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RESEARCH ARTICLE

Temperature tunable infrared optical parametric generation based on periodically poled MgO:LiNbO$_3$ crystals

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Abstract By using a short-pulse field, periodically poled grating ($\Lambda = 29$ μm) was successfully fabricated in a 1.0 mm-thick MgO:LiNbO$_3$ (mole fraction of doped MgO is 5%). A high-repetition-rate optical parametric generation (OPG) based on periodically poled MgO: LiNbO$_3$ (PPMgLN) was pumped by a 1.064 μm acousto-optically Q-switched Nd:YVO$_4$ laser. With 3 W of input pump power, 44 mW of output signal power was obtained at a conversion efficiency of 1.5%. Tunable infrared (IR) output from 1.4538–1.4750 μm was also obtained by tuning the temperature of PPMgLN, which is 45°C–160°C.

Keywords laser technique, optical parametric generation (OPG), periodically poled MgO:LiNbO$_3$ (PPMgLN) crystal, quasi-phase matching

1 Introduction

Tunable coherent infrared sources can be used in atmospheric sensing, biology, spectroscopy and laser radar imaging. The optical parametric generator (OPG) and optical parametric oscillator (OPO) are two very effective devices for obtaining tunable coherent infrared sources [1–3]. The OPG is different from the OPO due to its operation without optical resonators. It is also easier to realize a coherent source with a narrow spectral width by injection seeding with OPG, which has a simpler cavity configuration and better stability. The main limitations of OPG are its higher threshold and lower conversion because of its nonresonant structure [4–8].

Quasi phase matching (QPM) [9–12] is an alternative to birefringent phase matching (BMP) for compensating phase velocity in frequency conversion application. The phase matching condition for QPM can be satisfied by the grating period irrespective of the inherent properties of the crystal. It can use the largest tensor component which allows high conversion and a compact structure. Ferroelectric lithium niobate (LiNbO$_3$) crystals are extensively used in various fields, such as electro-optics, piezoelectric devices and surface acoustic wave (SAW) devices, because of their large electro-optic and nonlinear optical coefficients. Polarization reversal of congruent LiNbO$_3$ ([Li]/[Nb] = 48.5/51.5) crystals is known to be quite difficult at room temperature , the high electric field (about 21 kV/mm) required for domain crystals limits the sample thickness, and a large internal field in the congruent crystals limits sample thickness and the ability to control domain periodicity [13,14].

LiNbO$_3$ doped with MgO is a very promising nonlinear optical material, as it has greatly improved resistance to photorefractive damage and a slightly larger nonlinear optical coefficient d_{33} compared with congruent LiNbO$_3$ [15,16]. Domain inversion with an electric field of MgO (mole fraction of doped MgO is 5%) is as low as 3 kV/mm and periodic poling with thickness above 1 mm MgLN can be obtained [17,18].

In this paper, periodically poled grating ($\Lambda = 29$ μm) was successfully fabricated in 1.0 mm thick MgO: LiNbO$_3$ (mole fraction of doped MgO is 5%) by using a short-pulse field, and we demonstrated the high-repetition-rate OPG based on PPMgLN pumped by a 1.064 μm acousto-optically Q-switched Nd:YVO$_4$ laser. With 3 W of input pump power, 44 mW of output signal power was obtained and conversion efficiency was 1.5% at 160°C. A tunable infrared out from 1.4538–1.470 μm was also obtained by tuning the temperature of PPMgLN (45°C–160°C).

