Tunable and chirp free femtosecond signal pulses generated by a PPLN OPO pumped by Ytterbium fiber laser chirped pulses

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ABSTRACT

Chirp of the pulses generated in the 1.4 µm-1.8 µm spectral ranges and in a singly resonant OPO build around a 3 mm long PPLN crystal pumped at 108 MHz by 40 nJ, 1 ps chirped or 350 fs weakly chirped pump pulses centered at 1035 nm is analyzed. Whatever the chirp of the pump pulses, we achieved a pump to signal conversion efficiency > 30%. We demonstrate that by adjusting the cavity length around synchronism condition, chirped or almost chirped free (down to 80 fs) signal pulses are generated. A simple mechanism accounts for this phenomenon.

Keywords: Optical parametric oscillators, Parametric amplification, Parametric generation, Three-waves mixing, Femtoseconde pulse, Chirped pulse, Ytterbium fiber laser, PPLN crystal.

1. INTRODUCTION

Many different optical parametric amplifiers and oscillators (OPO) taking advantage of Periodically poled (PP) ferroelectric crystals such as $LiNbO_3$, KTP, KTA have been proposed [1,2]. These crystals exhibit high effective nonlinear coefficient which under quasi phase-matching conditions (QPM) make it possible to record efficient second order nonlinear processes such as as second harmonic generation (SHG), sum-frequency generation (SFG) or difference frequency generation (DFG) in the visible and IR range. These crystals are a good mean to develop mid-infrared tunable sources. When pumped with chirped femtosecond pulses, it has been shown that chirped PP gratings impinged in the crystal can compensate for the chirp of the pump pulse [3]. This makes it possible to generated Fourier transform-limited femtosecond pulses. Hereafter, we show that when chirped pump pulses are used, one can also generate a signal pulse Fourier transform-limited without using chirped PP crystal taking advantage of velocity group delay and velocity group dispersion between the pump and signal in the PP crystal [4]. Accordingly, we show that a slight detuning of the resonator-length makes it possible to generate almost chirped free signal pulse at the expense of a reasonable decrease of the conversion efficiency. The phenomenon is investigated for weakly and largely chirped pump pulses.

2. EXPERIMENTAL SET-UP AND RESULTS

2.1 Set-up

A sketch of our singly resonant OPO is depicted in Fig. 1. Our linear OPO cavity is build with two plane and two concave mirrors with 10 mm radius of curvature. The mirrors $CM_{1,2}$ and M_2 transmit more than 99 % of the pump wavelength and reflect more than 99 % of light at wavelengths in between 1.4 µm and 1.8 µm. In this spectral range, mirror M_1 is reflecting 90 %. All the mirrors have very low dispersion in the 1.4 µm and 1.8 µm spectral range. The pump pulse is focused with a 20 cm focal lens through the mirror CM_2 in a 3 mm thick MgO:PP-$LiNbO_3$ (PPLN) crystal (MOPO1-1.0-3, from Covesion) in which five gratings with periods ranging from 29.52 to 31.59 µm are impinged. This crystal is inserted in a thermally regulated oven whose temperature can be tuned between 30 °C and 200 °C. It is also antireflection coated for both the pump and signal wave (R < 1.5 % at 1030 nm and R < 1 % in the 1.4 µm-1.8 µm range). We adjusted the cavity length of the OPO, by translating with a remote piezo-mechanic translation stage the mirror M_2. To finely adjust their distance, the two concave mirrors are mounted on micrometric mechanic stages. The length of our singly resonant OPO's length is firstly adjusted at the repetition rate at 108 MHz. We also performed similar experiments at twice the repetition rate of the pump laser that will be not presented hereafter. The small leak through mirror M_2 is used to measure the spectra of the signal and idler wave produced by our OPO. The latter is sent in an optical spectrum analyzer (OSA205 Thorlabs) which records spectra in between 1 µm and 5.6 µm. The autocorrelation trace of the signal and pump pulses are measured with a homemade autocorrelator using a 300 µm thick BBO crystal.

