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Continuous-wave and passively Q-switched 1.06 μm ceramic Nd:YAG laser

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ABSTRACT

In this paper, a diode-pumped continuous-wave and passively Q-switched 1.06 μm laser with gain medium of ceramic was demonstrated. Laser output characteristics using Nd:YAG ceramics with different doping concentrations of 1.0%, 2.0%, and 4.0% were studied. A maximum output power of 7.74 W with optical efficiency of 51.6% was obtained through the optimization of the coupler's transmission. By using Cr^{4+}:YAG crystals with initial transmissions of 80% and 90% as saturable absorbers, the pulsed ceramic Nd:YAG laser performance was investigated.

1. Introduction

In recent years, extensive investigations have been conducted on Nd:YAG ceramic laser [1–5]. A laser and thermo-optical investigations of Nd:YAG ceramics was reported by Jabczyski. They obtained a maximum output energy of 5 mJ at absorbed pump energy of 16 mJ with 34% slope efficiency [2]. Li et al. studied LD-end-pumped passively Q-switched Nd:YAG ceramic laser with single wall carbon nanotube saturable absorber. The minimum pulse duration of 1.2 μs and maximum pulse energy of 4.5 μJ was generated at a repetition rate of 31.8 kHz [3]. A continuous-wave Nd:YAG ceramic lasers at 946 nm was reported by Zhu et al. They obtained a maximum output power of 10.5 W at the incident pump power of 35 W by using a 5 mm ceramic, corresponding to an optical conversion efficiency of 30% [4]. Compared with single-crystal Nd:YAG materials, the ceramic has many favorable characteristics, such as higher doping concentration [6], more function design freedom [7], low cost, and especially superior resistance to fracture than that of single-crystal [8]. Usually, the doping concentration of Nd^{3+} is ranging from 0.1–1.0 at% in ceramic lasers study. In this paper, ceramic laser with higher Nd^{3+} doping concentrations has been researched.

Q-switched lasers with high repetition rate and high power are widely used in many areas, such as remote sensing, laser lidar, and microsurgery [9,10]. Passively Q-switching technique has many advantages of obvious low cost, compactness, and simplicity in setup and operation since they do not require external control [11]. The Cr^{4+}:YAG saturable absorber has advantages of large absorption cross section, low saturable intensity and high damage threshold [12,13]. So, it is the most promising candidate for small size and low cost lasers.

In this paper, we demonstrated a continuous-wave (CW) and passively Q-switched 1.06 μm laser with ceramic Nd:YAG. The ceramic Nd^{3+} doping concentration of 1.0, 2.0, 4.0 at% and output couplers with different transmissions were investigated. Furthermore, Cr^{4+}:YAG crystal as the saturable absorbers with initial transmission of 80% and 90% were employed and the pulse laser output performance was compared and analyzed.

2. Experimental setup

The experimental configuration of Cr^{4+}:YAG passively Q-switched ceramic Nd:YAG laser under 808 nm laser-diode end-pumping was shown in Fig. 1.

The pump laser used in this experiment was a fiber coupled 808 nm CW laser diode. The fiber had a core diameter of 400 μm and a numerical aperture (NA) of 0.22. L1 and L2 were a set of collimating and focusing lenses. The diameter of pump laser spot

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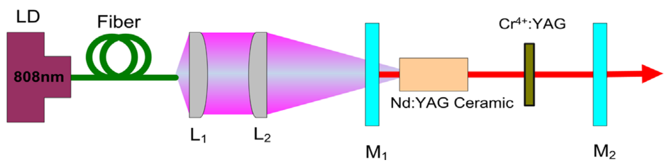

Fig. 1. Experimental configuration of passively Q-switched ceramic Nd:YAG laser.

in the ceramics was 501.4 µm. The ceramic Nd:YAG was provided by Shanghai Institute of Ceramics, Chinese Academy of Sciences in China. The size of the Nd:YAG ceramic were 3 mm × 3 mm × 10 mm. The doped ceramics had an Nd^{3+} ion concentration of 1.0, 2.0 and 4.0 at%, respectively. The ceramic was wrapped with indium foil and placed into water-cooled copper heat sink with microchannel structure. M1 was a flat mirror with antireflection at 808 nm and high reflectivity at 1064 nm. The output couplers M2 had different transmission (T) of 20%, 25%, 30%, 35% and 40% at 1064 nm. Cr^{4+}:YAG crystals with initial transmission (T_0) of 80% and 90% were used as the saturable absorbers. The total cavity length was about 50 mm.

3. Results and discussion

3.1. CW operation

Without Q-switch Cr^{4+}:YAG crystal, the CW operation was carried out firstly with five kinds of output couplers which had different transmission of 20%, 25%, 30%, 35% and 40%. The measured results are shown in Fig. 2(a) and (b).

