Fourier transformed picosecond synchronously pumped optical parametric oscillator without spectral filtering element

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An optical parametric oscillator for the infrared region pumped by a picosecond Ti:Sapphire laser is demonstrated. Fourier transform limited pulses of 15 and 10 ps, for signal and idler wavelengths respectively, have been obtained using a periodically poled stoechiometric lithium tantalate nonlinear crystal, without any spectral filtering. A complete experimental study of the influence of the cavity length detuning on the spectral and temporal dynamic of the output radiation is discussed. [DOI: 10.2971/jeos.2008.08037]

Keywords: optical parametric oscillator, PPSLT crystal

1 INTRODUCTION

Synchronously pumped optical parametric oscillators (OPO) are widely used as sources of ultrashort tunable pulses. The short pulse duration on the one hand and narrow bandwidth on the other hand makes picosecond OPO systems promising sources for a variety of applications. Moreover, the flexibility of wavelength tuning in the infrared region makes OPOs useful for gas detection [1, 2], material characterization [3], high-resolution spectroscopy [4] or laser ablation [5].

Operation of tunable infrared OPO systems has previously been achieved using $KTiOAsO_4$ [6], $KTiOPO_4$ [7, 8], BiB_3O_6 [9], LiB_3O_5 [10, 11], $KTiOAsO_4$ [12] crystals. However, the spatial walk-off and reduced gain associated with the non-collinear interaction, limits the efficiency of the parametric process. These restrictions can be cancelled by using periodically poled structures.

Nowadays, OPOs are mainly based on periodically poled crystals such as PPLN [13]–[16], PPKTP [15, 17], PP-$RbTiOAsO_4$ [18] etc. The reasons for this are flexibility in reaching desirable wavelengths in the transparency region of the crystal by choosing the appropriate period and long interaction lengths because there is no spatial walk-off. Quasi-phase-matching in periodically poled crystals allows to work with higher nonlinear coefficients in the crystals. It should be also noted that, working with collinear non-critical phase-matching at arbitrary wavelengths is convenient.

In this paper we demonstrate a tunable synchronously pumped OPO system delivering picosecond Fourier-transform limited pulses in the near infrared region without any spectral filtering element. A PPSLT crystal was chosen because of high resistance to photorefractive damage [19] and because it has already been successfully used for OPOs operating in the CW [20], nanosecond [21] and femtosecond [22] temporal regimes.

This OPO has been developed in order to achieve nonlinear spectroscopic characterizations of photonic crystals [23]. Short pulses give high peak powers, which are required to easily generate the nonlinearities under study. In addition to that, they also give access to time resolution in a pump probe configuration. The resonant behaviour of photonic crystals [24] also imposes the use of short pulses with sufficiently narrow spectral widths in order to efficiently couple light into the resonant structures. The source we developed offers a good compromise, because it produces Fourier transformed pulses around 10 ps that are tunable in the whole telecommunication window (1300-1600 nm) with high average powers. Therefore, it can be used in measurement setups including optical spectrum analyzers or autocorrelators for instance.

2 EXPERIMENTAL SETUP

A stable, bow tie, singly resonant OPO cavity has been designed to minimize the round-trip loss [25]. The OPO was pumped by a mode-locked Ti:Sapphire laser delivering 10 ps

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pulses at 725 nm with a spectral width of $\Delta\lambda = 0.06$ nm and a repetition rate of 80 MHz. The maximum output power was 1.7 W. The pump power was controlled by a half-wave plate – polarizer pair. The ring-cavity used, consists of a pair of concave mirrors CM1 and CM2 that are 25.9 cm in radius and a plane mirror PM (Figure 1). These elements have been chosen so as to be highly reflective in the 1300-1600 nm region. Due to the relatively long pulse duration of the pulse considered in this study the dispersion of mirrors and couplers can be considered negligible. The cavity is singly resonant at the signal wavelength when using the output couplers OC with a 80% and 90% reflectance coefficient in the 1550-1640 nm range. The output couplers are antireflective for the idler wavelength.

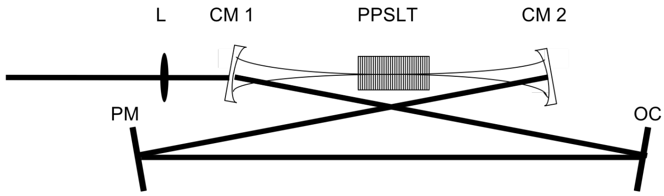

FIG. 1 Experimental setup. L- 15 cm focal length lens, CM1 and CM2 – concave mirrors, PM – plane mirror, OC- output coupler, PPSLT - periodically poled stoechiometric lithium tantalate crystal.

