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Parasitic oscillation in mid-infrared optical parametric generator based on PPMgLN

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ABSTRACT

Parasitic oscillation of optical parametric generator (OPG) seriously affects transform efficiency, stability and beam quality of mid-infrared laser. And because of the cross-section of the light spot and nonlinear effect, it is difficult to eliminate parasitic oscillation. This paper focuses on the analysis of the causes of parasitic oscillation and its influence on the output power. Optical parametric oscillator (OPO) and optical parametric amplifier (OPA) in the parasitic oscillation are inconsistent. Through the study on parasitic oscillation in the optical parametric process, it can effectively improve conversion efficiency, and improve device performance.

1. Introduction

Relative to other tunable lasers (such as titanium sapphire laser, Ar^+ laser, free electron laser, the overtone CO laser), tunable OPG has a great competition force in the tuning range, efficiency, volume and weight. It has a wide range of applications in the classic areas, and a lot of applications in the field of quantum optics. OPG is widely used in optoelectronic countermeasures, laser ranging, laser radar, spectral measurements, and environmental testing.

Many developed countries attach great importance to OPG devices and applications technology. Currently, low-power OPG technology has matured, and high-power optical parametric transformation technology has also developed rapidly. Especially in the last few years, with the development of high-quality periodically poled crystal (such as PPLN [1–5], PPKTP [6], PPRTA [7], PPMgLT [8], PPMgLN [9,10]), tunable optical parametric technology has demonstrated its vitality and has become a major research focus of the laser field.

But the stability of OPG also seriously limits its scope of application, and improving its stability is of great significance. Parasitic oscillations, the resonant cavity structure, the thermal effect of the nonlinear crystal are important factors, which affect the power stability and the beam quality. This paper focuses on the causes of parasitic oscillation, and we also compared the difference between OPO and OPA in the parasitic oscillation.

2. Experiment setup

OPO and OPA experimental setup is shown in Fig. 1. The pump source is an acousto-optic Q-switched $Nd{:}YVO_4$ laser with wavelength 1.064 μm. In order to effectively alleviate the heat of the laser crystal, laser gain medium is 0.5 at% doped $YVO_4/Nd{:}YVO_4/YVO_4$ (2 mm:6 mm:2 mm) bonded crystal. 5% MgO-doped PPLN crystal is using as nonlinear crystal. It had an interaction length of 50 mm and a thickness of 1 mm. The crystal was of multi-grating form with 7 domain polling periods ranging from 28.5 to 31.5 μm with a constant step of 0.5 μm. The domain duty factor was 50%. The crystal faces were broadband AR coated at 1.4–1.6 μm ($R < 2\%$), 3.2–4.2 μm ($R < 5\%$) and 1.064 μm ($R < 1.5\%$).

The resonator of the OPO system was consisted of two plane-concave mirrors (M1, M2) with 200 mm a radius-of-curvature, which were separated by about 70 mm. The input (M1) mirror had a HR coating at the signal radiation, a HR coating at the idler radiation, and a high transmission (HT) coating at the pump light; the output mirror (M2) had a HR coating at the signal wavelength ($R = 5\%$ at 1.4–1.6 μm), a HT coating at the idler wavelength, and a HR coating at the pump light. We could deduce that the OPO system was singly resonant optical parametric oscillator (SRO). To optimize use of the PPMgLN crystal, the pump and signal beams must be mode matched.

3. Results and discussion

The pump light at 1.064 μm is linearly polarized light (Fig. 2), and the angle α is less than 5° between its polarization direction and the crystal optical axis (z-axis). According to the

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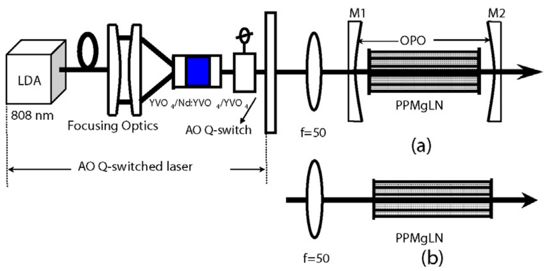

Fig. 1. Experimental setup of the PPMgLN OPG system (a: optical parametric oscillator; b: optical parametric amplifier).