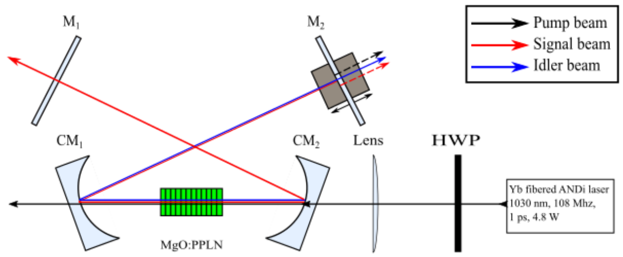

Figure 1: Experimental setup of the OPO. HWP = Half-wave plate; M_{1-2} = mirrors; CM_{1-2} = concave mirrors. Doted arrows: signal leak and residual pump beam.

Our OPO is pumped by an all-normal-dispersion ytterbium fibered oscillator [4]. The linearly polarized and chirped pump pulse centered at λ_p=1035 nm has a duration at a spectral bandwidth of ~1.06 ps (Fig. 2a) and ~8 nm (Fig. 2b), respectively. The time bandwidth product of these pulses is ~2.2. At 108 MHz repetition rate, the averaged power delivered by this laser is ~6 W. To evaluate the impact of the pump pulse on the chirp of the signal pulses delivered by our OPO we have recompressed them using two chirped mirrors with a group delay dispersion of 10000 fs^2 at 1035 nm. The autocorrelation trace of the signal pulse after 10 reflections by these mirrors is presented in Fig. 1c. This indicates that the pump pulse, compressed down to ~380 fs, has the time bandwidth product of ~0.8 by and presents a residual chirp.

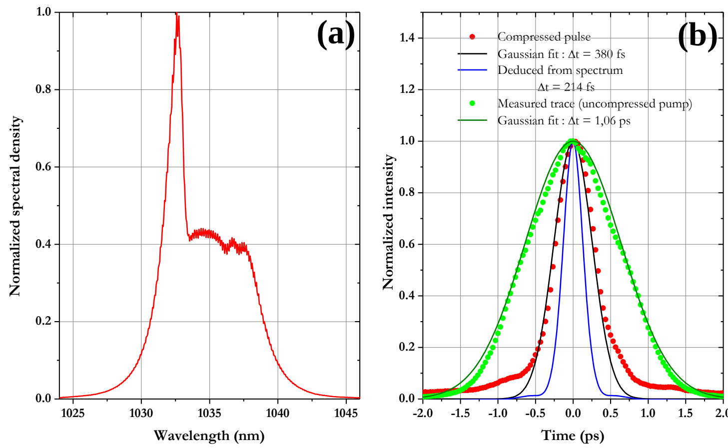

Figure 2: (a) Spectrum of the pump pulse. (b) Autocorrelation trace of the uncompressed and compressed pump pulse.

2.2 Results

Figure 3a displays the evolution of the signal power versus pump power for different gratings when the cavity length is synchronized with the repetition rate of the pump pulse. The pump threshold is P_{th}~300 mW whatever the used grating period. The slope is ~30 % and almost independent of used grating period and temperature of the crystal. The pump to signal + idler conversion efficiency C is ~44 %. It is defined as follow $(P_s+P_i)/(P_p-P_{th})$ where P_x refers to the power of the signal (s), idler (i); pump (p). At maximum, the depletion of the pump within our OPO is 52 %. The evolution of the signal wavelength was found to be in good agreement with the Sellmeier equations of the used for our PPLN crystal [5]. In this synchronized regime, we found the duration at the half width of signal pulse (Δt ~1.03±0.2 ps) was about the duration at half width of the pump pulse ((Δt~1.06±0.2 ps) whatever the grating or the temperature of the crystal. Typical spectra and pulse duration recorded using the 30.49 µm grating at 30 °C is presented in Fig. 3b-c. According to its spectrum, we found the duration at half width of a gaussian signal pulse should be at most 0.2 ps, showing that the time-bandwidth product of the generated signal pulse is ~2.2 almost similar to the time bandwidth product of the pump pulse.

