High power output quasi-continuous-wave nanosecond optical parametric generator based on periodically poled lithium niobate*

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We report on a high power output quasi-continuous-wave nanosecond optical parametric generator (OPG) of congruent periodically poled lithium niobate (PPLN) pumped by a 1 064 nm acousto-optically Q-switched Nd:YVO_4 laser (duration: 70 ns, repetition rate: 45 kHz, spatial beam quality $M^2<1.3$). The OPG consists of a 38.7 mm long PPLN crystal with a domain period of 28.93 μm. With 5.43 W of average pump power the maximum average output power is 991 mW at 1 517.1 nm signal wave of the PPLN OPG.

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Quasi-phase matching (QPM)[1-3] is an alternative technique to birefringent phase matching (BPM) for compensating phase mismatching in frequency-conversion applications. It does not require birefringence for non-linear mixing. QPM can be implemented in a ferroelectric material, such as $LiNbO_3$, $LiTaO_3$ etc. by periodic reversal of the ferroelectric domains. In a first-order QPM device, the nonlinear coefficient is modulated with a period twice the coherence length of the interaction to offset the accumulated phase mismatch. In QPM any interactions within the transparency range of the material can be non-critically implemented at a specific temperature even the interactions for which birefringent phase matching is impossible.

And the interacting waves can be chosen so that coupling occurs through the largest element of the $\chi^{(2)}$ tensor. In $LiNbO_3$, all waves polarized parallel to the z-axis yield a gain enhancement over the birefringently phase-matched process as high as $(2d_{33}/\pi d_{31})^2\approx 20$. The major advantage of QPM over BPM are increased conversion efficiency[4], the absence of beam walk off in the crystal and the use of longer crystals.

For optical parametric generation (OPG), the theories of amplification of parametric fluorescence to high power level have been studied for more than 30 years [5]. OPG is a nonresonant device[6~7] with higher threshold. In fact when the birefringently phase-matched crystals were used the OPG threshold is more difficut to achieve because the optical damage threshold of the nonlinear crystal limits the pump power. To solve this problem multiple passes of pump beam through the crystal have been commonly used[8]. However, with the development of QPM technology and the commercial periodically poled crystal, periodically poled lithium niobate (PPLN) has been demonstrated to be a suitable material for compact ns OPG[9]. As regards the wavelength tuning methods, we can obtain the wide tuning range for OPG easily by changing the crystal temperature[3].

In this paper we present a high power output high-repetition-rate PPLN OPG pumped by an acousto-optically Q-switched Nd: YVO_4 laser with about 70 ns (FWHM) pulse duration operating at a repetition rate of 45 kHz. When the average pump power was 5.43 W the maximum average output power of the signal wave of the PPLN OPG is 858 mW at 1 502.3 nm and 991 mW at 1 517.1 nm at the fixed crystal temperature of 155 ℃ and 200 ℃ respectively. The output power we measured is only the power of signal wave.

In a general three-wave interaction, the frequencies ω_p, ω_s and ω_i must satisfy the energy conservation criterion:

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$$\omega_p = \omega_s + \omega_i \tag{1}$$

where ω_p is the angular frequency of signal light and ω_i is the angular frequency of idle light. It can also be written as following:

$$\frac{1}{\lambda_p} = \frac{1}{\lambda_s} + \frac{1}{\lambda_i} \tag{2}$$

where λ_p is the angular frequency of pump light, λ_s is the wavelength of signal light and λ_i is the wavelength of idle light.

In QPM the crystal is commonly periodically poled along the crystal *z-axis* and the three wave vectors $\boldsymbol{k}_p$, $\boldsymbol{k}_s$ and $\boldsymbol{k}_i$ are collinear along the crystal *x-axis*. The wave vector mismatc for QPM $\Delta \boldsymbol{k}$ is desribed as[4]

$$\Delta \boldsymbol{k} = \boldsymbol{k}_p - \boldsymbol{k}_s - \boldsymbol{k}_i - \boldsymbol{k}_m \tag{3}$$

In collinear QPM $k_m = 2\pi m/\Lambda$ is the grating vector analogous to the wave vector. Λ is the grating period and m is the QPM order which is usually taken to be unity to obtain the largest effecrtive nonlinear coefficient for QPM.

