Gas-pressure tuning of wavelength of photon pair emitted by Four-Wave-Mixing in Nanofibers

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Abstract. We present experimental results demonstrating the possibility to tune the wavelength of the photon pair emitted through four wave mixing in a nanofiber, using the pressure of a gas surrounding the nanofiber. Using Argon, a shift of idler wavelength of -1.1nm/bar is measured demonstrating fine adjustment possibility of emission wavelength, allowing to choose between different WDM channels.

1 Introduction

Nanofibers are a very interesting system to realize generation of pairs of photons, either using third order nonlinearity using Four Wave Mixing [1, 2], or using new second order nonlinear mechanisms allowed by surface nonlinearities brought by the small dimension of the fiber [3]. The nanofiber is pulled with tapers that gives good injection and extraction of pump beam and emitted photons. Moreover, the small diameter permits to realize phase matching with large wavelength shifts for which the detrimental influence of Raman scattering can be minimized. Thanks to these properties bright source operating either in the pulsed or in the Continuous wave regime with Coincidence to Accidental Ratio (CAR) higher than 20000 could be realized [4].
To improve the flexibility of the realized source, several methods were proposed to allow the tuning of the emitted wavelength of the given pulled nanofiber, using either temperature of the fiber or a longitudinal stress [2]. In the present paper we choose to use, as a tuning method, the pressure of a gas that surrounds the nanofiber. This method was already successfully used in Photonic Crystal Fibers [5,6] but, in that case, the time necessary to fill the fiber might limit the dynamics of the tuning like in the case of the thermal tuning.

2 Nanofiber design and experiment

The nanofiber characteristics were choosen in order to realize phase matching for a Pump beam issued from a Ti:Sapphire laser operating in the near IR, an Idler beam emitting in the telecom band (typically between 1520nm and 1620nm) and thus a Signal beam in the Red (typically around 600-650nm). This means that the nanofiber has to be in the 850nm diameter range. The phase matching characteristics can be calculated using the model of a silica rod surrounded by Argon [4], which wavelength dependences of the refractive index are known from the literature [7, 8], as well as pressure dependence of Argon. Other gases with higher refractive index such as Xenon may be used to obtain higher emitted wavelength shifts.
The 2cm nanofiber and its tapers is fixed on a 3D printed support and sealed in a ½" inox tube connected through a Swagelok's quickfit connector to the gas bottle. The pigtail outputs are used to easily insert the fiber on the Four Wave Mixing set-up. The emitted spectrum is characterized using a Stimulated Emission Tomography set-up (see [4] for details of the set-up), using a tunable telecom laser diode as a seed beam injected in the nanofiber together with the pump beam. At the output of the nanofiber, Pump, Idler and Signal beams are separated using dichroic mirrors and filters. Stimulated emission in the visible due to interaction at energy conservation, of Pump and Seed beams is detected using a Si-APD single photon detector, which signal is recorded as a function of the Idler seed beam wavelength. The measurement of the emitted spectrum as a function of Argon pressure shows a clear shift of the photon pairs emission (Fig.1).

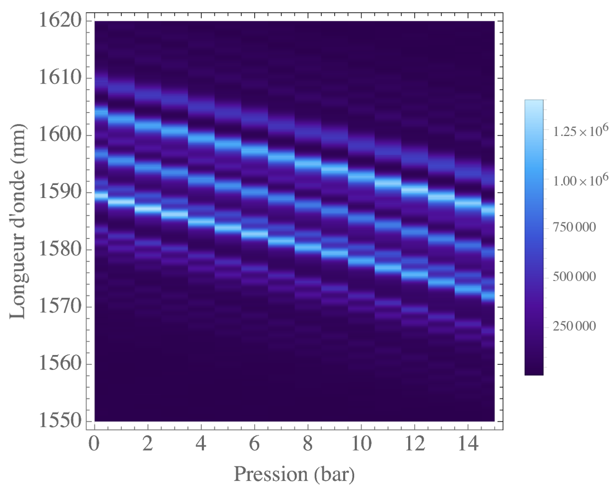

Fig. 1. Plot of the nanofiber emission spectra as a function of Argon pressure for a pump beam at 885.4nm.

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The emitted spectrum of that specific nanofiber presents multiple peaks due to non-uniformity of the fiber diameter (Fig.2). The three-main-peaks structure is compatible with a sinusoidal fluctuation of nanofiber diameter [4] with an amplitude 3.6nm around a mean value of 854.24nm and a period 4.1mm along the fiber of total length 20mm (See insert in Fig.2).

