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Doubly Q-switched tape casting YAG/Nd:YAG/YAG ceramic laser

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ABSTRACT

A doubly Q-switched 1.06 μm pulsed laser using a novel tape casting YAG/Nd:YAG/YAG composite ceramic with a sandwich structure was demonstrated for the first time. Compared to purely acousto-optical (AO) Q-switching, this laser using an AO Q-switch and Cr^{4+}:YAG saturable absorber simultaneously can generate shorter pulses. The pulsed laser performance was investigated at two modulated repetition rates of 10 and 20 kHz.

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1. Introduction

All-solid-state 1.06 μm pulsed lasers with high repetition rates and narrow pulse widths are widely used in various fields such as in lidar, laser micro-machining and laser-induced plasma ignition (*1–3*). The acousto-optical (AO) Q-switch has been adopted widely in actively Q-switched lasers because of its simplicity, compactness and high efficiency. Such an AO Q-switch can obtain a stable pulse train output with a narrow pulse width. Using both an active and passive Q-switch in the cavity simultaneously, the laser can obtain an even shorter pulse width when compared with single active Q-switching. In such a doubly Q-switched laser, an AO Q-switch is used to control the pulse repetition rate and at the same time allows the laser medium to store energy to ensure that the population inversion is fully saturated, while the passive Q-switch saturable absorber is used to generate symmetric short laser pulses as a result of normal saturable absorption characteristics. Doubly Q-switched lasers with electro-optic modulator and passive saturable absorber have been reported (*4,5*). Compared with a single crystal material, the ceramic has many favourable characteristics, such as higher doping concentration, more design freedom, lower cost, and especially superior resistance to fracture (*6–8*). Due to these merits, extensive investigations have been conducted on Nd:YAG ceramic laser (*9–12*).

Theoretical and experimental results have demonstrated that the thermal effect of laser media can not only influence the cavity stability but also change the spot sizes of the TEM_{00} mode, which will greatly affect the performance of Q-switched lasers (*13*). For example, a laser with good beam quality will reduce the transiting time of the acoustic wave passing through the laser spot in an AO Q-switch and increase the diffraction efficiency of the Q-switch. The active ions such as Nd^{3+}-doped YAG can degrade its thermal properties significantly. The thermal conductivity of 1.0 at% Nd:YAG is ~1.4 times lower than that of pure YAG (*14*). Therefore, a composite Nd:YAG ceramic laser medium is an effective method to reduce thermal effects due to the superior thermal conductivity of the undoped section (*15–17*).

In this paper, we report the demonstration of a doubly Q-switched 1.06 μm pulsed laser using a novel composite YAG/Nd:YAG/YAG ceramic with a sandwich structure for the first time. The pulsed laser performance was investigated of an AO modulator and a Cr^{4+}:YAG saturable absorber.

2. Experimental

2.1. YAG/Nd:YAG/YAG ceramic fabrication

High purity commercial α-Al_2O_3 (99.98%), Y_2O_3 (99.999%) and Nd_2O_3 (99.99%) powders were used as starting materials. Y_2O_3, α-Al_2O_3 and Nd_2O_3 powders with chemical compositions of $Y_3Al_5O_{12}$ and $Nd_{0.03}Y_{2.97}Al_5O_{12}$ (1.0 at% Nd:YAG) were employed. An appropriate amount

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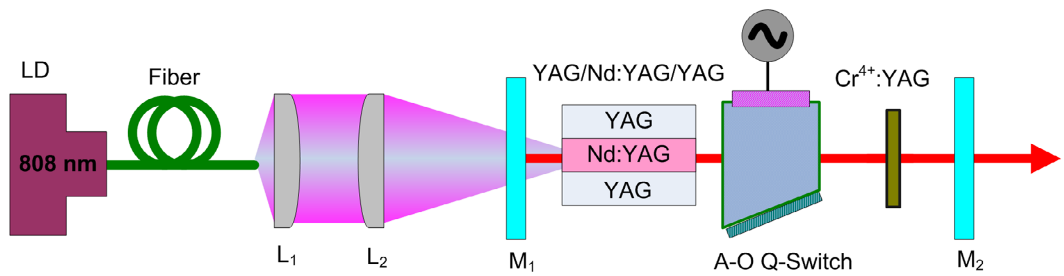

Figure 1. Experimental setup of a doubly Q-switched YAG/Nd:YAG/YAG ceramic laser.

of MgO (99.999%) and TEOS (99.999%) were added as sintering aids. These powders were mixed and milled for 10 h in a solvent consisting of ethanol and xylene with fish oil added as a dispersant. Next, a binder (PVB) and a plasticizer (PEG-400 and BBP) were added into the slurry and milled for another 12 h. The slurries were then cast at a rate of 100 cm/min with a gap height of 450 μm. The thickness of the dried tapes was about 150 μm. By using a round mold, the dried tapes were cut into pieces. About 20 layers of the α-Al_2O_3 + Y_2O_3 component tape were laminated on both sides with 10 layers of *α*-Al_2O_3 + Y_2O_3 + Nd_2O_3 component tape slices at a temperature of 70 °C at 57 MPa for 30 min. The organic materials were then removed by calcining at 600 °C for 10 h and the green bodies were then cooled isostatically pressed at 250 MPa to obtain a homogeneous ceramic. Composite YAG/Nd:YAG/YAG transparent ceramics with different doping concentrations were fabricated by vacuum sintering at 1760 °C for 10 h. The as-sintered ceramics were annealed at 1450 °C for 10 h in air to eliminate stress and oxygen vacancies. Finally, the composite YAG/Nd:YAG/YAG ceramics was cut, polished and coated for laser testing.