2 Theoretical analysis

The OPG is a high-gain amplification process initiated by the spontaneous emission of signal and idler photons, since

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the emission is a quantum noise process. Figure 1 is the simple configuration of OPG. It endows the output fields with fluctuations characteristic of the underlying vacuum fields. In a general three-wave interaction, the frequencies ω_p, ω_s and ω_i must meet the energy conversion criterion:

$$\frac{1}{\lambda_p}-\frac{1}{\lambda_s}-\frac{1}{\lambda_i}=0. \tag{1}$$

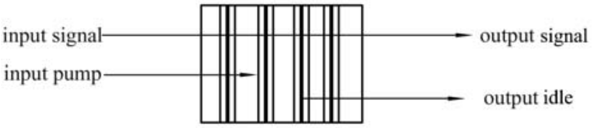

Fig. 1 Simple configuration of OPG

In QPM, the highest conversion occurs at the center of the phase-matching peak, where the phase mismatch Δk is equal to zero:

$$\begin{aligned}\Delta k &= k_p-k_s-k_i-\frac{2\pi m}{\Lambda}\\ &=\frac{2\pi n(\lambda_p,T)}{\lambda_p}-\frac{2\pi n(\lambda_s,T)}{\lambda_s}-\frac{2\pi n(\lambda_i,T)}{\lambda_i}-\frac{2\pi m}{\Lambda}=0,\end{aligned} \tag{2}$$

where Λ is the grating period of periodically poled $LiNbO_3$ (PPLN); Δk is the phase mismatch; k_p, k_s and k_i are the vectors of the pump wave, signal wave and idler wave, respectively; and m is the QPM order. In general, m is taken to be unity to obtain the largest effective nonlinear coefficient for QPM. λ_p, λ_s and λ_i are the pump, signal and idler vacuum wavelength, respectively. n_p is the extraordinary refractive index at the pump wavelength, and n_s and n_i are the corresponding qualities for the signal and idler waves respectively.

3 Experimental result

Periodic poling of MgLN was done by the conventional electric-field method. We used an electric field with a pulse width of 10 ms and a pulse period of 110 ms to eliminate the heating effect of the polarization current. The periodically poled grating (Λ = 29 μm) was successfully fabricated in 1.0 mm thick $MgO:LiNbO_3$ (mole fraction of doped MgO is 5%) [19–21]. The experimental results show that the domain reversal for the MgLN crystal requires a switching field with strength of only 3 kV, which is just one tenth of the switching field for congruent $LiNbO_3$ crystals. A cross-sectional micro-photograph of the periodically domain inverted structure with a period of 29 μm is shown in Fig. 2. MgLN crystal shows a good periodic structure when it is used in frequency conversion through quasi-phase-matching processes, and it has great potential in the realization of infrared optical parametric generators and optical parametric oscillators.

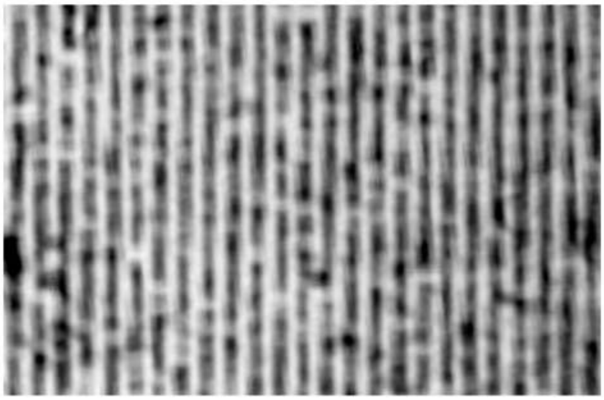

Fig. 2 Cross-sectional micro-photograph of the periodically domain inverted structure with a period of 29 μm

The experimental set-up of the OPO operation is shown in Fig. 3. A Q-switched $Nd:YVO_4$ laser was used as a 1.064 μm pump source. The repetition rate was 50 kHz with a pulse width of 80 ns. The polarization of the pump laser was set parallel to the z axis of the PPMgLN device. To prevent thermal fracture, the Nd:YAG crystal was mounted on a water-cooled copper crystal holder whose temperature was controlled at about 24°C. The crystal was placed in an oven with temperature stability of 0.1°C and heated from 30°C to 200°C during the operation. We tuned the signal wavelength of the PPLN OPO infrared radiation from 1.4538 to 1.4750 nm at the grating period of 29 μm by adjusting the crystal temperature from 30°C to 200°C. A filter was utilized to eliminate visible output and pump wave from signal waves. The input mirror was an optically coated K_9 glass. An Agilent 86142B optical spectrum analyzer was used to measure the spectrum in the range of 600–1700 nm. A Molectron PM500A-2 power meter measured the pump laser and OPG output average power.

