to investigate the coupling efficiency with longer crystals, we test a 4 cm PPLN crystal. With an average pump power of $54 \mu\text{W}$, we measure 54 kHz of counts of the Si-APD and 2.6 kHz of coincidences with the InGaAs detector triggered by the Si-APD. The overall transmission of the telecom photon is 48%. We measure an overall transmission of the photon at 800 nm of 24.5%. With these values we calculate a number of photon pairs per pulse p of 0.001. The difference in coupling efficiency between the 1 cm and 4 cm crystal can be attributed in part to the difficulty of aligning the 4 cm crystal which has a $0.5 \text{ mm} \times 0.5 \text{ mm}$ clear aperture and in part, as we shall see below, to the fact that the group velocity mismatch between the pump and the photons is more critical in the longer crystal: the photons are not emitted coherently over the all length of the crystal, and therefore they are not in a single spatial mode.

To illustrate the effects of group velocity mismatch in the long crystal, we characterize it in CW pumping mode, where these effects are negligible. In this case we measure the overall transmission to be 60% for the telecom photon and 20% for the 810 nm one. The 4 cm source in a CW mode shows a better fibre coupling with respect to when it is pumped in a pulsed mode. We measure the spectrum of the telecom photons in the two pumping regimes (left part of Fig. 2). The spectrum calculated by our software is in good agreement with that of the CW case. In the pulsed configuration, the spectrum is broader and has a different shape. The model in [13] only considers a monochromatic pump, which is the case in the CW configuration, therefore it does not take into account dispersion effects for the pump pulses inside the crystal. The difference between the pulsed and CW regime is related to the group velocity mismatch between the signal and the idler fields with respect to the pump. The generated photons acquire, in the 4 cm crystal, a temporal delay with respect to the pump that is larger than the coherence time of the pump pulses. This causes a reduction of the effective crystal length in which the nonlinear interaction takes place. Moreover, the single mode photon emission is deteriorated, causing a drop in the coupling efficiency.

Let us give a simple, yet illustrative estimation of the effect of the group velocity mismatch in the pulsed pumping mode. The group velocity mismatch per unit length [s/m] is given by the

difference of temporal delays of the telecom photon and of the pump pulses

$$\tau = \frac{1}{v_g^{532}} - \frac{1}{v_g^{1550}} = \frac{n_g^{532}}{c} - \frac{n_g^{1550}}{c}, \quad (4)$$

where $v_g^{532(1550)}$ and $n_g^{532(1550)}$ are the group velocities and group indices of the fields at 532 and 1550 nm, and c is the speed of the light in the vacuum. By considering the PPLN dispersion properties [35], we found, with $n_g^{532} = 2.4746$ and $n_g^{1550} = 2.1762$ at 180 °C, a $\tau_{1550} = 9.994$ ps per cm. In a similar way, with $n_g^{810} = 2.2697$, we find a delay of $\tau_{810} = 6.830$ ps per cm for the photon at 810 nm, with a mean delay of 8.412 ps per cm. The group velocity mismatch reduces the effective interaction length between the pump and the down-converted components to a value at which the group delay is close to the coherence time of the pump pulses, which is around 8 ps. Therefore, the group velocity mismatch turns out to be less critical in a PPLN crystal of 1 cm pumped by our laser. Indeed, in the right part of Fig. 2, we report the spectrum of the telecom photons produced by the 1 cm crystal and with the pulsed pump. In this case, the spectrum is in better agreement with the one calculated without considering the group velocity mismatch.

Taking into account these effects seems very important for optimizing the fibre coupling in a pulsed regime for SPDC sources. For this reason an extension of the theoretical model in [13], taking into consideration the spectral and temporal properties of the pump should be formulated.