The active medium for the OPO is a 20 mm antireflection coated (from 1300 nm to 1650 nm) PPSLT crystal from HC photonics. In order to achieve a signal radiation around 1550 nm, the crystal period was set to 18 μm and the temperature of the crystal was maintained around 127°C. Characterization of the OPO has been performed using a power meter, an optical spectrum analyser with a resolution of 70 pm and an autocorrelator with a temporal scanning of up to 50 ps.

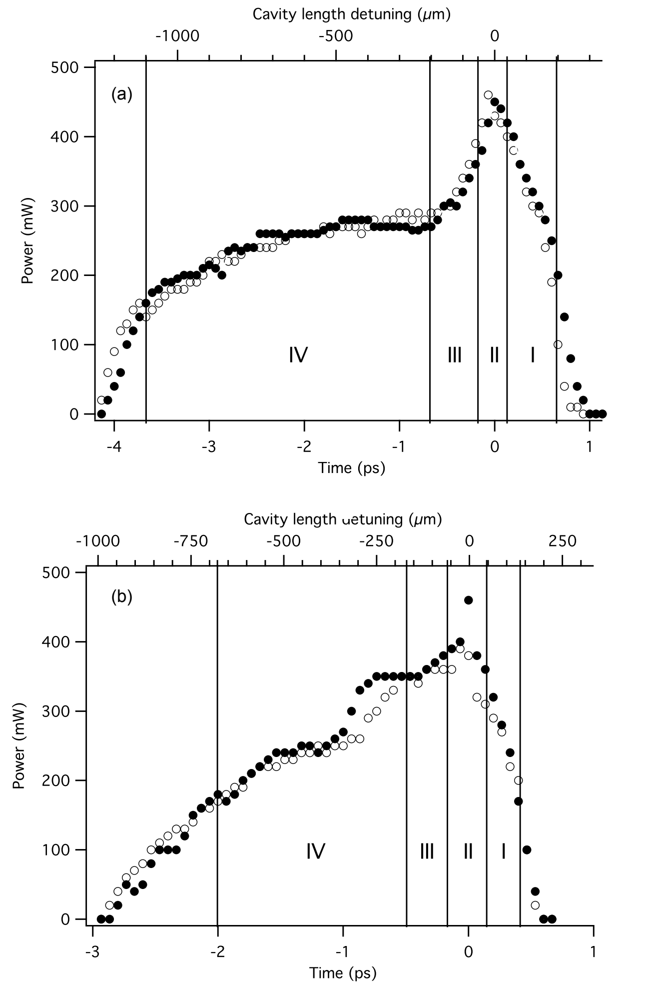

FIG. 2 Dependence of the OPO output power with the cavity length detuning for signal (filled circles) and idler waves (open circles). (a) 80% output coupler and (b) 90% output couplers.

3 TEMPORAL AND SPECTRAL CHARACTERIZATION OF THE OPO

The cavity was first optimized to obtain the maximum output power. The oscillation thresholds were found to be 400 mW and 700 mW for the 90% and 80% output couplers respectively. With a maximum pump power of 1.7 W, we obtained up to 500 mW of signal and idler radiation for both output couplers. In that regime the spectrum for both signal and idler was considerably broadened with a full bandwidth of 10-15 nm at 1550 nm in comparison with the spectral linewidth of the Fourier transformed pump radiation.

