Optimized tunable optical parametric sources using cylindrical nonlinear crystals

J.P. Fève [(a)], B. Boulanger[(a)], B. Ménaert[(b)], M. Lenoble[(a)], A.V. Smith[(c)] and O. Pacaud[(d)]
(a) *Laboratoire de Spectrométrie Physique,140 avenue de la Physique, BP 87,* 38402 St MARTIN d'HERES Cedex, France
(b) *Laboratoire de Cristallographie, avenue des Martyrs,* 38042 GRENOBLE Cedex 9, France
(c) *Sandia National Laboratories,* Albuquerque NM 87185-1423, USA
(d) *JDS Uniphase Commercial Lasers,31 Chemin du Vieux Chêne, ZIRST 4101,* 38941 MEYLAN, France

Abstract: Continuous spectral tuning (1420nm-1700nm and 2800nm-4200nm) is obtained in an optical parametric generator using a cylindrical ppLN, with high efficiency (30%). Optimized phase-matched OPO using cylindrical KTP is also reported and compared to numerical modelling.

OCIS codes : (190.4410) Nonlinear optics, parametric processes ; (190.4970) Parametric oscillators and amplifiers

1. Introduction

We report on recent progresses of widely and continuously tunable optical parametric sources based on cylindrical crystals. Such a geometry has already proved to offer broad angular and spectral tuning in both phase-matched[1] and quasi-phase-matched[2] optical parametric oscillators (OPO), and to generate beams with optimum and constant beam quality[3]. In this paper, a single grating ppLN crystal allows us to achieve optical parametric generation (OPG) over a wide spectral range in the infrared. A second section is devoted to the influence of the mirror reflectivity and of the pulse duration in a phase-matched KTP OPO, leading to simultaneous optimisation of the beam quality and of the output energy.

2. Quasi-phase-matched ppLN OPG

In the present study, a 40mm-long, 0.5mm-thick, ppLN crystal, cut as a cylinder with its revolution axis parallel to the ferroelectric axis ***c***, is pumped by a commercial microchip Nd :YAG laser emitting 430ps pulses at 1.064µm with 1kHz repetition rate. The ppLN crystal has a period of 27.5µm over its entire width ; it is left uncoated. It is heated at 140°C to prevent photorefractive damage. Proper focusing of the pump beam ensures collinear interaction in the crystal.
The tuning curve reported on figure 1 is obtained by rotation of the sample, leading to continuous variation of the effective period[2]. The signal wavelength varies over 300nm, and the corresponding idler over 1400nm.
The output energies of both signal and idler beams are shown on figure 2, for an incoming pump energy of 68µJ. The conversion efficiency, larger than 22% for the signal alone, is comparable with that of OPG based on parallelepipedic ppLN crystals[4]. The ratio of the idler to signal energy, also shown on figure 2, is in good agreement with the calculation over all the whole considered spectral range, which proves that incidence angles as large as 26° lead no additional losses.
The spectral bandwidth measured for the signal beam varies from 1.8nm at 1420nm to 20nm at 1700nm: these values are similar to the ones obtained in a 50mm parallelepipedic ppLN[4] ; they are also very close to the calculated spectral linewidth over the whole spectral range. The spectral bandwidth of the signal at λ_s=1421nm increases from 1.4nm to 2.8nm, while the beam divergence changes from 5 to 12 mrad, when the input pump intensity increases from 200 to 550MW/cm². These two variations are very consistent with the model developed in reference[4] for the calculation of the spectral bandwidth of the OPG. This agreement also proves that the crystal has a good homogeneity over its entire volume, and in particular that the duty cycle of the inverted domains exhibits negligible variations.
As a conclusion, such OPG based on cylindrical quasi-phase-matched crystals offer a very simple and compact solution for the realization of efficient continuously and widely tunable sources.

