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1-W, high-repetition-rate room temperature operation of mid-infrared optical parametric oscillator based on periodically poled MgO-doped LiNbO*

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In this paper a high-repetition-rate mid-infrared (mid-IR) optical parametric oscillator based on periodically poled MgO-doped $LiNbO_3$ (PPMgLN) at room temperature was demonstrated. The maximum average mid-IR output power at 3.63μm was 1.02 W with the repetition rate of 60kHz and corresponding efficiency from the pump to the idler was 26.7%. The temperature tuning and the period tuning characteristics were also discussed.

Keywords: optical parametric oscillator, mid-infrared, periodically poled MgO-doped $LiNbO_3$, room temperature

PACC: 4265K, 4270, 4260F

1. Introduction

Nowadays, periodically poled $LiNbO_3$(PPLN) has become the most widely established material in mid-infrared (mid-IR) optical parametric oscillator (OPO) with the advantages of its relatively mature fabrication and poling technology, commercial availability in long interaction lengths (up to 60mm), wide transmission range (up to 5μm) and large effective nonlinear coefficient ($d_{\rm eff} \sim 16$pm/V).[1] While, due to the unexpected photorefractive effect in congruent $LiNbO_3$ at room temperature (RT, 28°C in this paper), it has to be operated at elevated temperatures (> 80°C), which restricts the practical application of the congruent PPLN. However, the performance of congruent $LiNbO_3$ operated at RT can be significantly improved by use of MgO-doped $LiNbO_3$ which has higher resistance to the photorefractive damage, lower coercive field for electric field poling (∼4.5 kV/mm) but comparable nonlinear optical coefficients.[2] All of these make the periodically poled MgO-doped $LiNbO_3$ (PPMgLN) a promising nonlinear crystal for mid-IR OPO at RT based on quasi-phase-matching (QPM) technique.

In high-repetition-rate QPM mid-IR OPO region, an average mid-IR output power of several hundred milliwatts has been demonstrated.[3−5] However, few have achieved the average power beyond 1W except the experiment exhibited by Hirano *et al*,[6] in which a doubly resonant oscillator operated at near degenerate point to improve the conversion efficiency, but the output wavelength was tuned only near 2μm. High-average-power mid-IR QPM singly resonant oscillator (SRO) over 3μm was rarely demonstrated, which is very important for atmospheric pollution monitoring and many military applications. In our previous papers, many near infrared PPLN-SROs based on different tuning methods were reported.[7−10] But due to the large absorption of the cavity mirrors and the filters at idler wavelength over 3μm, there was no mid-IR light in output waves. In this paper, a high-

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repetition-rate singly resonant mid-IR PPMgLN-OPO was demonstrated at RT. The maximum average output power of 1.02W at 60kHz repetition rate has been achieved at 3.63μm in an optimized symmetric resonator with the CaF_2 substrate.

2. Experimental arrangement

The schematic diagram of experimental arrangement is shown in Fig.1. The pump source was a commercially available 1064nm Q-switched Nd: YVO_4 laser (Aion Industrial-V, BAVARIAN PHOTONICS Corp.) with a beam quality factor $M^2 < 1.3$ and a maximum average power of 6.58W. The repetition rate of the pump laser can be adjusted in a range of 1–100kHz. To avoid possible damage in the periodically poled crystals, the average pump power was set at 4.5W and the repetition rate was fixed at 60kHz in the experiments. The pulse width was ∼30ns. The pump light was focused by a single 100-mm focal-length lens, resulting in a 60-μm beam waist (radius) inside the PPMgLN crystal.

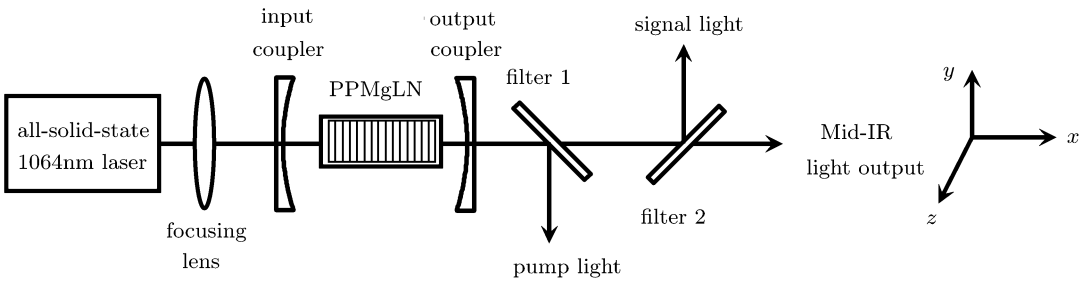


Fig.1. The experimental arrangement of the mid-IR PPMgLN-OPO.

The 5-mol.% PPMgLN crystal (HC Photonics Corp.) in the experiments has a period of 30μm and a dimension of 50 mm (length) × 5mm (width) × 1mm (thickness). Both end facets of PPMgLN were polished and antireflection-coated at 1064nm, 1.35–1.7μm and 2.85–5.03μm. Considering the simplification of the setup, we did not apply heating element for PPMgLN. So the temperature of the PPMgLN was at RT.