As previously shown with different types of synchronously pumped OPOs, one of the most important parameters that influences the output characteristics, is the difference in length between the OPO cavity and the pump laser cavity [10, 26]. We measured the dependency of the output power as a function of the cavity length detuning for the 80% (Figure 2(a)) and 90% (Figure 2(b)) output couplers, with the same input pump power of 1.7 W. First of all one can see that the behaviour for both signal and idler are the same for both output couplers. Secondly, the curves are asymmetric with respect to the zero detuning, corresponding to the maximum output power. Although such an asymmetric power dependence has been previously observed [26], the detailed experimental analysis of the temporal and spectral behaviour related to this power dependence has not been reported yet. It is worth noting that simultaneous autocorrelation and spectral measurements of the signal pulse show that both the spectral and temporal behaviour change dramatically when varying the cavity length detuning. We were able to identify four main regions, for which the typical autocorrelation traces and corresponding emitted spectra are shown in Figure 3. The four regions shown in Figure 3 are as follows: Region I – short pulse generation and spectrum broadening (Figure 3(a) and (b)); Region II – competition between short and long pulse generation (Figure 3(c) and (d)); Region III – pulse breakdown from single pulse to multiple pulses [27] (Figure 3(e) and (f)) due to generation of several closely laying spectral components and their interference; and Region IV, which is more interesting for application due to generation of stable Fourier transformed tunable pulses (Figure 3(g) and (h)) with durations comparable to the pump pulse duration. The same behaviour has been obtained for both the 80% and 90% output couplers with slightly different extensions for the different regions. It should be also noted that this operating regime was obtained without using any additional intracavity elements such as birefrigent filters

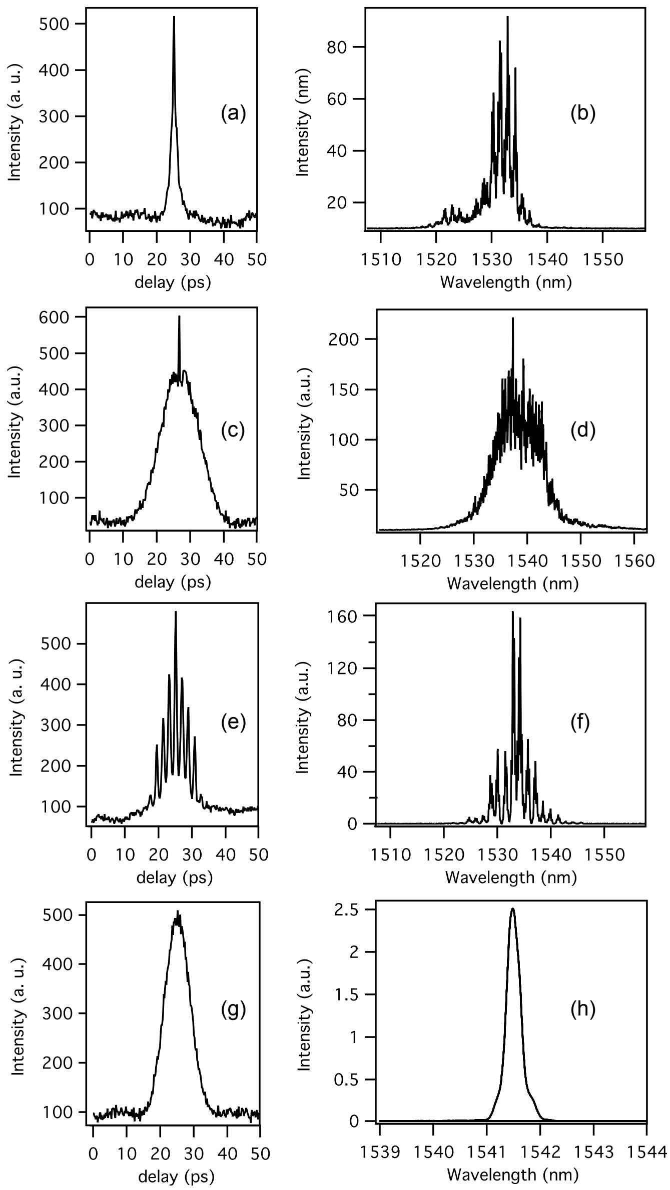

FIG. 3 Correspondence between pulse duration and line width measurements in the different operating regimes for the 80% output coupler.

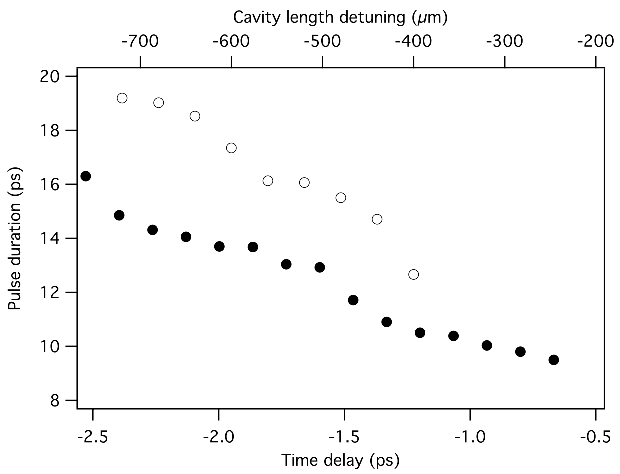

FIG. 4 Dependence of the pulse duration of the signal wave on the cavity length detuning for the 80% (filled circles) and 90% (open circles) output couplers.