3. Optimized phase-matched KTP OPO

The experiment considered here is similar to the one described in reference [3], using a 21.2mm long KTP crystal ; the phase-matching is in the x-z plane, leading to continuous tuning of the signal wavelength between 1570nm and 1800nm by rotation of the crystal. In this study, the pulse duration of the pump laser and the reflectivity of the output coupling mirror have been varied, in order to study their respective influence on the OPO performances. The pump energy of the flash-lamp pumped Nd :YAG laser varies in the range 0-4mJ.
Figure 3 shows the variation of the threshold intensity and of the slope efficiency of the OPO (slope of the in-out energy curve). For a given pump-to-threshold ratio, the slope efficiency is proportional to (1-R_s), similarly to the energy transmitted through the coupling mirror. This efficiency is lower without pump recycling because the amplification of the signal only occurs in one pass ; the maximum slope efficiency is 42%, corresponding to an overall energy conversion of 48% at 4 times above threshold. That value is very close to the optimum efficiency published for the same interaction with parallelepipedic KTP crystals[5]. The threshold intensity decreases with increasing R_s, and with double pass of the pump. The measurement without pump recycling well agrees with the threshold calculated from reference [6]. This shows that losses which are induced by the idler absorption and by the roughness of

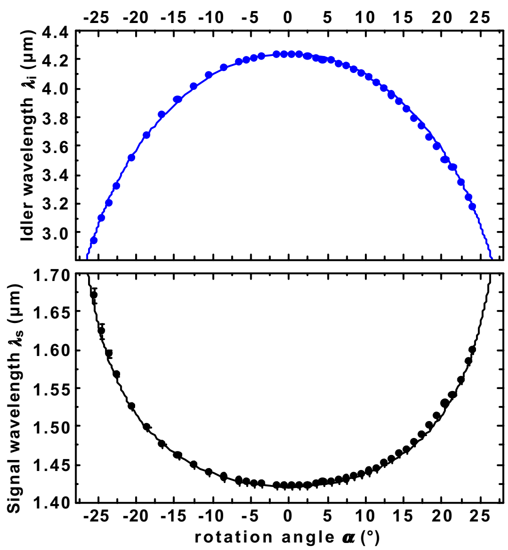

Fig. 1 : Angular tuning curve of the ppLN OPG. α is the angle between the direction of propagation and the normal to the grating.

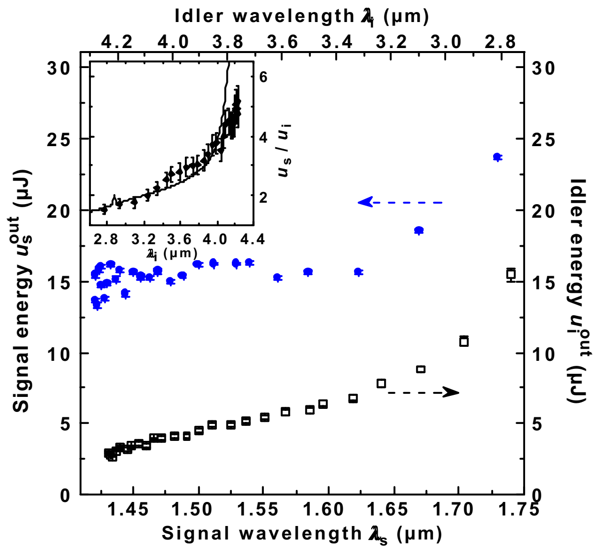

Fig. 2 : Signal and idler energies at the exit of the ppLN. The incoming pump intensity is I_p=530MW/cm² (pump energy u_p=68µJ). Insert : measured and calculated ratio of the signal to idler energies.

the crystal surfaces are negligible. The slope efficiency has only little variation with respect to the pulse duration, while the intensity threshold decreases with increasing Δt, in good agreement with the calculations.

We must first note that M^2 slightly decreases for increasing signal wavelength, which also corresponds to an increase of the walk-off angle ; this is in accordance with our previous results[3] and with theoretical predictions[7]. The measurements for different values of the pump-to-threshold ratio show that it has no effect on the beam quality, even for low reflectivity of the coupling mirror. As shown on figure 4, M^2 is quite constant whatever the reflectivity of the coupling mirror, and the pump recycling has no influence on M^2. These results demonstrate that the spatial filtering effect is the dominant factor for the beam quality[3], even if the number of roundtrips in the cavity is very small. Similar results are obtained when the pulse duration is varied in the range 9ns-18ns.

These different measurements prove that it is possible to achieve a simultaneous optimization of the beam quality and of the efficiency. Numerical modelling of these results are currently under study. This will then provide a complete tool for the design of the future devices based on cylindrical crystals.