5. Comparison with other HSP sources

In Table 1 the most relevant synchronous and asynchronous HSP sources based on SPDC and FWM at telecom wavelength are compared. Different parameters are considered:

- the repetition rate of the pump laser (f_{pump});
- the average pump power (P_{pump});
- the number of photon pairs generated per pulse (p) in the case of synchronous sources, or, alternatively, the number of pairs generated per ns for the asynchronous sources;
- the spectral bandwidth of the heralded telecom photon ($\Delta\lambda^H$);
- the reported heralding rate (R^H and rate $R_{p=0.1}^H$ in the case of $p = 0.1$);
- the heralding efficiency (η^H);

The results in Table 1 suggest that HSP sources based on SPDC have better heralding efficiencies when working in an asynchronous way. All asynchronous sources listed in Table 1 are based on periodically poled crystals, except for the source in [17], made of a nonlinear waveguide. However, this source shows only a 37% coupling, confirming the fact that the waveguide technology still needs optimization in terms of internal losses and single mode operation.

Among the synchronous HSP sources at telecom wavelengths reported in the literature, only two, as far as we know, are based on SPDC [23, 24]. However, these sources show poor heralding efficiencies of 19% and 12% respectively. In the last few years, more efficient synchronous HSP sources have been obtained with fibre-based FWM, such as in [26]. However, the source described in this paper, producing single telecom photons at MHz heralding rates with 45% heralding efficiency, turns out to be the fastest and the most efficient among the synchronous HSP sources in the telecom regime.

Table 1. Comparison between HSP sources based on SPDC and FWM at telecom wavelengths. Synchronous (SYNCH) and asynchronous (ASYNCH) HSP sources are listed in the upper and lower block of the table respectively.

		Year	Process	f_{pump} [MHz]	P_{pump} [mW]	p	$\Delta\lambda^H$ [nm]	R^H [kHz]	$R_{p=0.1}^H$ [kHz]	η^H [%]
	This work	2012	SPDC	430	7.5	0.1	3	$4.4 \cdot 10^3$	$4.4 \cdot 10^3$ ^a	45 ± 5
S	This work	2012	SPDC	430	0.068	0.009	3	94	-	80 ± 8
Y	Söllner [28]	2010	FWM	1	0.1	0.08	35	16.5	26	28
N	Slater [27]	2010	FWM	100	20	NR ^b	5.8	54	-	25
C	McMillan [26]	2009	FWM	80	65	0.094	0.8	92	97	52
H	Bussièrès [24]	2008	SPDC	5	0.5	0.04	15	25	63	12
	Soujaeff [23]	2007	SPDC	82	240	0.083	18	216	260	19 ^c
A										
S	Tengner [19]	2007	SPDC	-	1.2	0.0013/ns	7	81	$6 \cdot 10^3$	48
Y	Castelletto [18]	2006	SPDC	-	100	NR	4	NR	-	48
N	Alibart [17]	2005	SPDC	-	0.01	NR	20	104	-	37
C	Fasel [16]	2004	SPDC	-	49	$\approx 0.013/\text{ns}$ ^d	6.9	845	$\approx 6.5 \cdot 10^3$	60
H										

^a This is a measured value, while the others reported in same column are calculated.

^b 'NR' stands for not reported.

^c In [33] a value of 29.6% is reported for the same source.

^d A SPDC conversion efficiency of 10^{-10} is considered in this case.

6. Conclusion

In this paper we have described a synchronous SPDC source of heralded single photons at telecom wavelengths with high heralding efficiency and MHz heralding rates. This source, which uses a 1 cm PPLN crystal pumped at 532 nm and generating photons at 810 nm and 1550 nm, achieves a 45% heralding efficiency with a 4.4 MHz heralding rate, and 80% heralding efficiency when we focus only on the coupling of the heralded photon. These are the best results reported so far for a source of heralded telecom photons based on SPDC and a pulsed pumping regime. Moreover, they show that even with a pulsed pump one can obtain high fibre couplings. The length of the nonlinear crystal has to be chosen in order to make a trade off between high coupling, limiting the issues related to the group velocity mismatch for a given pulsed pumping configuration, and high brightness. Our synchronous HSP source could be well suited to building up multi-photon quantum communication experiments in which low-losses and high count rates are demanded.

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