2.2. Experimental setup

The experimental configuration of a doubly Q-switched YAG/Nd:YAG/YAG ceramic laser with 808 nm laser-diode end-pumping is shown in Figure 1.The 808 nm excitation source employed in the experimental setup was a fibre-coupled laser-diode. The fibre had a core diameter of 400 μm and a numerical aperture of 0.22. The output beam was reshaped using a pair of collimating and focusing lenses L_1 and L_2 and the diameter of beam waist was ~500 μm. The composite YAG/Nd:YAG/YAG ceramic was 3.5, 3.0 and 3.5 mm in width, height and length, respectively. The doped part had a height of 1 mm and had Nd^{3+} ion concentrations of 1%. The laser cavity was constructed by two plano–plano mirrors. The input mirror M_1 was antireflection coated at 808 nm and had a high reflectivity at 1.06 μm. The output coupler M_2 had different transmissions (*T*) of 10, 15 and 20% at 1.06 μm. A Cr^{4+}:YAG saturable absorber with a thickness of 1 mm and an initial transmission of 90% was chosen.

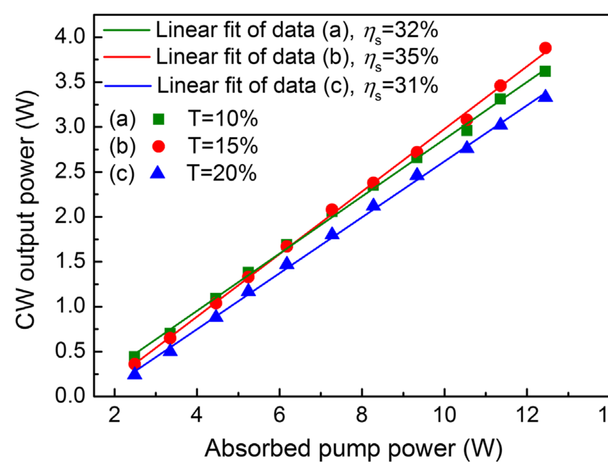

Figure 2. CW output power as a function of absorbed pump power.

3. Results and discussion

In the absence of an AO Q-switch and Cr^{4+}:YAG, continuous-wave (CW) laser operation was implemented with three kinds of output couplers which had transmissions of 10, 15 and 20%, respectively. The measured results are shown in Figure 2. The absorption efficiency of the pump beam was about 90%. We can see from Figure 2 that with increasing absorbed pump power the CW output power increased as well. A maximum CW output power of 3.88 W was obtained at an absorbed pump power of 12.5 W when an output coupler with transmission of 15% was used, which resulted in a slope efficiency of 35%. The laser beam quality factor M^2 was measured by a 90/10 traveling knife-edge method in the far field at this condition and it was found to be 1.42. For output couplers with transmission of 10 and 20%, the slope efficiency was 32 and 32%, respectively.

In the following experiments, the output coupler with transmission of 15% was used. The average output power of AO Q-switched and doubly Q-switched YAG/Nd:YAG/

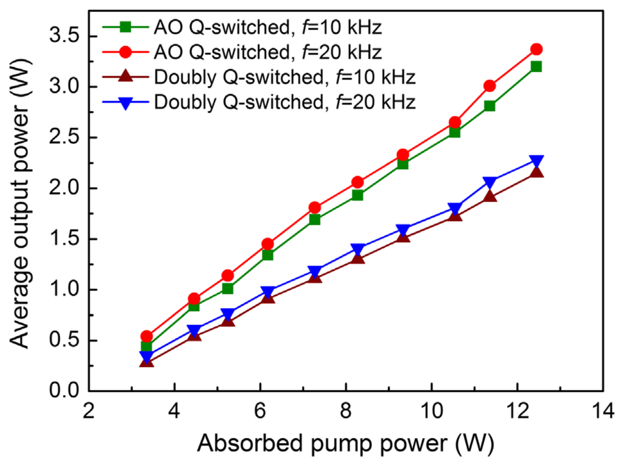

Figure 3. Average output power of AO Q-switched and doubly Q-switched YAG/Nd:YAG/YAG lasers as a function of absorbed pump power.