[28], etalons [13, 29] or volume Bragg gratings, which were recently used for wavelength narrowing and fine tuning [15].

By analyzing region IV, we observed continuous variation of the pulse duration as shown in Figure 4. The pulse duration increases by almost a factor of two, from 9 to 17 ps for the 80% output coupler and from 12 to 20 ps for the 90% output coupler, when the cavity length is shortened in Region IV. The duration-linewidth product was measured to be 0.4 ± 0.02 (Figure 3(g) and (h)), thus being close to the Fourier transform limit of 0.441 for Gaussian-shape profiles [30]. We can also note that the higher the transmission of the output coupler, the shorter the pulse duration.

4 DISCUSSION ON THE TEMPORAL BEHAVIOUR OF THE OPO

The asymmetric dependency of the output power with the cavity length was previously described by theoretical simulations [31, 32] and was observed experimentally [26]. The new aspect described in the present work concerns the observation of Fourier transformed pulses with a pulse duration of 10-20 ps without the use of any wavelength selective element and the detailed analysis of the influence of the cavity length on both the temporal and spectral behaviour of the output radiation.

The OPO cavity length introduces asynchronism between the signal and pump pulses travelling within the cavity. If the length of the cavity is short (i.e. negative cavity length detuning) the signal pulse arrives before the pump pulse. This advance increases when propagating inside the crystal due to the higher group velocity of the signal pulse ($v_g = c/2.161$) compared with the pump pulse ($v_g = c/2.255$). The difference in propagation time through the crystal between signal and pump pulses is 6 ps. In the opposite case, a long OPO cavity (i.e. positive cavity length detuning), delays the signal pulse with respect to the pump pulse, at the entrance of the crystal. However, due to its higher group velocity the signal pulse travels faster than the pump pulse inside the crystal. During propagation in the PPSLT crystal, the signal beam goes past the pump pulse and even overruns it.

In this last regime, short pulses with durations between 1 and 2 ps (Figure 3(a)) are generated through a compression effect [27]. Note, that the pump power is 2 and 4 times larger than the threshold power of the OPO, when it operates with the 80% and 90% output couplers, thus leading to pump depletion. During the build-up of the parametric oscillation process, the leading edge of the signal pulse is amplified by interacting with the trailing edge of the pump pulse, thus leading to depletion of the latter edge. The trailing edge of the signal pulse is not efficiently amplified due to pump depletion and this results in a shorter pulse. While the pulse propagates in the PPSLT crystal, the signal wave uses up the pump power and gradually depletes it from its tail leaving no pump power for amplification of the signal tail. Consequently, the signal pulse compression is increased. This process allows a compression of the signal pulse by a factor of 5 to 10 in comparison with the pump duration.

On the other hand, decreasing the OPO cavity length induces a delay between signal and pump pulses that increases during propagation in the PPSLT crystal. This results in two effects. First, the number of wavelengths, which are synchronous with the pump pulse, decreases. Furthermore, below a certain cavity length the only one signal wavelength with a group velocity corresponding to the condition of the best temporal overlaping with the pump is generated [26]. Second, the trailing part of the signal pulse coincides with the maximum of the pump pulse and is thus better amplified, leading to a temporal broadening of the signal pulse and giving birth to the Fourier transformed pulses in the 10-15 ps range, observed in Region IV. The pulse duration increases as the OPO cavity length decreases and the delay between signal and pump increases as shown in Figure 4.

