Low-threshold mid-IR MgO:PPLN optical parametric generation with high reflectivity mirror for signal wavelength

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A low-threshold middle-infrared (mid-IR) MgO:PPLN optical parametric generation (OPG) pumped by a laser diode (LD) end-pumped Z-type Nd:YLF laser at 1047 nm is realized with high reflectivity(HR) mirror for signal. At repetition rate of 10 kHz, the OPG threshold of 50 μJ has been achieved with HR mirror for signal. Compared with the threshold without mirror, the threshold decreases by 17%. Using HR mirror for pump at output side of crystal, the threshold of 40 μJ is achieved. The $2.7-4.1$ μm continuous tunable output is produced with seven grating periods from 28.5 to 31.5 μm and temperatures from 30 to 200 °C. When the incident average pump power is 3 W, the OPG idler output power is 0.46 W at 3.26 μm, which corresponds to optical-to-optical conversion efficiency up to 15.3%.

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Tunable middle-infrared (mid-IR) coherent sources have obtained a variety of applications, such as remote sensing, spectroscopy and laser radar. Optical parametric generation (OPG) is an efficient way to obtain such a laser source in mid-IR regions. In recent years there has been increasing interest in the use of a periodically poled lithium niobate (PPLN) with the largest nonlinear coefficient and quasi-phase-matching (QPM) capability. PPLN doped with magnesium oxide (MgO) is an important nonlinear material because it has low coercive field, which greatly improved its resistance to photorefractive damage threshold in contrast to the normal PPLN[1,2]. Thus, MgO:PPLN OPGs are important devices for achieving widely tunable mid-IR optical sources. Rahm *et al.*[3] reported a PPLN OPG by using a 55-mm-long PPLN pumped by a 10-kHz nanosecond single-mode Nd:YVO$_4$ laser. Missey *et al.*[4] reported a low repetition rate PPLN OPG. Zhang *et al.*[5] demonstrated a PPLN OPG with a threshold of 535 mW at a repetition rate of 22.6 kHz. Zhao *et al.*[6] reported a PPLN OPG with a threshold of 41.2 μJ at a repetition rate of 4.1 kHz. However, MgO:PPLN used in high-repetition rate OPG has been reported little.

In this paper, an experimental demonstration of a low-threshold mid-IR MgO:PPLN OPG by high reflectivity (HR) mirror for signal and for pump is reported. The OPG threshold of 40 μJ is achieved. The method of reducing threshold is used in high-repetition rate MgO:PPLN OPGs. The idler's tuned characteristics in $2.7-4.1$ μm are also investigated.

Figure 1 shows a schematic of the experimental setup for a high-repetition-rate MgO:PPLN OPG. A diode dual end-pumped Nd:YLF laser is built as a pump source. A Z-type resonator is designed with distance of 50 cm, which ensures an optimum mode matched between the pump and laser and ensures that the laser beam size is almost constant in the resonator stability zone. A "Z" cavity is formed by a Nd:YLF crystal, an acousto-optically (AO) Q-switching, and four mirrors. The active medium is an a-cut 0.6 at.-% Nd:YLF crystal with the length of 10 mm. The crystal is antireflection-coated for 1047 and 792 nm, and is wrapped with indium foil and mounted in water cooled copper blocks. The water temperature is maintained at 25 °C. The acousto-optically Q-switch is a ZF6 glass, driven by 8-V electric power supply. The core diameter and numerical aperture (NA) of 792-nm fiber-coupled laser diode (LD) are 400 μm and 0.2, respectively. Two focusing lens with 25 and 40 mm focal length are used to re-image the LD beam into the laser crystal. The spot radius is 300 μm or so.

A multi-grating 5 mol.-% MgO-doped PPLN (from hgih capacity (HC) Photonics) is used to avoid photorefractive damage to the crystal at room temperature. The PPLN is 50 mm in length, 8.2 mm in width, and 1 mm in thickness with seven different grating periods from 28.5 to 31.5 μm in 0.5-μm increment. The both end facets of the crystals are polished and antireflection-coated for 1.064, $1.44-1.605$, and $3.16-4.07$ μm. The crystals are mounted in heating oven which makes it possible to adjust the temperature of the crystals over a range of $25-250$ °C with a precision of ±0.1 °C. In our experiment, a broadband filter (M$_1$) with cutoff wavelength 3 μm is used to block the signal and residual pump light.

