

A Planar Ring Cavity ZnGeP₂ Optical Parametric Oscillator Cascade Pumped by 2μm Tm-Ho Laser

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Abstract: 3-5μm mid-infrared lasers have applications in several domains including spectrum detection, environmental monitoring, and medical diagnosis and optoelectronic countermeasures. The ZnGeP₂ optical parametric oscillator (OPO) pumped by 2μm laser is the important device for wavelength conversion into the 3-5μm mid-infrared waveband. A planar ring cavity ZnGeP₂ OPO cascade pumped by 2μm Tm-Ho laser was reported in this paper. When the pulse Tm-Ho laser pump power of 15W, the maximum output power of the ZnGeP₂ OPO laser was 4.12W, corresponding to the optical-optical conversion efficiency and the slope efficiency were 27.5% and 36.2%, respectively. The output peak wavelength is 3.9μm and 4.5μm, the pulse width is 17.5ns, and the beam quality is $M^2 \approx 2.8$.

1. Introduction

3-5μm mid-infrared coherent light source is one of the infrared atmosphere transmission windows, which includes absorption peaks of many atoms and molecules. So it is called the "fingerprint spectrum" of molecular. Its unique characteristics make it widely used in military and civilian fields such as spectrum detection, environmental monitoring, and medical diagnosis and optoelectronic countermeasures. There are many ways to obtain high-power 3~5μm laser output. One is to use the quasi-phase matching technology to directly realize the mid-infrared laser output from 1.06μm to 3~5μm. The activating material is periodically polarized lithium niobate crystal (PPLN) or Doped MgO periodically polarized lithium niobate crystals (PPMgLN) [1-2], although those crystals have higher nonlinear coefficients and the potential value of simplified mid-infrared laser structure, there are still many problems in the preparation of large-size crystals. Another way is to use a 2μm band laser-pumped optical parametric oscillator (OPO) to achieve 3-5μm laser output [3-4]. ZnGeP₂ crystal is the best nonlinear crystal for obtaining high power mid-infrared laser output in this kind of technical scheme because of its high nonlinearity coefficient ($187 \times 10^{-24} \text{ m}^2/\text{V}^2$) [5], good thermal conductivity (0.36 W/cm K) [6] and wide transmission spectrum range (2-12μm). The main challenge of this technical scheme is to design an efficient Q-switched 2μm pumped laser with high average output power and good beam quality.

In this paper, a planar ring cavity ZnGeP₂ OPO pumped by a 2μm Q-switched Ho: YAG laser was reported. The Ho: YAG laser was pumped by two orthogonally polarized 1.9μm Tm: YLF lasers. Under the acousto-optic Q-switched operation mode, the output average power of Ho: YAG laser was 22.8W with the pulse width of 20.01ns at the re-frequency of 6 kHz. The output center wavelength is 2090.73nm, the linewidth is 0.40nm, and the beam quality is $M^2 < 1.6$. The maximum output power of the planar ring cavity ZnGeP₂ OPO laser pumped by the Ho: YAG laser was 4.12W, corresponding to the optical-optical conversion efficiency and the slope efficiency were 27.5% and

36.2%, respectively. The output peak wavelength is 3.9 μm and 4.5 μm , the pulse width is 17.5ns, and the beam quality is $M^2 \approx 2.8$.