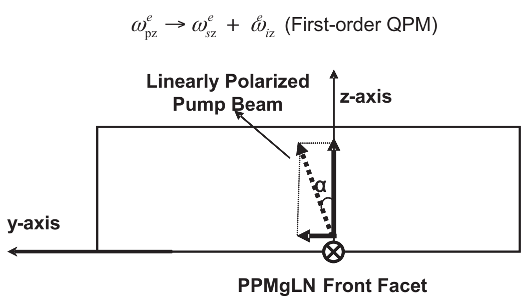

Fig. 2. The polarization of pump light in the PPMgLN crystal.

characteristic of PPMgLN crystal birefringence, the pump light polarization direction can be divided into two parts (*z*-axis and *y*-axis). The pump light directed along the crystal *z*-axis results in signal and idler light because of the first-order QPM process. It is the most important conversion process of PPMgLN crystal, and this is also the key factor to produce parasitic oscillation.

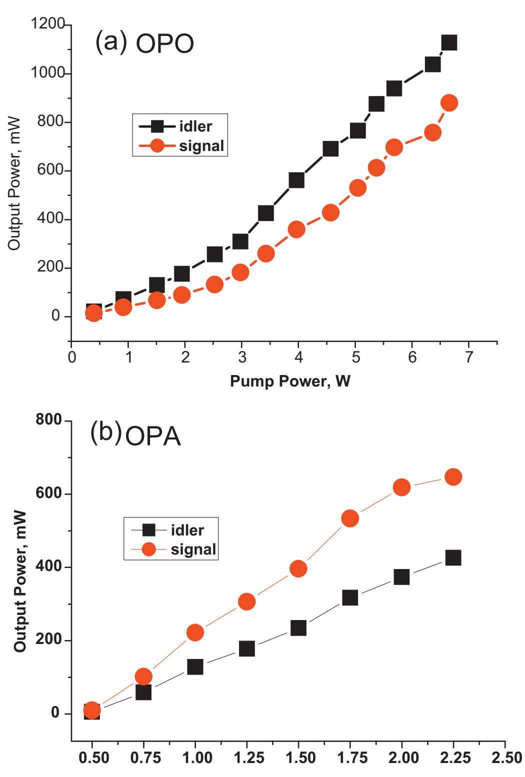

Fig. 3. The output power of the PPMgLN optical parametric generator system (a: optical parametric oscillator; b: optical parametric amplifier).

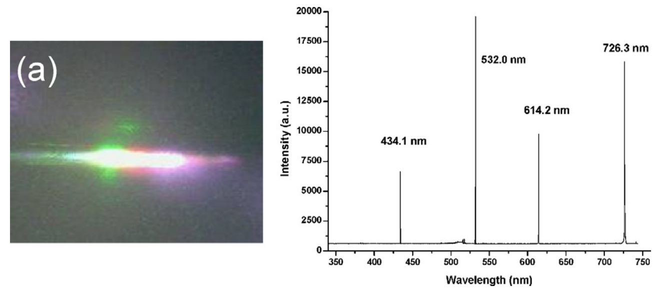

Fig. 4. Parasitic oscillation in mid-infrared OPG system.

If the poled period of PPMgLN crystal is 30 μm, and the wavelength of pump light is 1.064 μm, the idler light at 3.61 μm and the signal light at 1.51 μm can be obtained, which is named first-order quasi-phase-matching process. Fig. 4 showed the idler power and signal power versus the pump power. For OPO and OPA, upon increasing the pump power, the idler power and signal power would increase further. However, in the OPO system, the signal light power significantly is less than the idler, and in the OPA system the power of the signal light is greater than the power of the idler.

Usually in a periodically poled nonlinear crystal, in addition to the existence of quasi-phase matching (QPM) optical parametric transformation process; there is also birefringence phase matching (BPM) nonlinear effects [10]. Along with signal and idler light, there will be a strong visible light appeared, which consists of green, red and weak violet light. They are nonlinear effects based on BPM, and this is the parasitic oscillation. Parasitic oscillation affects the transformation efficiency, the stability, and beam quality of the parametric light. With spot distribution and nonlinear effects, parasitic oscillation phenomenon is difficult to eliminate. For example, when the poled period of PPMgLN crystal is 30 μm, we observe and measure the wavelength of visible light generated by the parasitic oscillation, as shown in Fig. 4.

The signal light of the OPO system, due to the characteristics of its single resonance structure (see Fig. 1a), repeatedly transmits through the nonlinear crystal, and each time the signal light (wavelength 1.51 μm) will cause nonlinear effects. As shown in Fig. 4b: (1) the frequency doubled process of the signal light can produce 726.3 nm red light; (2) the sum frequency of the signal light and pump light (wavelength 1.064 μm) can produce 614.2 nm red light; (3) the sum frequency of second harmonic signal light and pump light can produce the violet wavelength 434.1 nm. These non-linear conversion processes will be a serious impact on output power of the signal light. Therefore, in terms of OPO, even single photon energy of the signal light is greater than the single photon energy of idler light; the output power of the signal light has to be less than idler optical power (the size ratio of 0.7, as shown in Fig. 3a).