5 TUNABILITY OF THE OPO

As has already been pointed out, the signal and idler waves can be continuously tuned by changing the temperature of the PPSLT nonlinear crystal. We observed that the same OPO behaviour and especially the operation in the Region IV can be obtained in the whole tuning range of the OPO, i.e. with a signal emitting within the region of 1530-1640 nm (limited only by a output coupler transmission range) and idler wavelength in the corresponding region of 1300-1375 nm. In order to tune the OPO wavelengths from 1530-1640 nm, we acted on the 123-150°C range for the temperature of the crystal. A minimum tuning step of 0.5 nm (Figure 5) was obtained by changing the crystal temperature by 0.1°C, which corresponds to the minimum achievable temperature step of our temperature controller. On the whole wavelength tuning range, Fourier transformed pulses were observed with typical duration in the 10-15 ps (Figure 6) and typical spectral width in the 0.2 nm range (Figure 5). One can see that a constant pulse duration is measured over a wide wavelength range (1550-1640 nm), where the output coupler reflectivity is constant. At the edge of this range (1520-1550 nm) a decrease in pulse duration is observed in accordance with previous measurements that showed a decrease in pulse duration with increasing of the output coupler transmission (Figure 4). The same dependencies have been observed for idler radiation with slightly shorter pulses. For the 80% output coupler, the idler pulse duration was measured and belonged to the 6.5-7.5 ps range, whereas for the 90% output coupler it was measured to be in the 8-10 ps range.

6 CONCLUSION

A picosecond optical parametric oscillator is demonstrated without any spectral filtering element. Based on a stoechiometric PPSLT nonlinear crystal, it provides tunable transform limited picosecond pulses in the 1550-1640 nm region for signal, and 1300-1375 nm for idler radiations respectively. The influence of the cavity length detuning on the spectral and temporal dynamic of the output radiation was analyzed in detail. The possibility of continuous tuning of the pulse duration in the 9-17 ps region for the 80% output coupler, and the 12-20 ps region for the 90% output coupler is demonstrated by reduction of the OPO cavity length. Moreover the possibility of signal pulse compression by a factor of 5 to 10 is shown

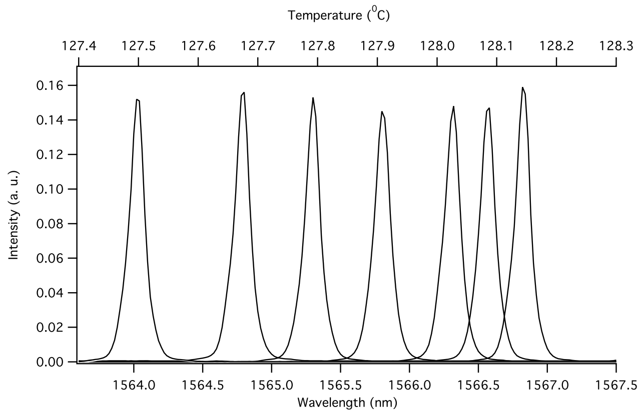

FIG. 5 Dependence of the wavelength of the generated radiation with the temperature of the PPSLT crystal.

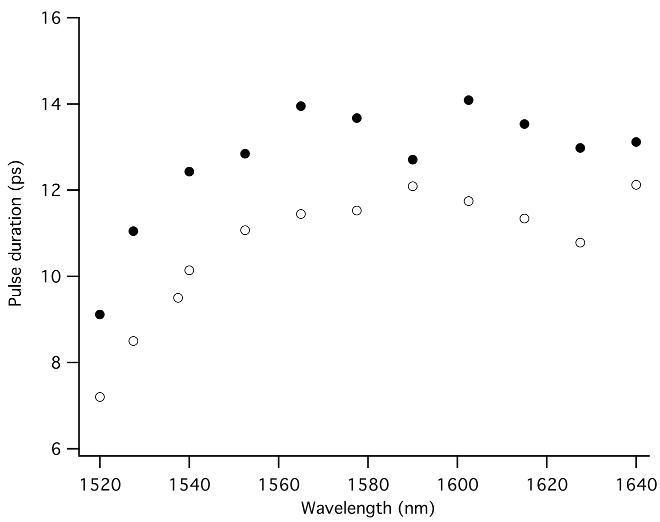

FIG. 6 Correspondence between the wavelength of the signal wave and its pulse duration for the 80% (filled circles) and 90% (open circles) output couplers when the temperature of PPSLT crystal is tuned from 123°C to 150°C in region IV.

when the cavity length is increased. The possibility of changing the wavelength of the output radiation with a precision of 0.5 nm has been demonstrated by changing the temperature of the crystal by 0.1 °C. This has been achieved with a pulse duration that is constant over the whole wavelength operating range of the OPO. The demonstrated performance of the OPO makes it the ideal source to perform nonlinear characterizations of slow modes in photonic crystal waveguides [23].

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