1.99 micron Tm:YAP acousto-optical Q-switch laser

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Abstract: Report the acousto-optical Q-switched operation of double ended pump big energy Tm:YAP laser. Tm:YAP crystal was a-cut, the dimensionas were 3mm×3mm×10mm and doped was 3at%. The laser diode center wavelength of 795nm. When the pump power was 79.2W, the repeat frequency was 1 kHz, a 1.99 μm wavelength laser output of up to 16.36 mJ was obtained, the narrowest pulse width of 38.04 ns, the peak power of 430.07 kW. The slope efficiency was 29.42%, light and light conversion efficiency was 20.66%. When the Q-switched average power was 15W, the beam quality factor of M² was estimated of 3.19 in x-direction and 3.29 in y-direction.

1. Introduction

The mid-infrared 2μm laser was in the weak absorption zone of the atmosphere and has features for human eye safety[1]. It has been used in atmospheric environmental gas monitoring, laser radar, medical clinical diagnosis and treatment, material processing and processing, and optoelectronics[2-3]. At the same time, it has been also an efficient pump source for 3-5μm, 8-12μm medium and far infrared OPO. Therefore, high power, high energy 2μm band pulse laser has been currently the focus of research[4-5]. Compared with Tm laser pumping Ho-Q laser and pumping OPO, we had used Q-switched of Tm:YAP laser as the OPO pumping source. This method could greatly reduce the overall structure of the laser and made the structure of the laser more compact.

In 2008, Harbin Institute of Technology had reported an acousto-optic Q-switched Tm:YAP laser with a Tm:YAP block crystal of 2.6mm×2.6mm×5mm. When the repetition frequency was 5 kHz, the pulse width was 80 ns and the average output power was 3.9 W, the center wavelength was 1937nm, the single pulse energy was 0.78mJ, the light and light conversion efficiency was 21.6%, and the slope efficiency was 29.4%[6]. In 2008, Zhejiang University had reported an acousto-optic Q-switched Tm:YAP laser with a Tm:YAP crystal of 3mm×3mm×7mm. When the pump power was 12.6 W, the repetition frequency was 1 kHz, obtain a single pulse energy of 1.57mJ, the narrowest pulse width was 120 ns, and the center wavelength was 1989 nm[7]. In 2015, Harbin Engineering University had reported a sound and light Q-switched Tm:YAP cavity Raman laser with a Tm:YAP block crystal of 3mm×3mm×10mm. At a repetition rate of 1kHz, the maximum output power was 880mW with the maximum single pulse energy 0.88 mJ, and pulse width of 400 ns, center wavelength of 19.4 μm[8]. In 2018, Harbin Engineering University had reported an acousto-optic Q-switched Tm:YAP laser with a Tm:YAP block crystal of 3mm×3mm×10mm. When the repetitive frequency was 1kHz and the pumping power was 21.1W, the maximum output power was 870mW. Meanwhile, the pulse width was 150.04ns, with the single pulse energy of 0.87mJ, center wavelength of 1990nm, slope efficiency of 14%[9].

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It is important to study Tm:YAP lasers with large energy, for the reason that 1.99 μm is closer to the absorption peak of 2 μm deviating from water and the 1.99 μm pulsed lasers can be directly used as the pump source of nonlinear crystal such as AgGaSe₂. In summary, the maximum single pulse energy of 0.88 mJ at 1.94 μm and 1.57 mJ at 1.99 μm. Longer laser crystals and heating more uniform are needed to lead the Tm:YAP crystal to absorb more pump light and obtain a large energy laser output because the thermal distortion and thermal effect of Tm:YAP crystal are serious, and the damage threshold (~330 MW/cm²) is low.

In this experiment, Tm:YAP crystal was a-cuts, the dimensions were 3 mm × 3 mm × 15 mm, the doped was 3 at.%. Used LD double-end pumping with a center wavelength of 795 nm. When the pump power was 79.2 W, the maximum output power was 20.43 W. The acousto-optic Q-switching technique was used, when the high-repetition-rate was 1 kHz, obtained 1.99 μm laser output which had a single pulse energy of 16.36 mJ, a narrowest pulse width of 38.04 ns, and a peak power of 430.07 kW. The beam quality at this time was measured $M^2_x = 3.19, M^2_y = 3.29$.