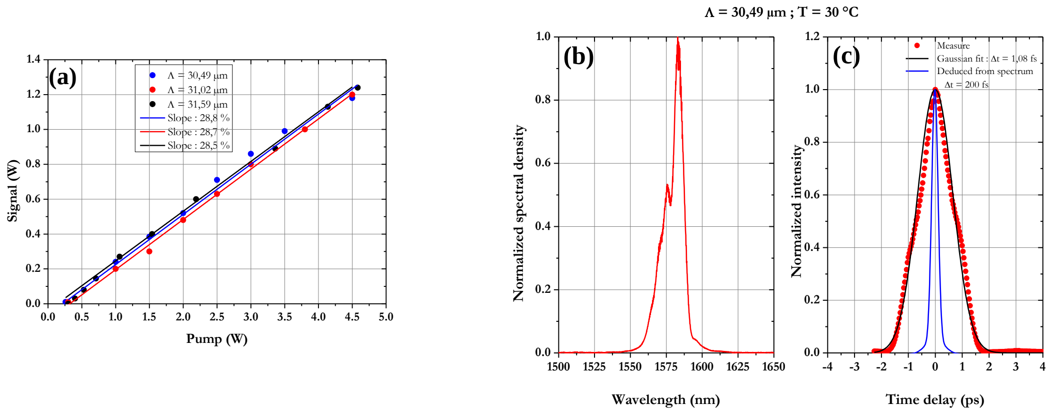

Figure 3: (a) Conversion efficiency of the OPO. (b-c) spectrum and autocorrelation trace of the signal pulse.

To reduce the pulse duration of this signal pulse, we slightly detuned the cavity length of our OPO. Besides the change of the pulse duration, the change of the cavity length results in both a decrease of the signal intensity and a shift of the central wavelength of the signal pulse. The typical evolution of this ensemble of parameters is recorded at 30 °C when using the 30.49 µm grating presented in Fig. 4. One can notice that the shorter pulse duration is achieved when the cavity length is increased by about 6 µm.

(a) (b) (c)

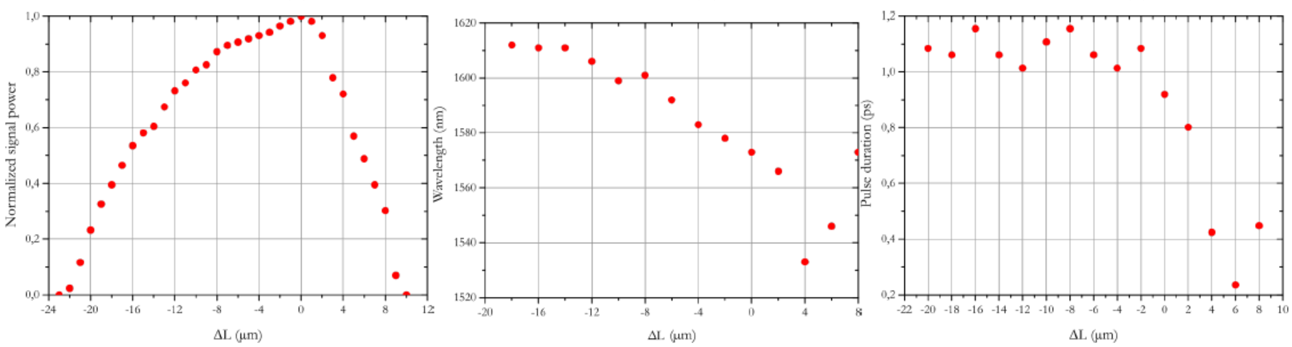

Figure 4: Impact of the cavity detuning on the signal average power (a) the central wavelength (b) and pulse duration (c).

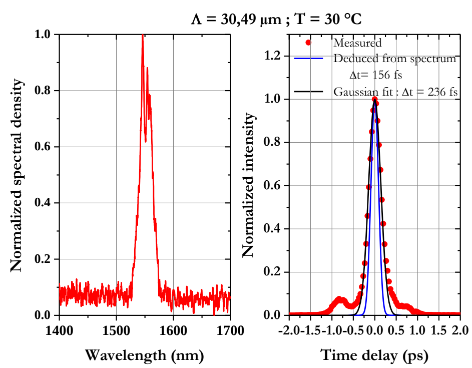

Figure 5: Spectrum and autocorrelation trace of the signal pulse.