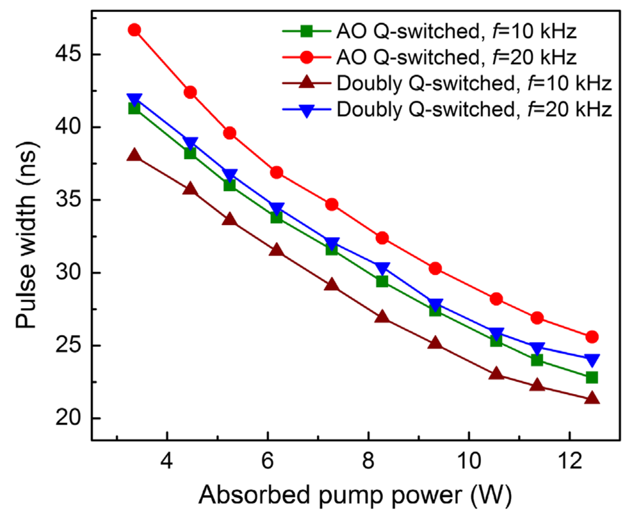

Figure 4. Pulse width of AO Q-switched and doubly Q-switched YAG/Nd:YAG/YAG ceramic lasers as a function of absorbed pump power.

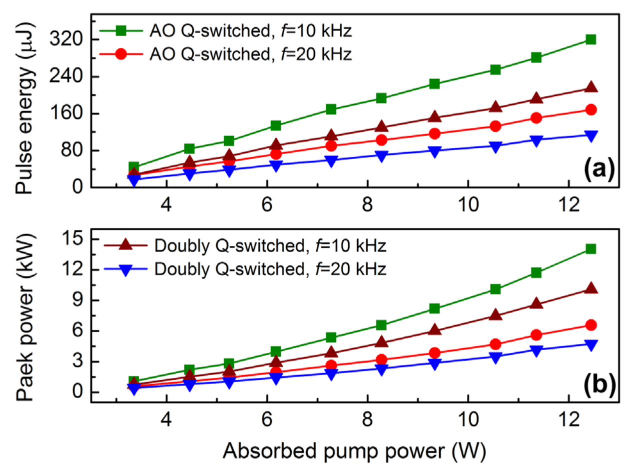

Figure 5. Performance of AO Q-switched and doubly Q-switched YAG/Nd:YAG/YAG ceramic lasers: (a) pulse energy; (b) pulse peak power.

YAG ceramic lasers at two repetition rates (*f*) of 10 and 20 kHz is shown in Figure 3. The average output power of the doubly Q-switched laser was smaller than that of purely AO Q-switched due to the absorption loss of Cr^{4+}:YAG crystal. The maximum average output power was 3.2 and 3.37 W for a purely AO Q-switched laser at a repetition rate of 10 and 20 kHz, respectively. For the doubly Q-switched laser, the maximum average output power values were 2.15 and 2.28 W, respectively.

The pulse width at a repetition rate of 10 and 20 kHz as a function of absorbed pump power is shown in Figure 4. For the doubly Q-switched laser using both active and passive Q-switches in the cavity simultaneously, the output characteristics such as the pulse repetition rate and pulse width were mainly controlled by the active Q-switch. The passive Q-switch saturable absorber is only used to generate short laser pulses as a result of normal saturable absorption characteristics [*18*]. From Figure 4, we can see that the pulse width of doubly Q-switched lasers was narrower than that of purely AO Q-switched lasers, especially for low absorbed pump power levels. For example, when the absorbed pump power was 3.3 W and the repetition rate was 20 kHz, the pulse width was 46.7 and 42 ns for AO Q-switched and doubly Q-switched lasers, respectively.

The calculated results of pulse energy and pulse peak power for AO Q-switched and doubly Q-switched YAG/Nd:YAG/YAG ceramic lasers are shown in Figure 5(a) and (b), respectively. The pulse energy and pulse peak power got higher when the absorbed incident pump power was increased. The pulse energy and pulse peak power at $f = 10$ kHz were higher than those of 20 kHz for the AO Q-switched laser and doubly Q-switched laser, respectively. Although the pulse width of the doubly Q-switched laser was shorter than that of AO Q-switched laser, the pulse peak power was reduced. For an absorbed incident pump power of 12.5 W, the pulsed peak power for AO Q-switched and doubly Q-switched YAG/Nd:YAG/YAG ceramic lasers at $f = 10$ kHz were 14 and 10.1 kW, respectively. At $f = 20$ kHz, the peak powers were 6.6 and 4.7 kW, respectively.

4. Conclusions

In conclusion, we have demonstrated for the first time a doubly Q-switched laser using tape casting YAG/Nd:YAG/YAG composite ceramic. The laser performances were investigated at modulated repetition rates of 10 and 20 kHz. Due to the saturable absorption characteristics of Cr^{4+}:YAG, compared with AO Q-switched laser, the doubly Q-switched system can generate shorter pulses, especially with low absorbed pump power. The maximum pulse peak power for AO Q-switched and doubly Q-switched YAG/Nd:YAG/YAG ceramic lasers were 14 and 10.1 kW, respectively, at a repetition rate of 10 kHz.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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