When the interaction is phasematched ($\Delta k = 0$) Eq. (3) can been written as

$$\frac{n_p(T,\lambda_p)}{\lambda_p} = \frac{n_s(T,\lambda_s)}{\lambda_s} + \frac{n_i(T,\lambda_i)}{\lambda_i} + \frac{1}{\Lambda(T)} \tag{4}$$

where n_p is the refractive index of pump light. n_s is the refractive index of signal light and n_i is therefractive index of idle light. Obviously we can obtain large spectral tuning range of OPG's output by only changing the crystal temperature. Theoreticaly we obtained the spectral-tuning curve as a function of the temperature of the PPLN which is shown in Fig. 1. The signal wavelength increased with the increase of the crystal temperature. From 155 ℃ to 200 ℃ the range of the signal wave spectrum was 1 501. 7-1 517. 3 nm.

The schematic diagram of the OPG system is shown in Fig. 2. An acousto-optically Q-switched Nd:YVO_4 laser (beam diameter: 0. 8 mm, beam divergence: 2 mrad, spatial beam quality $M^2 < 1.3$) operating at a repetition rate of 45 kHz served as the pump source for the OPG. The pulse duration (FWHM) of the 1 064 nm pump source was about 70 ns. A 50 mm-focal-length lens was used to couple the pump beam into the PPLN crystal.

The PPLN crystal is 38. 7 mm long by 5 mm wide, with a thickness of 1 mm. It is poled along the width dimension, with poling period 28. 93 μm. On the two polished end faces it has antireflection coatings at 1 064 nm, 1 350 nm~1 700 nm and 2 846 nm~5 027 nm. The crystal was mounted in a temperature-controlled oven with the operating range from room temperature to 250 ℃. In our experiment it was operated from 155 ℃ to 200 ℃ in order to avoid the photorefractive effect.

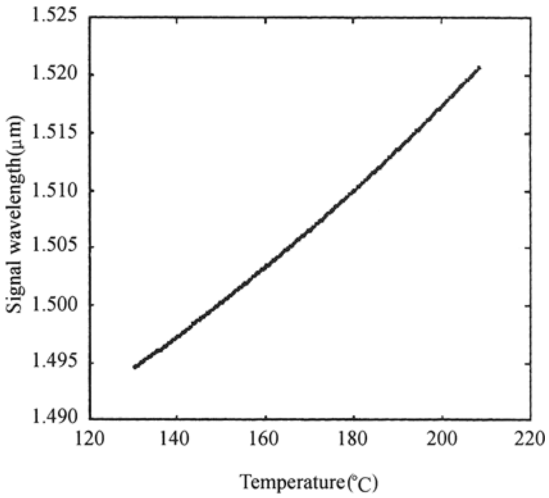
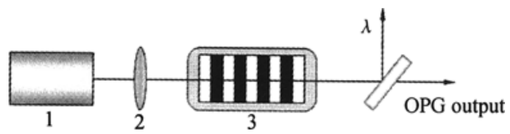


Fig. 1 The spectral-tuning curve as a function of the temperature of the PPLN



1:Pump source (1 064 nm acousto-optically Q-switched Nd:YVO_4 laser)
2:Focus lens (f=50 mm);3:PPLN crystal and its heating oven

Fig. 2 Schematic diagram of PPLN OPG

A Molectron PM500A-2 power meter is used to measured the powers of the pump laser and the average output of OPG. And an Agilent 86142B optical spectrum analyzer was used to measure the spectrum in the range of 600-1 700 nm.

When measuring the OPG output power at different temperatures we used a filter to reflect the residual pump source and only measured the average output power of the signal wave light. The average output power of the signal wave of the OPG versus the average pump power is shown in Fig. 3.