2. Experimental setup

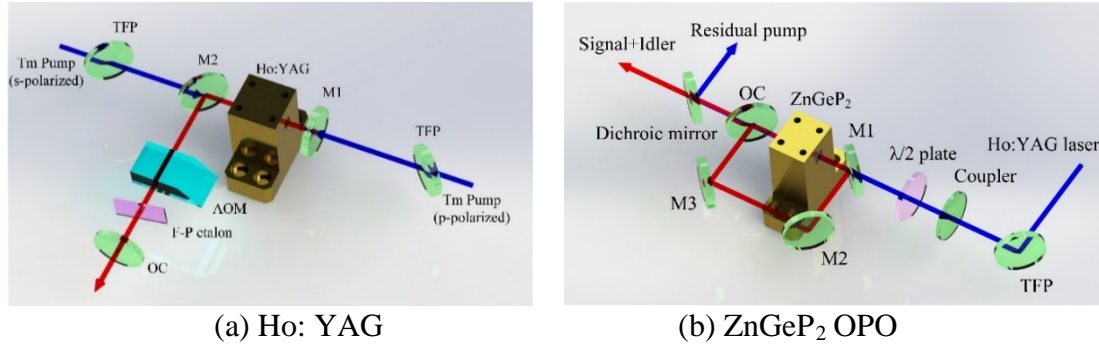


Figure 1. Schematic diagram of the laser system

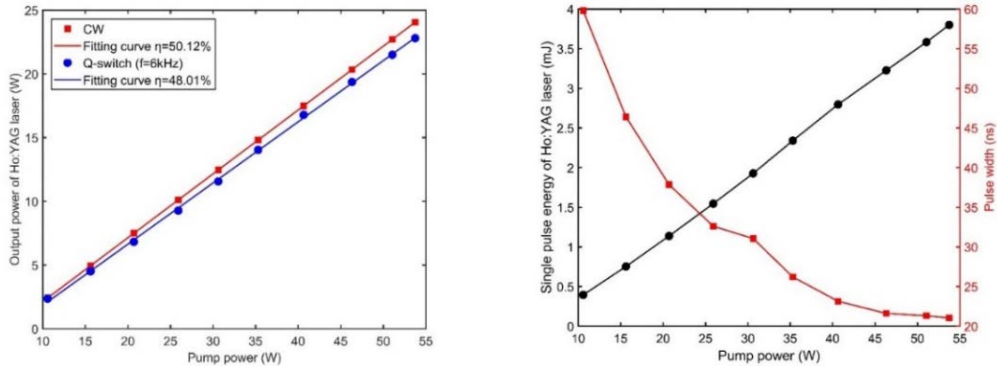
Figure 1 (a) schematically shows the Ho: YAG laser system used in the experiment. In the experimental system two orthogonally polarized Tm: YLF lasers were used as the pump source for the Ho: YAG laser system. Both of Tm: YLF lasers were used fiber-coupled LD pumping structures which had a maximum output power of 25W and the wavelength of 1908nm. Since the two Tm: YLF laser sources were s-polarized and p-polarized, respectively, the both Tm lasers can be polarization-isolated each other. This design effectively prevents the residual pump light from returning to the pump sources again and causing damage. Two TFPs were high transmission for s-polarized and p-polarized, respectively. The Ho: YAG crystal was $\Phi 5 \times 20 \text{mm}^3$ in diameter and the Ho^{3+} doping concentration was 1.0at. %. The Ho: YAG crystal wrapped in indium foil was placed in a copper heat sink, which was cooled by water cooling to maintain its temperature at 18°C. The resonant cavity of the laser system with a physical length of 150mm consisted of a laser output coupling mirror (OC), a flat laser reflecting mirror (M1), and a 45° laser reflecting mirror (M2). The laser reflecting mirrors were coated high reflection at 2090nm and high transmission at 1908nm. The output coupling mirror coated a light transmittance of 30% for 2090nm had a radius of curvature of 300mm. The YAG F-P etalon with a thickness of 0.5mm was placed at a certain angle in the cavity to achieve narrow linewidth laser output, and also to stabilize the laser output. The Acousto-optic Q-switching device (AOM) was used to realize the Q-switched pulse output of the laser system. The AOM had the RF frequency of 40.68MHz and the maximum RF power of 50W.

Figure 1 (b) schematically shows the planar ring cavity ZnGeP_2 OPO pumped by the Q-switch Ho: YAG laser. The planar ring cavity of ZnGeP_2 OPO consists of three plane mirrors (M1, M2, M3) with $T > 99\%$ at 2 μm and $R > 99.5\%$ at 3-5 μm and a plane output coupler with $T = 40\%$ at 3-5 μm . After passing the coupler mirror, the Ho: YAG laser pump spot size of approximately 700 μm in diameter was focused into the ZnGeP_2 crystal. The ZnGeP_2 crystal was $5 \times 5 \times 16 \text{mm}^3$ in diameter and cut for Type I phase matching (55° to the c axis), which the both end faces were antireflection coated at 2 μm and 3-5 μm . The ZnGeP_2 crystal wrapped in indium foil was placed in a copper heat sink, which was cooled by water cooling to maintain its temperature at 20°C.