From Fig. 2(a), we can see that the CW output power increased with increasing of the incident pump power when the Nd^{3+} doped concentration of ceramic Nd:YAG was 1.0 at%. The maximum CW output power of 7.74 W was obtained at the incident pump power of 15 W when the optimized output coupler with transmission of 25% was used, which resulted in an optical conversion efficiency of 51.6%. The threshold pump power were 1.06 W, 0.70 W, 1.13 W, 1.48 W and 1.94 W for the output couplers with transmission of 20%, 25%, 30%, 35% and 40%, respectively. The experiment results shown in Fig. 2(b) illustrated the CW output power as a function of incident pump power with different output couplers when the Nd^{3+} doped concentration was 2.0 at%. The incident pump power was ranging from 0 to 16 W in Fig. 2 (a) while it was ranging from 0 to 10 W in Fig. 2(b), since the ceramic with Nd^{3+} doped concentration of 2.0 at% was damaged when the incident pump power was higher than 12 W. We chose 10 W as the maximum incident power for the greatest protection. It was obvious that the optical conversion efficiency was lower than the former one with Nd^{3+} doped concentration of 1.0 at% when ceramic with Nd^{3+} doped concentration of 2.0 at% was used. The increased scattering loss due to the high doped concentration contributed to decreased efficiency. Finally Nd:YAG ceramic with Nd^{3+} doped concentration of 4.0 at% was employed. Unfortunately we did not get laser output. The whole ceramic was full of red fluorescence in the study, and we think this phenomenon confirmed the strong scattering loss at high doped concentration. In order to reduce scattering loss and improve the quality of ceramic, the addition of sintering aid and sintering strategy will be optimized to lower the optical scattering loss of high doping 4 at% Nd:YAG transparent ceramics. And then, highly efficient laser oscillation can be realized by using Nd:YAG ceramics with high doping.

3.2. Passively Q-switched operation

In the following experiments, Nd:YAG ceramic with Nd^{3+} doped concentration of 1.0 at% and output coupler with transmission of 25% were adopted for the optimum performance. Cr^{4+}:YAG crystals with initial transmission of 80% and 90% at 1064 nm as the saturable absorbers were used to test the properties of passively Q-switched lasers. We set the incident pump power ranging from 0 to 10 W to make sure the ceramic would not be damaged. The average output power, repetition rate, pulse width, single pulse energy and peak power of passively Q-switched ceramic Nd:YAG lasers as a function of incident pump power were shown in Figs. 3–7, respectively.

Fig. 3 shows the average output power of passively Q-switched laser as a function of incident pump power. We can see that the average output power increased linearly with increasing of the incident pump power. At the incident pump power of 10 W, the maximum average output power were 2.44 W and 2.80 W for the Cr^{4+}:YAG crystals with initial transmission of 80% and 90%, respectively.

A high-speed Si detector and a digital oscillograph were used to detect the pulse laser signal and measure the repetition rate and the pulse width, respectively. The measured results are shown in Figs. 4 and 5. As shown in Fig. 4, the repetition rate increased with an increase of the incident pump power. At the incident pump power of 10 W, the maximum repetition rate were 3.0 kHz and 12.5 kHz of the Cr^{4+}:YAG crystals with initial transmission of 80% and 90%,

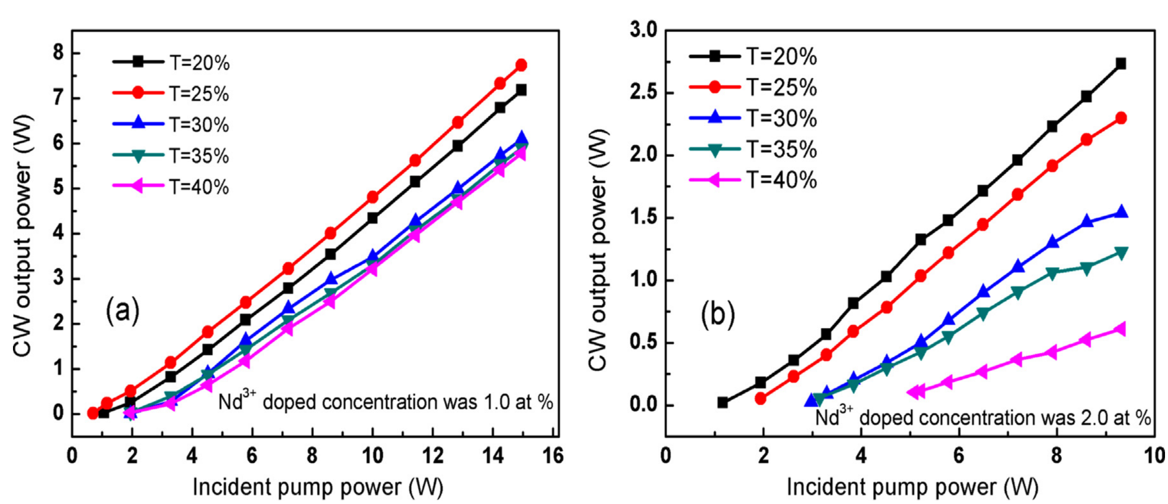

Fig. 2. CW output power as a function of incident pump power for different output couplers: (a) the Nd^{3+} doped concentration was 1.0 at% (b) the Nd^{3+} doped concentration was 2.0 at%.