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DIODE-PUMPED PASSIVELY *Q*-SWITCHED YAG/Yb:YAG LASER WITH Cr^{4+}:YAG AS A SATURABLE ABSORBER

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Abstract

We design an efficient passively Q-switched laser using a composite YAG/Yb:YAG crystal as the laser gain medium and a Cr^{4+}:YAG crystal as a saturable absorber. We obtain an average output power of 1.81 W in 1030 nm laser at an absorbed pump power of 4.8 W, corresponding to an optical-to-optical efficiency of 37.7% and a slope efficiency of 47.3%. The pulsed laser has a repetition rate of about 28.6 kHz and a pulse width of 15.8 ns, with the highest peak power of 4 kW. In addition, using a LBO as the intracavity frequency doubler, we obtain a maximum power of 246 mW in 515 nm pulsed laser at an absorbed pump power of 3.8 W.

Keywords: diode-pumped lasers, Q switching.

1. Introduction

Diode-pumped passively Q-switched lasers with high peak power, short pulse width, and good beam quality can be widely applied in target ranging, micromachining, lidars, remote sensing, and so on. Usually, passively Q-switched solid-state lasers operate using Nd^{3+}-doped or Yb^{3+}-doped materials as the gain media and Cr^{4+}:YAG or semiconductor saturable absorber mirror (SESAM) as a saturable absorber [1–13]. Cr^{4+}:YAG crystals are used as the saturable absorbers since they have several advantages due to the high damage threshold, low cost, and simplicity. Compared with Nd^{3+}-doped materials, Yb:YAG crystals are suitable for Q-switched pulse generation due to their long fluorescence lifetime (951 ± 15 μs). In addition, they have other merits such as a lower thermal loading ratio and the absence of excited-state absorption and up-conversion losses, because of the simple energy-level diagram of the Yb:YAG. Moreover, Yb:YAG crystals have strong and wide absorption bands near 940 nm and broad and sufficiently intense emission bands at 1030 nm.

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By now, passively Q-switched Yb:YAG lasers have been investigated and reported [14–20]. In 2006, diode-laser-pumped passively Q-switched Yb:YAG/Cr^{4+}:YAG microchip lasers were elaborated with a slope efficiency of 36.8% and an optical-to-optical efficiency of 27%, and a pulse width of 1.35 ns and a peak power over 8.2 kW were obtained [16]. In 2009, a passively Q-switched Yb:YAG/Cr^{4+}:YAG microchip laser with a pulse repetition rate above 100 kHz was experimentally demonstrated with an average output power of 0.45 W and a peak power of 1.5 kW at the single-mode operation [18]. In 2012, a high peak power passively Q-switched Yb:YAG/Cr:YAG laser was reported, and an output pulse energy of 0.8 mJ at 20 Hz was obtained with a duration of 4 ns and a peak power of 200 kW [19].

Laser materials doped with Yb^{3+} are quasi-three-level active media. The thermal population at the lower laser level leads to a re-absorption of the laser emission. To improve the laser performance, a high pumping intensity is needed, and the temperature in the laser medium should be reduced [21, 22]. Therefore, composite laser crystals are needed urgently, and composite YAG/Yb:YAG crystals can be employed for high efficient and high power quasi-three-level laser operation [23, 24].

In this paper, we demonstrate experimentally a high-efficiency passively Q-switched YAG/Yb:YAG laser with the Cr^{4+}:YAG crystal as a saturable absorber. We obtain a maximum average output power of 1.81 W at an absorbed pump power of 4.8 W with an optical-to-optical efficiency of 37.7% and a slope efficiency of 47.3%. We design the pulsed laser with a repetition rate of 28.6 kHz and a pulse width of 15.8 ns at an absorbed pump power of 4.8 W and with a highest peak power of 4 kW. Using a LBO as the intracavity frequency doubler, we also obtain a maximum power of 246 mW in 515 nm pulsed laser at an absorbed pump power of 3.8 W.

2. Experimental Setup

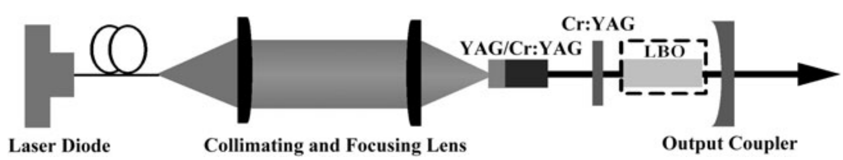

Fig. 1. Schematic diagram of a diode-end-pumped passively Q-switched YAG/Yb:YAG laser with the Cr^{4+}:YAG as a saturable absorber.