3. Results and discussion

The output power of the Ho: YAG laser system under two operation modes was measured, which is shown in Figure 2(a). From the figure it can be seen that both of the curves show a linear growth trend. Under the continuous wave (CW) operation mode, the output power of 24W was obtained, the corresponding optical-optical conversion efficiency was 44.75% and the slope efficiency was 50.12%. Under the Q-switched operation mode, output maximum average power is 22.8W at the re-frequency of 6 kHz. The corresponding optical-optical conversion efficiency and slope efficiency were 42.64% and 48.01%, respectively. The Q-switched laser pulse profile was measured by a

Tektronix DPO3050 oscilloscope with an HgCdTe detector. Figure 2(b) shows the dependence of the single pulse energy and pulse width of the Q-switched Ho: YAG laser on the pump power. It can be seen that as the pump power increased, the pulse width sharply narrowed. Finally, the maximum single pulse energy is 3.8mJ, and the corresponding peak power and pulse width are 180.78kW and 21.02ns.



(a) The output power (b) The single pulse energy and pulse width

Figure 2. The output characteristics of the Ho: YAG laser

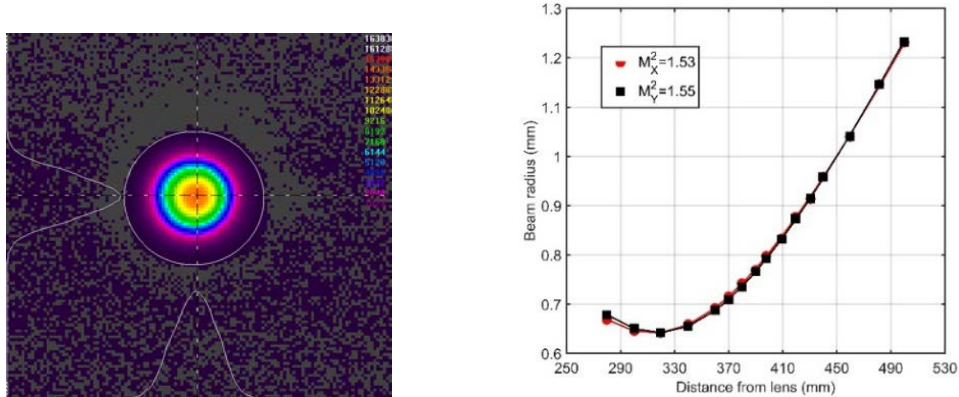


Figure 3. The laser output mode and beam quality of the Ho: YAG laser

The experiment further measured the output spectrum and beam quality of the Ho: YAG laser system. Figure 3 shows the laser output mode and beam quality fitting curve of the Ho: YAG laser measured by the 90/10 knife-edge method. It can be seen that the output laser is the fundamental mode output, and the beam quality in the X and Y directions is $M_x^2=1.53$ and $M_y^2=1.55$, respectively. Since there are many emission peaks of Ho: YAG laser in free running state, mainly 2090nm, 2097nm and 2122nm, as shown in Figure 4. During the experiment, we used the F-P etalon to limit the Ho: YAG laser output wavelength. The final output wavelength is 2090.73 nm and the linewidth is 0.4 nm. The stable single-wavelength Ho: YAG laser output is achieved.