The spectral width of the signal beam (FWHM) is between 0.1nm and 0.2nm, in good agreement with the calculated value of 0.21nm. For certain wavelengths, the output signal spectrum exhibits a double-peak behavior: the peaks spacing corresponds to the modes of the Fabry-Perot cavity formed by one mirror and one surface of the uncoated KTP. The use of antireflection coatings will then eliminate this effect, and simultaneously increase the OPO efficiency.

4. Conclusion

The two examples described here show that optical parametric sources based on cylindrical crystals can offer performances similar to those of classical devices using parallelepipedic samples, with the advantage of wide and continuous spectral tuning and good beam quality. Furthermore, the use of microchip lasers as pump sources leads to compact and stable setup, and will provide very practical sources for various applications.

References

1 O. Pacaud, J.P. Fève, B. Boulanger *et al.*, Opt. Lett. **25** (10), 737-739 (2000).

2 J.P. Fève, O. Pacaud, B. Boulanger *et al.*, Opt. Lett. **26** (23), 1882-1884 (2001).

3 J.P. Fève, O. Pacaud, B. Boulanger *et al.*, J. Opt. Soc. Am. B **19** (3) (2002).

4 M.J. Missey, V. Dominic, P.E. Powers *et al.*, Opt. Lett. **24** (17), 1227-1229 (1999).

5 L.R. Marshall and A. Kaz, J. Opt. Soc. Am. B **10** (9), 1730-1736 (1993).

6 S.J. Brosnan and R.L. Byer, IEEE J. Quantum Electron. **15** (6), 415-431 (1979).

7 W.J. Alford, R.J. Gehr, R.L. Schmitt *et al.*, J. Opt. Soc. Am. B **16** (9), 1525-1532 (1999).

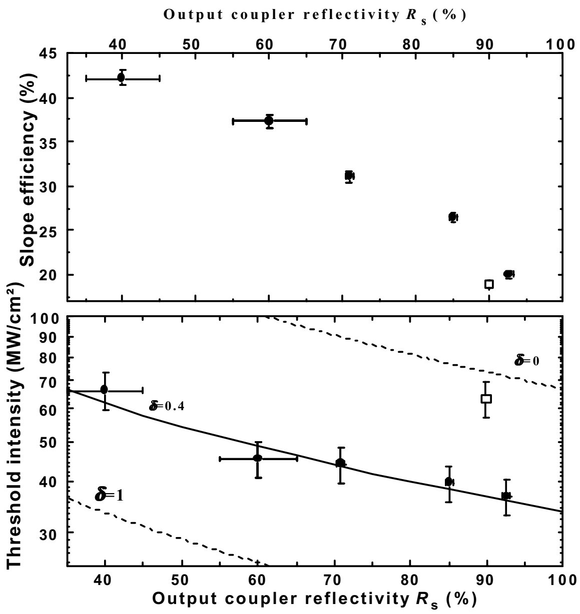

Fig. 3 : Variation of the slope efficiency and of the threshold intensity as a function of the output coupler reflectivity. Δt= 17ns. ● : double pass of the pump, □ : single pass of the pump. The dotted curves are calculated from reference[6], with zero or unity pump recycling ; the solid curve considers δ=0.4, to take into account the poor mode overlap of the backward propagating pump.

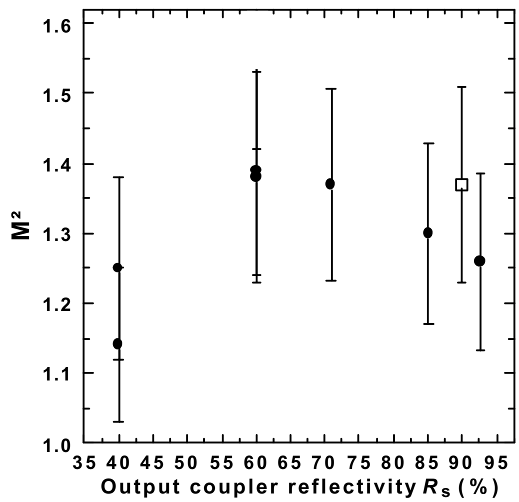

Fig. 4 : Beam quality M^2 as a function of the output coupler reflectivity. λ_s=1574.4nm, Δt=15ns. □ : without pump recycling ; ● : double pass of the pump.