Compared with optical parametric oscillator (OPO)[7],

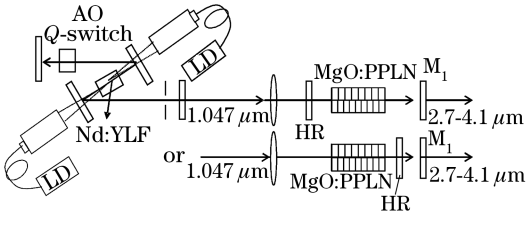

Fig. 1. Schematic of a high-repetition rate MgO:PPLN OPG.

OPG configuration is relatively simple and its threshold is higher. So, the key is to design 1-μm laser coupling system to achieve focused spot as small as possible to increase peak intensity. With such high-repetition rate of 10 kHz, short pulse of 20 ns, a 50-mm-long crystal, and a small pump spot, OPG achieves sufficient parametric gain to obtain efficient conversion to signal and idler in a single pass through the crystal without optical feedback. The maximum pump pulse energy used in the experiments is approximately 0.3 mJ. Assuming Gaussian beam profiles, the peak intensity at the centre of MgO:PPLN is 3 J/cm^2 for pump spot radius 80 μm and 1.91 J/cm^2 for 100 μm.

Figure 2 shows the measured characteristics of OPG idler output power with a 30-μm grating when the crystal temperature is 150 °C and both are pump spot radii. The maximum idler output power of 0.46 W at 3.26 μm is achieved at pump power of 3 W and spot radius of 80 μm, corresponding to total optical conversion efficiency of 15.3%. This indicates that small spot is favorable for threshold decrease and efficiency increase.

Two methods of reducing threshold are presented: Firstly, an external mirror at the pump input side of the MgO:PPLN crystal is employed to enhance signal feedback and to reduce the OPG threshold. The mirror is coated with 98% HR for signal and high transmission (HT) for the pump light and the idler. A weakly optical feedback is formed between external mirror and the anti-reflective (AR)-coated crystal ends. Secondly, a HR mirror for pump and signal at the output side of the crystal is employed. In contrast to the method mentioned above, the pump passes through the crystal twice. This design of double-pass pumping is mostly used in OPOs.

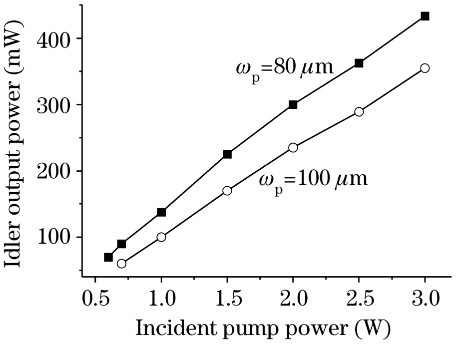

Fig. 2. OPG output powers versus incident pump powers at different pump spots.

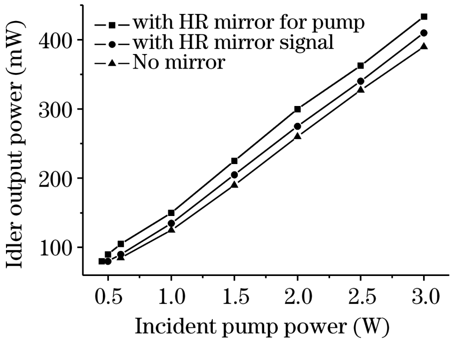

Fig. 3. OPG output powers versus incident pump powers with HR mirror.