At T=155 ℃ the maximal average output power was 858mW at 1 502. 3 nm signal wave of the PPLN OPG when the pump power was 5. 43 W. When the temperature of the crystal was up to 200 ℃ the maximum average output power was 991 mW at 1 517. 1 nm signal wave of the PPLN OPG at the same pump power. The range of signal wave from 1 502. 3 nm to 1 517. 1 nm was obtained which shows good agreement with the the-

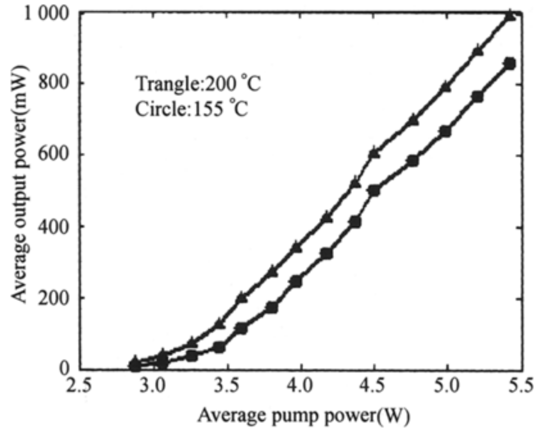


Fig. 3　The average output power of the signal wave of the OPG as a function of the average pump power

oretical result above. Fig. 4 (a, b) show the spectra of 1 502. 3 nm and 1 517. 1 nm signal wave light of the PPLN OPG by the optical spectrum analyzer separately.

In summary, we have demonstrated a high power output PPLN OPG pumped by a 1 064 nm acousto-optically *Q*-switched Nd: YVO_4 laser with about 70 ns (FWHM) pulse duration operating at a repetition rate of 45 kHz. When the average pump power was 5. 43 W the maximum average output power of the signal wave of the PPLN OPG is 858 mW at 1 502. 3 nm and 991 mW at 1 517. 1 nm at the fixed crystal temperature of 155 ℃ and 200 ℃ respectively. The experimental data of the wavelength range of the signal wave agree well with the calculated results. With the QPM technology it is possible to realize high power output OPG and we have demonstrated it in PPLN.

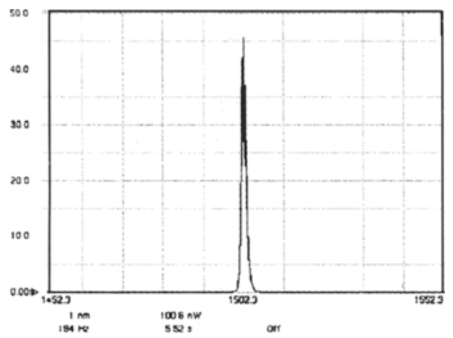


Fig. 4(a)　Spectrogram of 1 502. 3 nm signal wave of the PPLN OPG

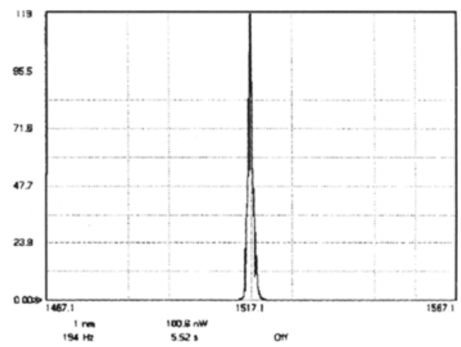


Fig. 4(b)　Spectrogram of 1 517. 1 nm signal wave of the PPLN OPG

References

[1] ZHANG Bai-gang, YAO Jian-quan, and LU Yang. *Journal of Optoelectronics • Laser*, **15**(2004), 337. (in Chinese)

[2] ZHANG Hao, YAO Jian-quan, and ZHANG Bai-gang. *Journal of Optoelectronics • Laser*, **14**(2003), 1250. (in Chinese)

[3] ZHANG Bai-gang, YAO Jian-quan, and ZHANG Hao. *Chin Phys Lett*. **20**(2003), 1077.

[4] L. E. Myers, R. C. Eckardt, and M. M. Fejer. *J. Opt. Soc. Am. B.*, **12**(1995), 2102.

[5] U. Bäder, J. P. Meyn, and J. Bartschke. *Opt. Lett.*, **24**(1999), 1608.

[6] P. E. Powers, K. W. Aniolek, and T. J. Kulup. *Opt. Lett.*, **23**(1998), 1886.

[7] J. M. Mark, D. Vince, and E. P. Peter. *Opt. Lett.*, **24**(1999), 1227.

[8] T. H. Jeys. *Opt. Lett.*, **21**(1996), 1229.

[9] J. J. Zayhowski. *Opt. Lett.*, **22**(1997), 169.