Under this condition the output power is reduced by a factor of two, but as indicated by the autocorrelation trace, the pulse duration at half width is reduced to Δt~236 fs (Fig. 5). This clearly indicates that the peak power of this latter signal pulse is larger. It is also interesting to mention that according to its spectrum the pulse duration at half width is at most Δt~156 fs indicating that under this condition the time bandwidth product of the signal pulse is reduced from ~2.2 to ~0.65, hence below the time bandwidth product of the pump pulse.

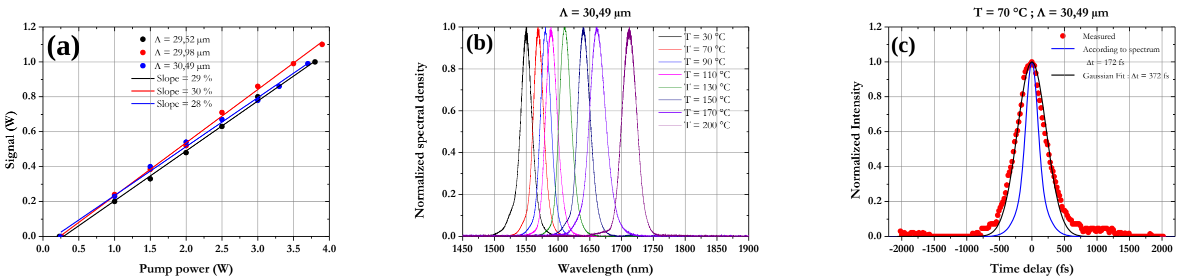

Figure 6: (a) Conversion efficiency, (b) evolution of the signal spectrum versus temperature, (c) typical autocorrelation trace of the signal pulse.

The evolution of the intensity of the signal pulse delivered by the OPO when it is pumped by compressed femtosecond pump pulse is presented in Fig. 6a. It is very similar to the results presented in figure 3a. However, a linear regression of the signal intensity versus the pump intensity indicates the threshold is reduced to ~150 mW in good agreement with the increase of the peak power of the pump pulse. The spectrum of signal pulse was found to broaden. The typical evolution of the spectrum as one increase the temperature of the crystal is displayed in Fig. 6b. The autocorrelation trace of the signal pulse recorded when the used 30.4 µm grating is heated at 70 °C is displayed in Fig. 6c. As expected for shorter pump pulse the signal pulse duration is also shorter and here again about the pulse duration of the pump pulse. However, the time bandwidth product of this signal is ~0.93 slightly above the time bandwidth product of the compressed pump pulse (~0.8). This phenomenon is likely due to cross- and self-phase modulation in the PPLN crystal.