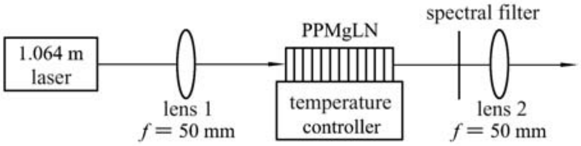

Fig. 3 Experimental configuration of the PPMgLN OPG

In the experiment, we showed that the output optical power is changed on a small scale by changing the entrance point of the crystal because of the well periodical structure of PPMgLN. We tuned the signal wavelength of PPLN OPG infrared radiation at the grating period of 29 μm by adjusting crystal temperature and calculated the corresponding idler wavelength. The signal wavelength of the PPLN OPG at different temperatures is shown in Table 1, and idler wavelength was calculated by Eq. (1), where λ_p = 1.064 μm. A signal wavelength of the PPLN OPG infrared radiation from

1.4538–1.4750 nm at the grating period of 29 μm was obtained by adjusting the crystal temperature from 45°C–160°C.

Table 1 Output wavelength of OPG at different crystal temperatures

T/°C	λ_s/nm	λ_i/nm
45.0	1453.8	3968
60.4	1456.0	3952
72.9	1458.2	3936
88.0	1460.0	3923
110.0	1465.0	3887
160.0	1475.0	3818

Figure 4 shows the PPMgLN OPG signal output optical power as a function of pump input power at the grating period of 29 μm. With 3 W of input pump power (P_p), 44 mW of output signal power (P_s) was obtained at a conversion efficiency of 1.5%. Furthermore, the signal wave can continuously operate above 100 h, while fluctuation of the output power was less than 8%.

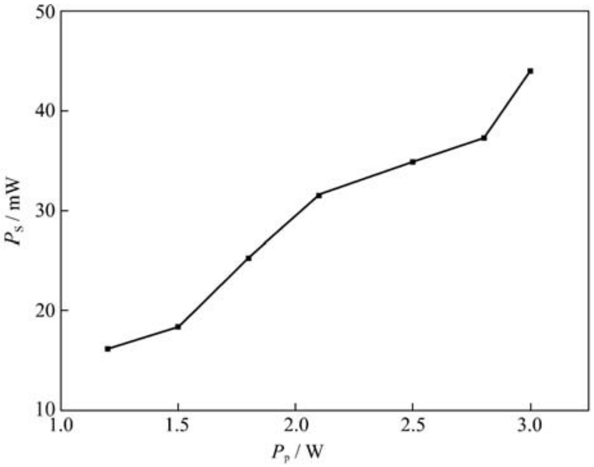

Fig. 4 PPMgLN OPG signal output power as a function of the pump input power

PPMgLN has great potential in the realization of infrared optical parametric generators and optical parametric oscillators because of its good periodical structure. We can increase the conversion efficiency of OPG by improving experimental conditions, including increasing peak power by reducing the repetition rate of the pump wave, reducing coating on the focusing lens for inducing loss, and improving the periodical structure and quality of the PPLN.

4 Conclusions

By using a short-pulse field, periodically poled grating ($\Lambda = 29$ μm) was successfully fabricated in 1.0 mm thick MgO:LiNbO$_3$ (mole fraction of doped MgO is 5%). A high-repetition-rate OPG based on PPMgLN is pumped by a 1.064 μm acousto-optically Q-switched Nd:YVO$_4$ laser. With 3 W of input pump power, 44 mW of output signal power was obtained at a conversion efficiency of 1.5%. A tunable infrared (IR) output from 1.4538–1.4750 μm was also obtained by tuning the temperature of PPMgLN (45°C–160°C).

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