2. Experimental setup and analysis
The experimental setup of LD dual-end pumped Tm:YAP acousto-optic Q-switched laser was shown in Figure 1. The LD was output through an optical fiber with a maximum power of 60 W, a center wavelength of 795 nm, a fiber core diameter of 400 μm, and a numerical aperture of 0.22. The pumping light was collimated and focused by focusing mirrors composed of two plano-convex mirrors M1 and M2 into the Tm:YAP crystal, with focal lengths of 25 mm and 75 mm respectively; Tm:YAP crystal was a-cut with a doping concentration of 3 at. %, its size was 3 mm × 3 mm × 15 mm³, and both ends of the crystal were coated with an antireflection film which had high permeability of 795 nm and 1.99 μm; The crystal adopted water-cooled heat dissipation method; the resonant cavity adopted "L" type structure, the cavity length was 120 mm, and the resonant cavity was composed of M3, M4, M5, in which M3 was full mirror, HT795 nm pumping light, HR1990 nm laser; M4 was 45° Mirror, HT795 nm pumping light, HR1990 nm laser; M5 was a flat concave output mirror with a transmittance of 5% for a 1990 nm laser, and its curvature radius was 300 mm.

AO is Gucci acousto-optic Q switch, which consists of two parts: acousto-optic Q head and driving power supply. The aperture is 2 mm, the RF power is 40.68 MHz. In the test, the AO head was cooled by water cooling and the temperature was 16 °C. The Q-switched crystal was added to the cavity, which will cause loss. At this time, the output power and pulse width when the free run and the repeat frequency was 1 kHz, 2 kHz, and 10 kHz are measured.

Fig. 1 The structure of acousto-optical Q-switch Tm:YAP laser

It can be seen from the figure 2 that after inserting the Q-switched crystal in the cavity, the laser oscillation threshold did not change much, and the loss caused by the Q-switched crystal in the cavity was small. Under the maximum power pumping conditions, the maximum average powers obtained when the repetition frequencies were 1 kHz, 2 kHz, and 10 kHz were 16.36 W, 17.63 W, and 19.75 W, respectively. The maximum output power obtained at the repetition rate of 1 kHz and 2 kHz was
equivalent, which means that the extraction efficiency of the laser was not much different when the repetitive frequency difference was small. When the re-frequency was increased to 10 kHz, there was a case where the output power tended to continuously run during the Q-switching operation.

![Fig.2 The output power of free running and Q-switching](image)

Figure 3 shows that the relationship between the pulse width and the pumping power when the repetitive frequency was 1 kHz, 2 kHz, and 10 kHz. It can be seen from the figure that under the same repetitive frequency condition, the pulse width gradually narrowed as the pumping power increased. When the pumping power was consistent, the smaller the retransmission, the narrower the pulse width. When the pumping power was 79.2W, when the repetition frequency was 1kHz, 2kHz, 10kHz, the maximum single pulse energy was 16.36mJ, 8.82mJ, 1.98mJ, and the pulse width was 38.04ns, 66.89ns, 89.9ns, respectively. The peak power was 430.07kW, 131.86kW, 22.02kW. Figure 4 shows the pulse sequence with the repetitive frequency of 1 kHz and the narrowest pulse width map.

![Fig.3 The pulse width with different repetition frequency](image)

Under the same excitation energy, the output Q-switched pulse width increases with the increase of the repetitive frequency, which can be understood as the increase of the re-frequency, which reduces the residence time of the photon in the cavity, thereby reducing the lifetime of the photon in the cavity. The pulse width is proportional to the photon lifetime, and as the repetitive frequency increases, the pulse width also increases.

![Fig.4 Typical pulse train(left) and pulse shape (right)with pulse Tm:YAP laser](image)
The laser output wavelength was measured by a spectrometer (AQ6375 Co.YOKOGAWA) with a center frequency of 1988 nm at a repetition rate of 1 kHz and an output power of 15 W. The spectral FWHM was 1.33 nm. Due to mode competition, the line width was slightly wider, but the center wavelength was stable, there was no phenomenon of wavelength drift. The spectrum was shown in Figure 5.

At the average output power of 15 W, the repetition rate of 1 kHz, the beam quality factor of M2 was estimated of 3.19 in x-direction and 3.29 in y-direction according to beam quality analyzer. The beam profile and the curve fitting shown in Fig. 6.

3. Conclusion

In this paper, the LD dual-end pumped Tm:YAP acousto-optic Q-switched laser were studied. When the repetition-rate was 1 kHz, the single pulse energy of 16.36 mJ, the narrowest pulse width of 38.04 ns, the peak power of 430.07 kW, and the center wavelength of 1988 nm were obtained. The beam quality in x direction was 3.19, and y was 3.29. Since the 2 μm lasers with large energy were widely used in many fields, this experiment obtained a higher single pulse energy and improved the output energy of the Tm:YAP Q-switched laser, which will benefit to the pump sources as a 3-5 μm, 8-12 μm far infrared lasers. But at the same time the laser line width was wide, the beam quality was general. So it will be efficient for obtaining 2 μm lasers with narrow linewidth and high beam quality by using body grating or inserting F-P into intracavity.

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