However, in the OPA system, the signal light and pump light are only a single-pass the PPMgLN crystal (signal light do not oscillate as shown in Fig. 1b), and the nonlinear effects are relatively

Table 1
Wavelength of the visible with their related conversion process and phase matching type.

Wavelength (nm)	Conversion process	Phase matching
726.3	SHG $\omega^e_s + \omega^e_s = 2\omega^e_s$	Second-order QPM
614.2	SFM $\omega^o_p + \omega^e_s = \omega^e_{SFM}$	BPM type II
532	SHG $\omega^o_p + \omega^e_p = 2\omega^e_p$	BPM type II
434.1	SFM $2\omega^e_s + \omega^e_p = \omega^e_{SFM'}$	Eighth-order QPM

SHG, second-harmonic generation; SFM, sum-frequency mixing.

minor. So the output power of the signal light is greater than the output power of the idler light, and the ratio (1.65) is close to its single-photon energy ratio (2.3). Therefore, due to the existence of resonance, the parasitic oscillation could seriously affect the output power, especially the output power of the signal light (Table 1).

4. Conclusion

Parasitic oscillation affects the transformation efficiency, the stability and beam quality of the parametric light of the OPG system. With spot distribution and nonlinear effects, parasitic oscillation phenomenon is difficult to eliminate. For the optical parametric oscillator, due to the oscillation of the signal light, parasitic oscillation is more serious, and seriously affected the output power of the signal light; for the optical parametric amplifier, signal light single-pass the PPMgLN crystal, the impact of parasitic oscillation is less.

Acknowledgements

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References

[1] I. Paiss, A. Englander, R. Lavi, Efficient long pulse generation with an intracavity F mid-IR PPLN OPO, Adv. Solid State Lasers OSA TOPS 19 (1998) 253–255.
[2] R.S. Conroy, C.F. Rae, M.H. Dunn, et al., Compact, actively Q-switched optical parametric oscillator, Opt. Lett. 24 (22) (1999) 1614–1616.
[3] O.B. Jensen, T. Skettrup, O.B. Petersen, et al., Diode-pumped intracavity optical parametric oscillator in pulsed and continuous-wave operation, J. Opt. A: Pure Appl. Opt. 4 (2) (2002) 190–193.
[4] Ki-Ho Cho, Bum Ku Rhee, Yuzo Sasaki, et al., Pulsed intracavity optical parametric oscillator with high average power based on periodically poled $LiNbO_3$, J. Nonlinear Opt. Phys. Mater. 14 (3) (2005) 383–389.
[5] L. Tsai, Y.F. Chen, S. Lin, et al., Compact efficient passively Q-switched $Nd:GdVO_4/PPLN/Cr^{4+}:YAG$ tunable intracavity optical parametric oscillator, Opt. Express 13 (23) (2005) 9543–9547.
[6] T. Edwards, G. Turnbull, M. Dunn, et al., Continuous-wave, singly-resonant, optical parametric oscillator based on periodically poled $KTiOPO_4$, Opt. Express 6 (3) (2000) 58–63.
[7] A. Carleton, D.J.M. Stothard, I.D. Lindsay, et al., Compact, continuous-wave, singly resonant optical parametric oscillator based on periodically poled $RbTiOAsO_4$ in a $Nd:YVO_4$ laser, Opt. Lett. 28 (7) (2003) 555–557.
[8] K.-H. Cho, B.K. Rhee, Intracavity infrared OPO using periodically poled Mg-doped stoichiometric $LiTaO_3$ for generating high average power, Proc. SPIE 6875 (2008) 68751A.
[9] Y.A.N. Bo-Xia, B.I. Yong, Z. Mi, Highly efficient continuous-wave mid-infrared intracavity singly resonant optical parametric oscillator based on MgO:PPLN, Chin. Phys. Lett. 27 (12) (2010) 124203.
[10] O. Paul, A. Quosig, T. Bauer, et al., Temperature-dependent Sellmeier equation in the MIR for the extraordinary refractive index of 5% MgO doped congruent $LiNbO_3$, Appl. Phys. B 86 (1) (2007) 111–115.