Design of an Optical Parametric Oscillator using a BBO partial cylinder for a continuous tunability between 0.4 µm and 0.9 µm

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Abstract. This work describes the different steps of the design of a cylindric Optical Parametric Oscillator. It is based on a BBO nonlinear crystal shaped as a partial cylinder to be pumped by a commercial micro-laser at 0.355 µm for an energetic and sub-nanosecond emission continuously tunable between 0.4 µm and 0.9 µm.

1 THE ADVANTAGES OF BBO

The choice of the nonlinear crystal was oriented towards three non-centrosymmetric borates: βBaB_2O_4 (BBO), LiB_3O_5 (LBO) and $CsLiB_6O_{10}$ (CLBO). Indeed, they are transparent down to 0.2 µm allowing a pumping wavelength of $\lambda p = 0.355$ µm emitted by a commercial and compact micro-laser [1]. They can also generate visible light from phase-matched frequency down-conversion [2].

We performed numerical calculations at room temperature using data from [3,4,5,6,7,8] in order to compare the conversion efficiency between these three crystals when pumped at $\lambda p = 0.355$ µm for parametric fluorescence (PF) $\frac{1}{\lambda p} = \frac{1}{\lambda s} + \frac{1}{\lambda i}$. λs and λi stand for signal and idler wavelengths respectively. We considered all the possible phase-matching directions (θ,φ) generating wavelengths between 0.4 µm and 0.9 µm with the three possible polarization schemes labelled Type I, II and III.

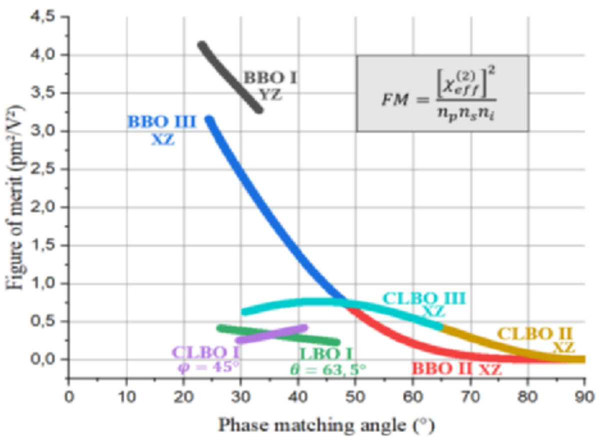

Fig. 1. Figure of merit as a function of phase-matching angles for BBO, LBO and CLBO crystals when pumped at 0.355 µm and generating between 0.4 µm and 0.9 µm from PF.

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For each phase-matching condition, we calculated the Figure of Merit defined as the ratio of the square value of the associated effective nonlinear coefficient over the product of the refractive indexes of the three interacting waves. It is shown in Fig. 1 as a function of phase-matching angles. It reports that BBO is much more efficient than LBO and CLBO crystals especially for a type I in YZ plane where the pump linear polarization is orthogonal to that of idler and signal.

BBO being a hygroscopic crystal, it is wise to impose to the crystal a working temperature higher than the room temperature in order to prevent any condensation on its surface. It is then necessary to check for any change of the phase-matching conditions as a function of temperature. Indeed, any variation of the principal refractive indices of the order of 10^{-4} can change phase-matching angles by more than 1°.

We performed such a study using our cylinder method [9]. We used a BBO sample cut as a cylinder (Ø10 mm), with a rotation plane corresponding to the YZ plane of the dielectric frame and its curved face polished to the optical quality but uncoated. The cylinder was inserted in an oven allowing a variation of temperature between 20°C and 40°C as shown in inset of Fig.2. With the sample mounted on a rotation stage and by using a commercial laser emitting a fundamental wavelength tunable between 0.7 µm and 1.9 µm, we directly recorded the phase-matching curve for Type I Second Harmonic Generation (SHG) at a given temperature, each data corresponding to a maximum value of the conversion efficiency.

As shown in Fig. 2 for 25 , 30 , 35 and 40°C, there is no influence of temperature on phase-matching conditions between 20°C and 40°C within an accuracy of 1 nm and 0.2° for the phase-matching wavelengths and angles respectively. It also corroborates calculations at room temperature using Sellmeier equations from [3].

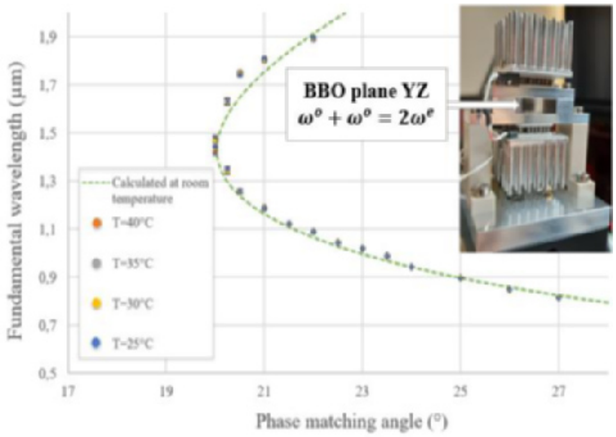

Fig. 2. BBO Type I SHG phase-matching curve for 4 different temperatures in the YZ plane.