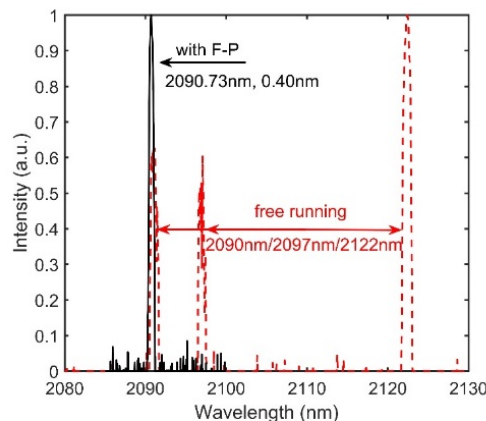


Figure 4. The spectrum of the Ho: YAG laser at the maximum output power

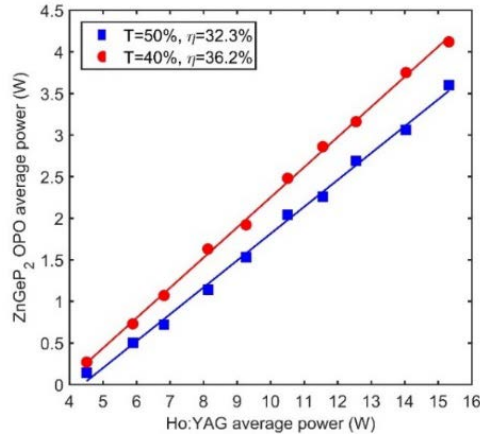


Figure 5. The output power of the planar ring cavity ZnGeP₂ OPO

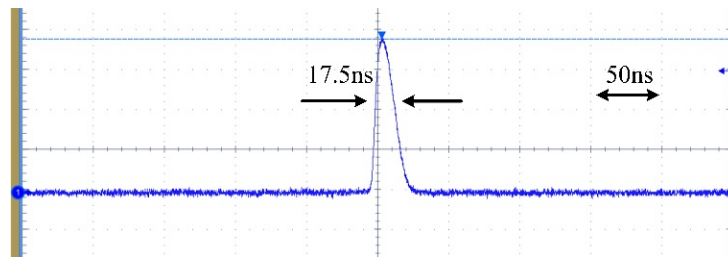


Figure 6. The pulse width diagram of the planar ring cavity ZnGeP₂ OPO

The published results show that if the OPO is doubly resonant and pumped by a multi-mode beam, when the OPO optical length matches the optical length of the pump light source, the output energy has a significant maximum, even if the length is much longer than the length of the pump light source. The shortest possible OPO. Based on the above investigation, we choose 150 mm physical length for further study. The output power of a ring resonator with a physical length of 150mm is shown in Figure 5. At 6 kHz pulse repetition frequency, the maximum output power of the resonator is 4.12W, corresponding to the optical-optical conversion efficiency and the slope efficiency were 27.5% and 36.2%, respectively. When the Ho event pump power is 15W, the shortest pulse width is 17.5ns. The typical oscilloscope trajectory is shown in Figure 6.

Figure 7(a) shows the laser output mode and beam quality fitting curve of the planar ring cavity ZnGeP₂ OPO. It can be seen the beam quality in the X and Y directions is $M_x^2=2.80$ and $M_y^2=2.70$, respectively. In addition, the output spectrum of the planar ring cavity ZnGeP₂ OPO was measured, which is shown in Figure 7(b). The output peak wavelength is 3.9 μ m and 4.5 μ m was obtained.

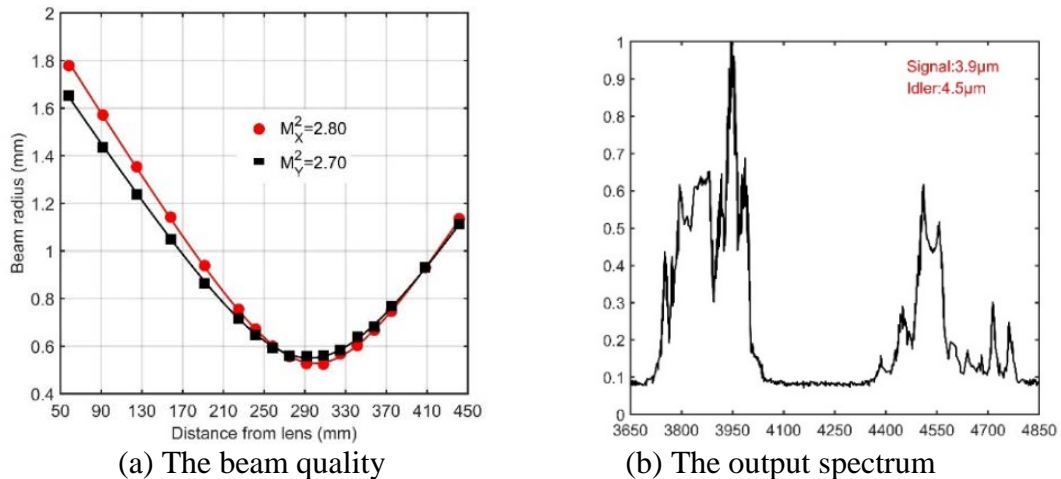


Figure 7. The beam quality and the output spectrum of the planar ring cavity ZnGeP₂ OPO

4. Conclusion

In conclusion, a planar ring cavity ZnGeP₂ OPO pumped by a 2μm Q-switched Ho: YAG laser was reported. The output average power of Ho: YAG laser was 22.8W with the pulse width of 20.01ns at the re-frequency of 6 kHz. The output center wavelength is 2090.73nm, the linewidth is 0.40nm, and the beam quality is $M^2 < 1.6$. The maximum output power of the planar ring cavity ZnGeP₂ OPO laser pumped by the Ho: YAG laser was 4.12W, corresponding to the optical-optical conversion efficiency and the slope efficiency were 27.5% and 36.2%, respectively. The output peak wavelength is 3.9μm and 4.5μm, the pulse width is 17.5ns, and the beam quality is $M^2 \approx 2.8$.

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