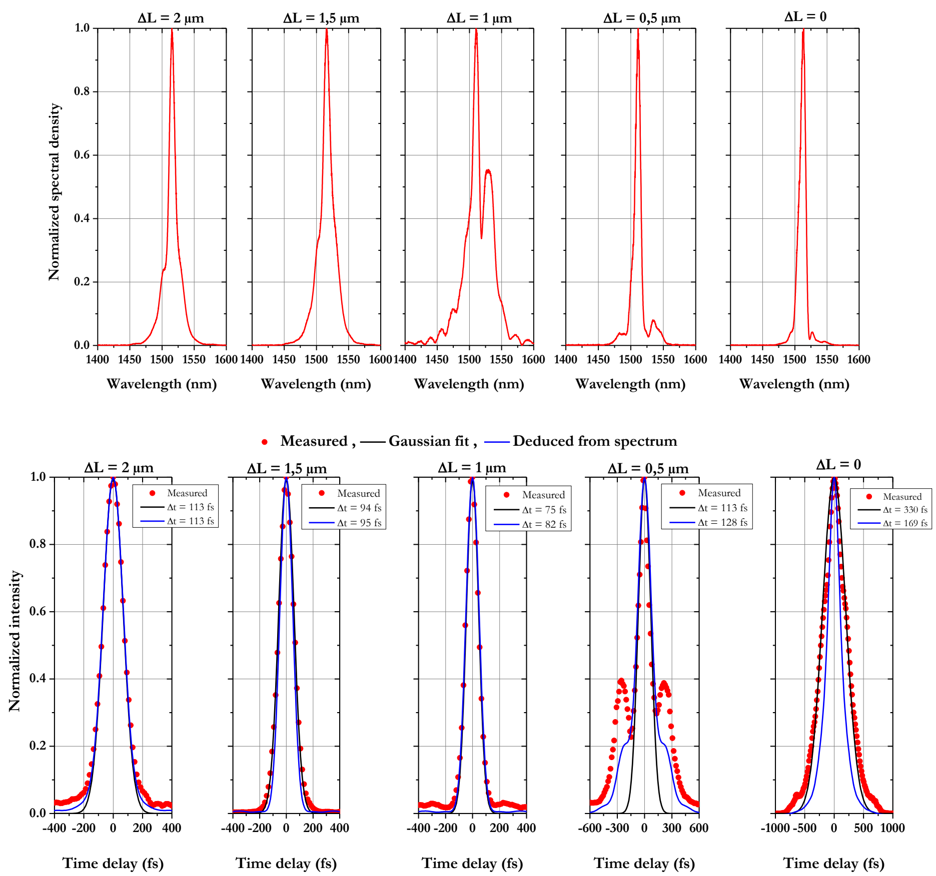

Figure 7: Spectrum and autocorrelation trace of the signal pulse versus the cavity length detuning.

We then measured the impact of the cavity length detuning on the signal pulse duration. Under this condition, the signal pulse duration and its intensity was found to change more drastically versus the cavity length. The intensity of the signal was found to decrease linearly when increasing the cavity length (0.2 W. μm^{-1}). As we increased the cavity length, we also recorded a drastic change of the pulse duration. The spectrum and the pulse duration recorded as the cavity length increases ($0<\Delta L<2$ µm) is displayed in Fig 7. The pulse duration is reduced down to ~80 fs at 1 µm and then increases again. It is important to stress that in between 1 µm and 2 µm, the pulses duration of the signal is almost limited by its spectrum and the time-bandwidth product is ~0.4. It is also important to indicate that while the pulse duration is reduced by a factor of ~4.7, the intensity of the signal wave is only reduced by 20 %. This clearly stress that the peak power of the generated pulse are increase by a factor of ~4. It is also worth mentioning that this behavior was recorded for all the grating whatever the temperature of the crystal.

2.3 Discussion

The impact of the cavity length detuning ΔL on a synchronously pumped OPO has been reported by many authors [6–14]. The phenomenon has been accounted by the model proposed by Khaydarov et al. [7] and experimentally reported by different authors [6,15]. In agreement with our experiment, this phenomenon occurs for $\Delta L > 0$ when group velocity of the signal pulse is larger than the group velocity of the pump pulse. One of the interesting points revealed by our experiment, not yet implemented in the available numerical simulations, is the impact of the pump chirp on the pulse compression of the signal pulse. Our experimental results clearly stresses that by slightly increasing the cavity length, indeed one can generate chirp signal pulse out of an OPO using chirp pump pulse. The compression mechanism results in a slight decrease of the conversion efficient of our OPO which is largely compensated by the increase of the peak power of the generated signal pulse. Yet, an interesting aspect will be to evaluate the chirp of the idler wave which according to the phase matching condition should carry out the chirp of pump pulse. This experimental work as well as the associated numerical simulations will be presented in a forthcoming publication.

3. CONCLUSIONS

We have developed a PPLN based OPO pumped at 108 MHz, 40 nJ, 1 ps chirped or 350 fs weakly chirped pump pulses centered at 1035 nm. Under optimal synchronous pumping condition signal pulse tunable from 1.4 to 1.8 µm were generated with a pump to signal conversion efficiency of ~30%. The duration of the signal pulse is then almost similar to the pump pulse. However, when the cavity is slightly detuned, shorter signal pulse are generated. Under this condition, the energy of the signal pulse is decreased by ~20 % while the peak power is increased by almost of factor 4. We also found that the time-bandwidth product of these pulses is ~0.4 indicating that the generated signal pulses are almost chirp free.

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