The symmetric linear OPO resonator had two cavity mirrors with a radius of curvature of 100mm, which were separated by 90mm. This configuration produced the mode sizes of 130μm (radius) inside the crystal for the resonant signal waves. The input coupler of the OPO cavity was coated with high reflectivity for the signal light and high transmission for the pump light. The output coupler had a reflectivity of 52%, 99% and 5% at the pump, signal and idler wavelengths. Therefore, the configuration satisfied the condition for SRO. The input coupler was a BK9 substrate, and the output coupler was made of a CaF_2 substrate which had the low absorption at the idler wavelength over 3μm. Both filters were made of CaF_2 substrates for idler output. Filter 1 was coated with high reflectivity for the pump light and high transmission for the signal and idler light to filter out the residual pump wave. Filter 2 had the high reflectivity for the signal light and high transmission for the idler light to separate the signal wave from idler wave.

3. Results and discussion

The signal spectrum was observed by an Agilent 86142B optical spectrum analyser. The mid-IR idler wavelength can be easily deduced by the energy conservation law as follows:

$$\frac{1}{\lambda_{\rm p}} = \frac{1}{\lambda_{\rm s}} + \frac{1}{\lambda_{\rm i}} \tag{1}$$

where λ_j (j=p, s, i) are the wavelengths of pump, signal and idler waves. In the experiment, the signal wave at 1.51μm and the idler wave at 3.63μm can be produced by the PPMgLN with the period of 30μm at RT.

The average output power of the PPMgLN-OPO at RT as a function of the average pump power was shown in Fig.2. The threshold of the PPMgLN-OPO was 11.8μJ, which agreed with the calculation result of 14.5μJ by use of a simple model of a pulsed SRO.[11] As the aim of the mid-IR obtainment, with the high signal reflectivity of the output mirror, the maximum

average mid-IR idler power at 3.629μm was 1.02W and the corresponding average signal power was 161mW with an average incident pump power of 4.5W. 77% of pump depletion was observed at the maximum pump power. The corresponding efficiency from the pump to the idler was 26.7%. In the experiments, we didn't observe any optical damage in the crystal.

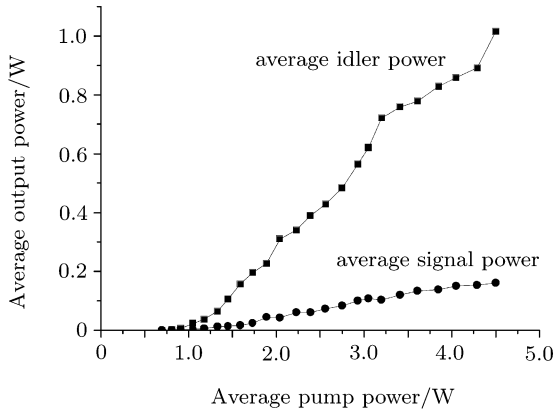


Fig.2. Average output power of the PPMgLN-OPO at RT as a function of the average pump power.

The average idler powers at elevated temperatures were shown in Fig.3, when PPMgLN was placed in a heating oven. The output idler powers had the maximum value of 1.19W at 80°C and declined at both sides of 80°C. This trend could be attributed to the wavelength-dependent reflectance of the OPO cavity mirrors and the temperature-dependent property of the parametric gain.[1] It was noted that the output idler power at RT was comparable with the powers at the elevated temperatures, which indicates no photorefractive damage in our PPMgLN at RT during the experiments. The corresponding temperature tuning curve was shown in Fig.4, where the solid lines represent the theoretical tuning curves calculated from quasi-phase-matching condition[1] and the dots show the experimental results. The idler wavelength could be tuning from 3.62μm to 3.33μm (RT ~200°C) when the period was 30μm. Only a single grating PPMgLN was applied in the experiments due to the limitation of the experimental condition. However, the theoretical calculation result of period tuning curve shows that tuning range from 1.35μm to 1.79μm and from 2.61μm to 4.99μm can be achieved by using multi-grating PPMgLN from 26μm to 32μm at RT. So the multi-grating PPMgLN will be preferable for the future requirement of the more widely tunable mid-IR source at RT.

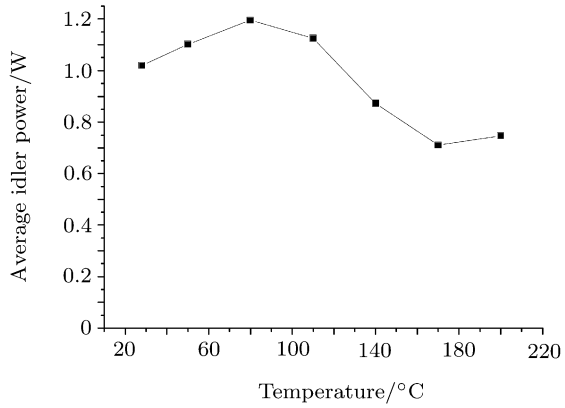


Fig.3. The average idler power at different temperatures.