The experimental setup for a diode-end-pumped passively Q-switched YAG/Yb:YAG laser with the Cr^{4+}:YAG as a saturable absorber is shown in Fig. 1. A fiber-coupled 940 nm laser diode with a core diameter of 400 μm and a numerical aperture of 0.22 is used as the pump source. The pump beam is coupled into the gain medium by two collimating and focusing lenses with focal lengths of 25 mm. A plane-parallel YAG/Yb:YAG crystal with a diameter of 3 mm and a Yb^{3+}-doped concentration of 10 at.% is used as the gain medium, the length of the one-end grown undoped YAG cap is 1 mm, and the length of the Yb^{3+}-doped region is 3 mm. The YAG-cap surface is antireflectively coated at 940 nm and has high reflection at 1030 nm to act as a cavity mirror. The other surface is antireflectively coated at 1030 nm. The laser crystal is wrapped with indium foil, mounted in a copper heat sink, and cooled by floating water. An 0.8 mm thick Cr^{4+}:YAG crystal with an initial transmission of 95% is used as the Q-switching element. When the pulsed 1030 nm laser operates, a concave mirror with 50 mm curvature is used as the output coupler with transmission of 10% at 1030 nm. The cavity length is about 25 mm. When a 10 mm length LBO crystal is used as the intracavity frequency doubler, the cavity length is extended to 45 mm. The average output power of laser pulses is measured with a power meter. The laser emitting spectra are measured with an optical spectral analyzer. Pulse characteristics are recorded with the help of an InGaAs photodiode and a 300 MHz Tektronix digital oscilloscope.

3. Results and Discussion

The average output power of the passively Q-switched 1030 nm Yb:YAG/Cr^{4+}:YAG laser as a function of the absorbed pump power is shown in Fig. 2. The absorbed pump threshold is about 0.6 W. At the beginning stage, the output power and efficiency are low enough, which can be attributed to the re-absorption effect existing under a quasi-three-level laser operation. To suppress this unfavorable effect, a higher pump intensity and a lower temperature in the laser medium are needed. When absorbed pump power exceeds 1.2 W, the average output power increases nearly linearly with the absorbed pump power. A maximum average output power of 1.81 W is obtained when the absorbed pump power is 4.8 W, the corresponding optical-to-optical efficiency is about 37.7%, and the slope efficiency is 47.3%. There is no saturation of the average output power, which assumes that the laser performance can be further enhanced.

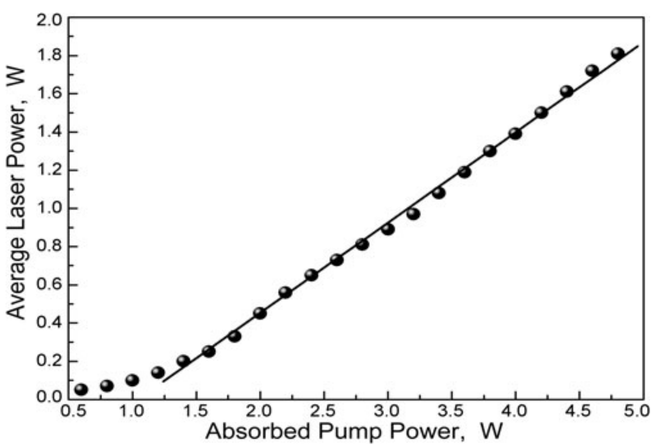

Fig. 2. Average output power of the passively Q-switched 1030 nm YAG/Yb:YAG laser versus the absorbed pump power. The slope efficiency is 47,3%.

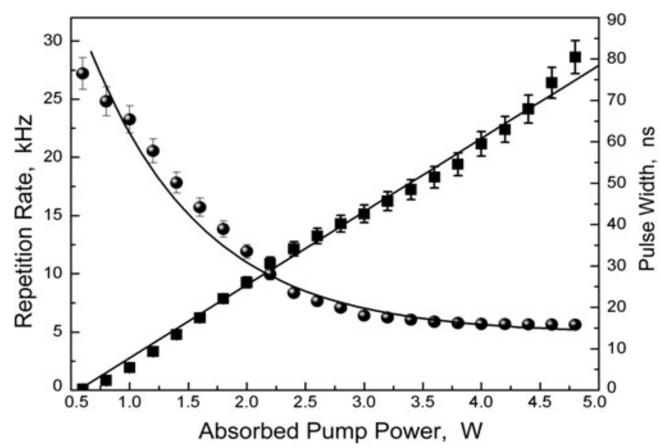

Fig. 3. The repetition rate (■) and pulse width (●) of the passively Q-switched 1030 nm YAG/Yb:YAG laser versus the absorbed pump power.

Figure 3 shows variations in the repetition rate and pulse width of the 1030 nm laser as a function of the absorbed pump power. The repetition rate increases nearly linearly and the pulse width decreases exponentially with the absorbed pump power. At an absorbed pump power of 4.8 W, the repetition rate increases to 28.6 kHz, and the pulse width decreases to 15.8 ns. Then, the average output power is 1.81 W, so the peak power of passively Q-switched lasers is estimated as 4 kW. Figure 4 shows a typical train of laser pulses and the oscilloscope pulse profile of 28.6 kHz. The Yb:YAG/Cr^{4+}:YAG passively Q-switched laser-pulse profile with a pulse width (FWHM) of 15.8 ns is shown in Fig. 5.