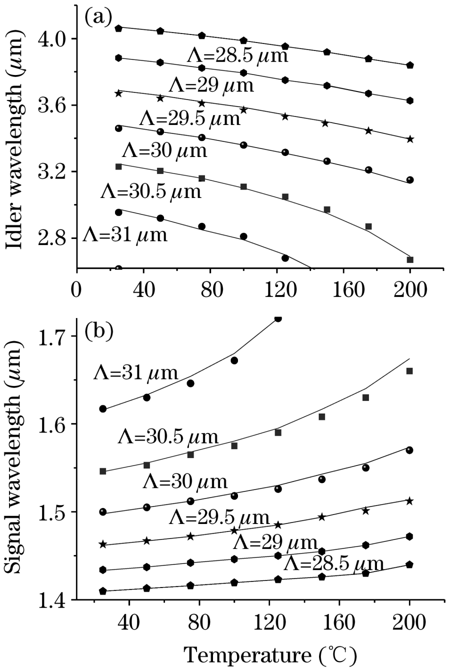

Fig. 4. Temperature-tuning curves of MgO:PPLN OPG with different grating periods. (a) Idler wavelength; (b) signal wavelength. Λ: grating period.

Figure 3 shows the measured output power characteristics of OPG with HR mirror. Using HR mirror for signal, the threshold of the OPG is measured as 50 μJ and decreased by 17% than that without mirror. Using HR mirror for pump and signal, the threshold is measured as 40 μJ, which decreased by 33%. This result predicts that the optical feedback from the AR-coated crystal ends (about 1% for both signals) is sufficient to turn the device into a parametric oscillator, resulting in considerably lower pump thresholds than that without any mirrors. This method is also applicable under high power pumping conditions.

The generated idler wavelength is measured by using a WDM1 – 3 monochromator with a focal length of 300 mm, a resolution of 0.8 nm, and an InS detector. With seven different grating periods and operation temperature, the signal and idler output can be tuned in the range of 1.41 – 1.7 μm and 2.7 – 4.1 μm respectively. Figure 4 shows the temperature-tuning curves of the OPG. Theoretical fitting curves and experimental data are shown by solid line and different marks respectively, which is in good agreement with each other.

In summary, we have demonstrated a low-threshold optical parametric generation based on periodically poled MgO-doped LiNbO$_3$ with HR mirror for signal. A diode-pumped actively Q-switched Nd:YLF laser with Z-cavity is used as the pump source, which produces 20-ns linearly polarized laser pulse with a repetition rate of 10 kHz. Using HR mirror for signal at the input side of the MgO:PPLN crystal, the threshold of the OPG is measured as 50 μJ and decreased by 17% than that without mirror. Using HR mirror for pump and signal at the output side of the crystal, the threshold is measured as 40 μJ and decreased by 30%. At a pump input of 3 W, the output power of 0.46 W at 3.26 μm and optical conversion efficiency of 15.3% are achieved (with period of 30 μm and temperature of 150 °C). By changing the crystal temperature and grating period, the OPG generates signal and idler output in the range of $1.41-1.7$ μm and $2.7-4.1$ μm respectively. The experimental results show that this method of decreasing threshold by HR mirror is effective and can be also used in high pumping conditions. The MgO:PPLN OPG is a useful and simple way to generate broadband mid-IR radiations.

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References

1. Y. Furukawa, K. Kitamura, S. Takekawa, K. Niwa, and H. Hatano, Opt. Lett. **23,** 1892 (1998).
2. Y. Furukawa, K. Kitamura, S. Takekawa, A. Miyamoto, M. Terao, and N. Suda, Appl. Phys. Lett. **77,** 2494 (2000).
3. M. Rahm, U. Bäder, G. Anstett, J.-P. Meyn, R. Wallenstein, and A. Borsutzky, Appl. Phys. B **75,** 47 (2002).
4. M. J. Missey, V. Dominic, P. E. Powers, and K. L. Schepler, Opt. Lett. **24,** 1227 (1999).
5. B. Zhang, J. Yao, X. Ding, H. Zhang, P. Wang, D. Xu, G. Yu, and F. Zhang, Chin. Phys. Soc. **13,** 364 (2004).
6. P. Zhao, B. Zhang, E. Li, R. Zhou, D. Xu, Y. Lu, T. Zhang, F. Ji, X. Zhu, P. Wang, and J. Yao, Opt. Express **14,** 7224 (2006).
7. X. Zhang, B. Yao, Y. Wang, Y. Ju, and Y. Zhang, Chin. Opt. Lett. **5,** 426 (2007).