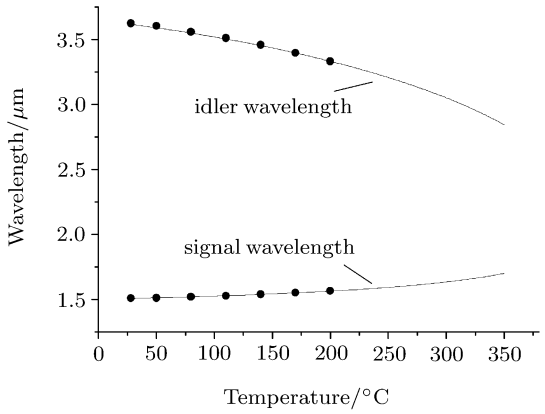


Fig.4. Temperature tuning curve for the period of 30 μm pumped by 1064nm.

The temporal behaviours of the incident pump, the depleted pump and the output signal waves were detected by an InGaAs photodiode and were presented in Fig.5. It was a pity that the temporal profile of the idler wave could not be given because the photodiode can not response the mid-IR light. The output signal pulse width was ~30ns and the idler pulse width could be deduced as the same magnitude as that of the signal wave because of the simultaneous generation of the signal and idler waves. It was observed that the signal profile had a tail due to the high signal reflectivity of the output coupler. The profiles in Fig.5 only showed the temporal relationship among the three waves, but the amplitudes could not represent the ratios of the three waves' intensities.

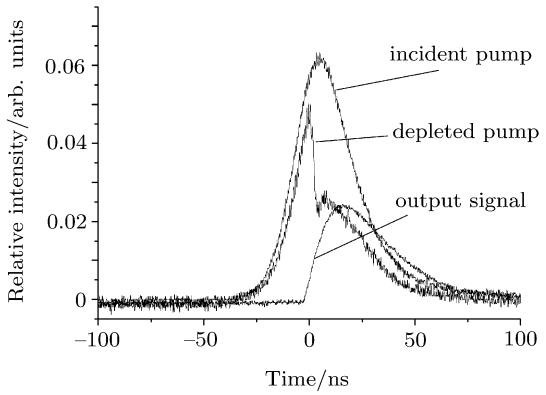


Fig.5. The temporal behaviours of the incident pump, the depleted pump and the output signal waves.

4. Conclusions

In conclusion, we have demonstrated a high-repetition-rate mid-IR singly resonant OPO at RT based on PPMgLN. Over 1-W mid-IR light at 3.629μm was obtained at repetition rate of 60kHz. The efficiency from the pump to the idler was 26.7%. The comparable idler powers were obtained at the elevated temperatures, as indicated no photorefractive damage occurred in the PPMgLN. The further theoretical analysis for the period tuning characteristics of the PPMgLN at RT showed discontinuous tuning range from 2.612μm to 4.988μm which would be realized by using multi-grating PPMgLN-OPO.

References

[1] Myers L E, Eckardt R C, Fejer M M, Byer R L, Bosenberg W R and Pierce J W 1995 *J. Opt. Soc. Am.* B **12** 2102

[2] Ishizuki H and Taira T 2005 *Proceedings of the CLEO* 2005 **CFC7** 2108

[3] Lin X C, Kong Y P, Zhang Y, Zhang J, Yao A Y, Bi Y, Sun Z P, Cui D F, Li R N, Wu L A and Xu Z Y 2004 *Chin. Phys.* **13** 1042

[4] Cai S S, Wu B, Xu H B, Shen J W and Shen Y H 2006 *J. Infrared Millim. Waves* **25** 338(in Chinese)

[5] Li H P, Tang D Y, Ng S P and Kong J 2006 *Opt. Laser Technol.* **38** 192

[6] Hirano Y, Yamamoto S and Taniguchi H 2001 *Proceedings of the CLEO* 2001 **CFH2** 579

[7] Zhang B G, Yao J Q, Zhang H, Zhang G Y, Xu D G, Wang T, Li X J and Wang P 2003 *Chin. Phys. Lett.* **20** 1077

[8] Zhang B G, Yao J Q, Zhang H, Xu D G, Wang P, Li X J and Ding X 2003 *Chin. Opt. Lett.* **1** 346

[9] Zhang B G, Yao J Q, Ding X, Xu D G, Zhang H, Yu G J, Wei Q F and Wang P 2004 *Chin. J. Lasers* **31** 897 (in Chinese)

[10] Zhang B G, Yao J Q, Lu Y, Ji F, Zhang T L, Xu D G, Wang P and Xu K X 2006 *Acta Phys. Sin.* **55** 1231(in Chinese)

[11] Brosnan S J and Byer R L 1979 *IEEE J. Quantum Electron.* **QE-15** 415