2 The OPO cavity

We aimed an Optical Parametric Oscillator (OPO) cavity architecture the simplest and the most compact as possible in a perspective of a commercialization with a pump laser providing 350 ps pulse width at 1 kHz repetition rate. Using our previous work from [10], we selected a linear cavity singly resonant on the signal only (SROPO) with a partial BBO cylinder (Ø27.6 mm) inserted between two plane mirrors for a continuous tunability.

It was inserted in an oven to set the working temperature at 40 °C. Thus, for type I PF in the YZ plane of BBO, our calculations showed (see Fig.1) that the partial cylinder had to be cut oriented to rotate over 11° between 23° and 34° in order to achieve a continuous tunability between 0.4 µm to 0.9 µm. Note that Type I PF has the advantage that in the YZ plane of BBO that belongs to the negative uniaxial optical class, the spatial walk-off applies on the pump beam only so that it is subject to refraction at the exit of the partial cylinder contrarily to generated signal and idler beams.

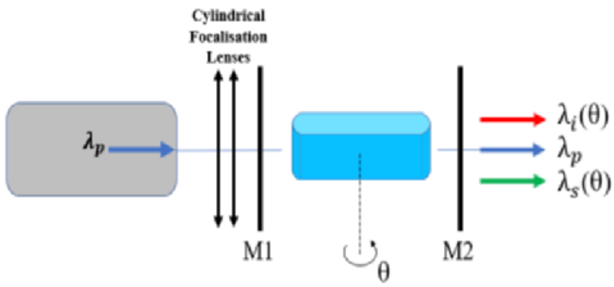

Fig. 3. OPO schematic layout. M stand for plane mirrors.

Among all the possible OPO cavity lengths from the stability domain provided by the partial cylinder, we selected the one for which the waist radius of the signal beam was located at the middle of the partial cylinder (symmetrical OPO) and corresponding to a Rayleigh length larger than its diameter. It provided small waist radii of the signal beam on the two plane mirrors that can be damaged but it had the advantage to reduce the spatial walk-off attenuation of the pump beam on the OPO efficiency. Figure 3 shows the schematic layout of the OPO we implemented.

Obviously, the OPO performances rely in the balance between the intensity of BBO parametric fluorescence and the threshold of our cavity. We recorded the phase-matched parametric fluorescence with a CCD camera imaging the output surface of the BBO partial cylinder oriented at 27° and with the output coupler M2 removed. It is depicted in Fig. 4 with an horizontal astigmatism due to the pump beam spatial walk-off when generating parametric fluorescence along the crystal.

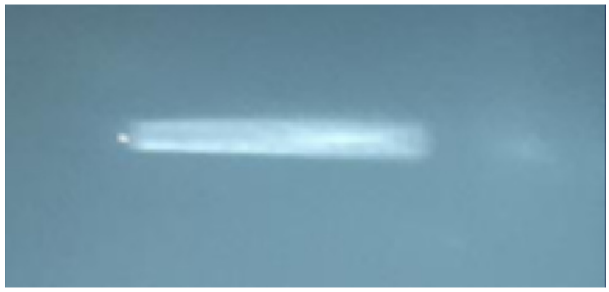

Fig. 4. Parametric fluorescence beam recorded at the exit of the BBO partial cylinder with M2 of the OPO cavity removed.

Measurement of the intensity is in progress. It will be followed by the optimisation of the OPO performances after adding the output coupler M2.

1. https://www.teemphotonics.com/laser/355-nm-laser-1khz-350ps/
2. R. Arun Kumar, Journal of Chemistry (2013).
3. K. Kato, N. Umemura, T. Mikami, Proc. SPIE **7582** (2010).
4. I. Shoji, H. Nakamura, K. Ohdaira, T. Kondo, R. Ito, T. Okamoto, K. Tatsuki, S. Kubota, J. Opt. Soc. Am. B **16**, *620-624* (1999).
5. Nikogosyan, Appl. Phys. A **58,** *181–190* (1994).
6. S. P. Velsko, M. Webb, L. Davis, C. Huang, IEEE J. Quant. Elec. **27**, *2182-2192* (1991).
7. N. Umemura, K. Yoshida, T. Kamimura, Y. Mori, T. Sasaki, K. Kato, ASSL **26** (1999).
8. I. Shoji, H. Nakamura, R. Ito, T. Kondo, M. Yoshimura, Y. Mori, T. Sasaki, J. Opt. Soc. Am. B **18**, *302-307* (2001).
9. B. Ménaert, J. Debray, J. Zaccaro, P. Segonds, B. Boulanger, Opt. Mat. Express **7**, *3017-3022* (2017).
10. V. Kemlin, D. Jegouso, J. Debray, P. Segonds, B. Boulanger, B. Menaert, H. Ishizuki, T. Taira, Opt. Lett. **38**, *860-862* (2013).