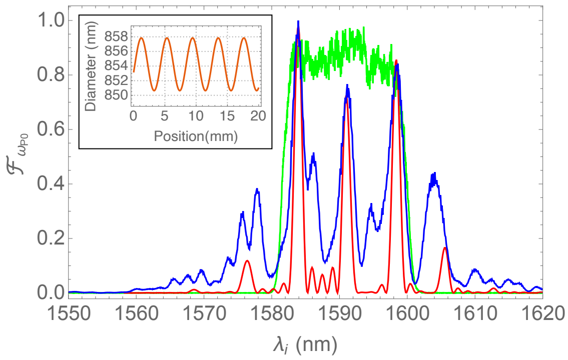

Fig. 2. Plot of the emitted spectrum at energy conservation at a pressure of 5 Bar (Blue curve), with the theoretical calculation (Red curve) for a nanofiber presenting a sinusoidal fluctuation of its diameter (shown in the insert). The pressure has been chosen so that all the main peaks, and thus most of the emitted idler photons, are inside the transmission band of the 1590nm channel of our Coarse WDM filter (Green curve).

The measured peak shift for two nanofibers with slightly different characteristics is similar within the current uncertainty of pressure measurement. When compared to the theoretical calculation (Fig.3), the accordance is very good despite the absence of free parameters. This indicates that the values of the used parameters, especially the refractive index of Argon, are correct.

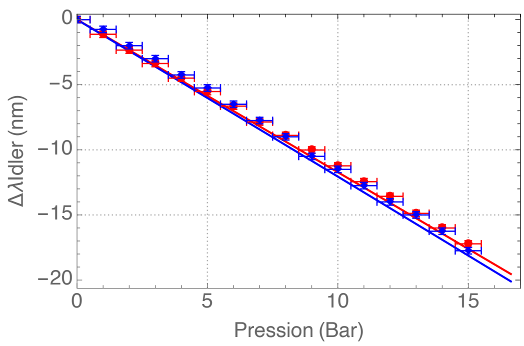

Fig. 3. Plot of peak shift as function of pressure for two nanofibers and the corresponding theoretical calculation with known parameters of the experiments. Red Symbols and line, nanofiber diameter 853nm, pump à 887nm. Blue Symbols and line, nanofiber diameter 867nm, pump at 916.5nm.

Playing with pump wavelength and pressure we can position the emitted spectrum either in the 1590nm or the 1570nm channel of the CWDM filter what allows to collect most of the emitted photons (Fig.2) and to limit the noise related to the broadband Spontaneous Raman Scattering of silica. We can thus reach very high Coincidence to accidental ratio around 70000 (Fig.4), which is the highest value measured in a fibered structure.

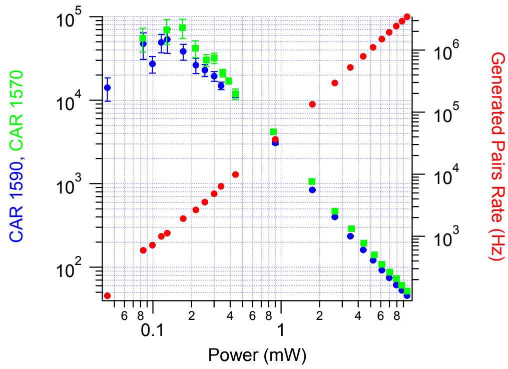

Fig. 4. Measured Coincidence to accidental ratio (Blue Symbols for pump at 887nm and pressure 4.75 Bar to work with the 1590nm output of the CWDM filter, and Green Symbols for pump at 895nm and pressure 9.25 Bar to work with the 1570nm output) and rate of pairs generated at fibre output (Red Symbols) as a function of the mean pump power.

3 Conclusion

We have shown that it is possible to finely tune the emission spectrum of a source of pairs of photons based on Four Wave Mixing in a nanofiber surrounded by a gas. Despite being preliminary, these results show potential of this technique. Using pressure tuning with an optimized fiber, both more uniform in order to have an emission peak closer to the ideal Sinc shape, and longer to have a smaller width of emission peak, we should be able to position the emission peaks in different output of a Dense WDM filter, and dynamically send the emitted idler photon in a specific WDM channel, together with addressing a specific wavelength on the signal side using pump wavelength tuning.

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