The beam radius for passively Q-switched 1030 nm laser at a power of 1.81 W is measured by the traveling 90/10 knife-edge method. By fitting the Gaussian-beam standard expression to the experimental data, the beam quality is estimated to be $M^2 = 1.18$.

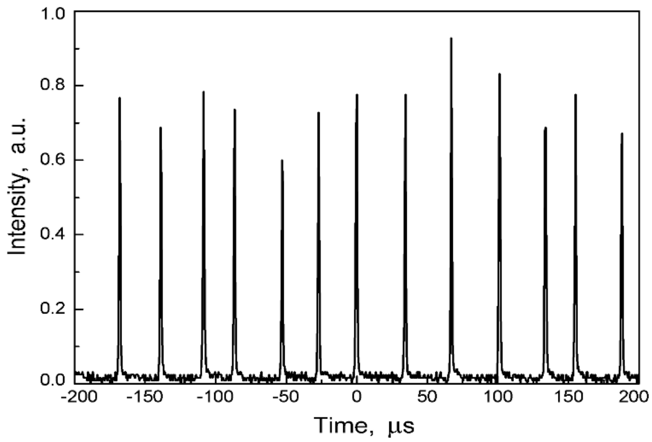

Fig. 4. Oscilloscope trace of the pulse train with a repetition rate of approximately 28.6 kHz.

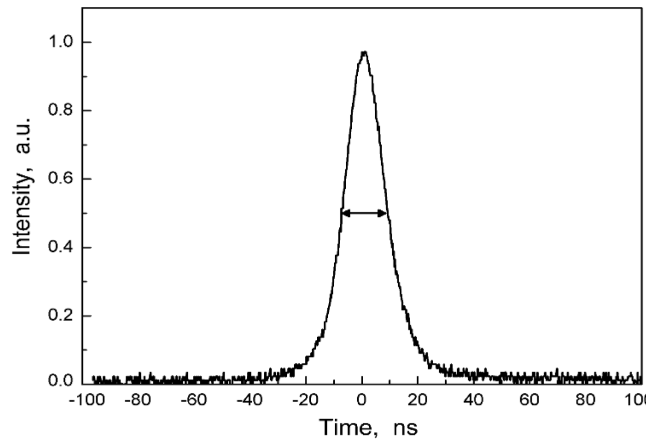

Fig. 5. Typical laser-pulse profile with a pulse width of 15.8 ns.

A LBO crystal with dimensions of $3\times3\times10$ mm^3 is employed as the intracavity frequency doubler. The crystal is cut for type-I critical-phase-matching condition and installed in a copper holder, whose temperature is precisely controlled by a thermal-electric cooler with an accuracy of 0.1°C. Figure 6 shows the average output power of the 515 nm laser versus the absorbed pump power. With increase in the pump power, the output power of the 515 nm laser increases exponentially. At a absorbed power of 3.8 W, the 246 mW laser at 515 nm is obtained.

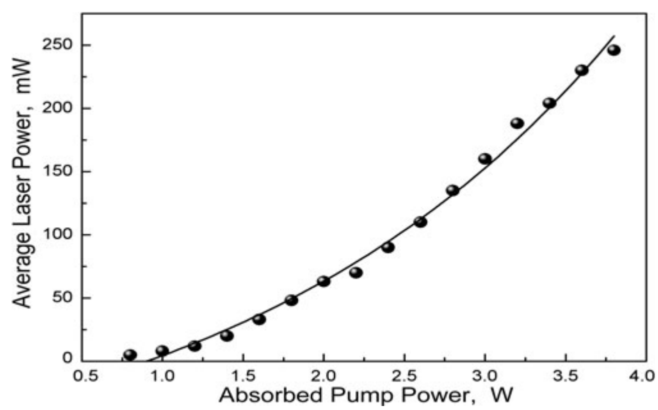

Fig. 6. Average output power of the 515 nm laser versus the absorbed pump power.

4. Conclusions

In summary, the efficient laser-diode-pumped passively Q-switched YAG/Yb:YAG laser with the Cr^{4+}:YAG crystal as an saturable absorber is obtained and investigated. The laser average output power increases linearly with the pump power, with a slope efficiency of 47.3%. A maximum average output power of 1.81 W is obtained at an absorbed pump power of 4.8 W, corresponding to an optical-to-optical efficiency of ~37.7%. Laser pulses at 1030 nm with a pulse energy of 63.2 μJ and a pulse width of 15.8 ns are achieved at a repetition rate of 28.6 kHz, with a corresponding peak power of 4 kW. In addition, using a LBO as the intracavity frequency doubler, a maximum power of 246 mW in pulsed laser at 550 nm is also obtained at an absorbed pump power of 3.8 W.

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