

Diode-pumped self- Q -switched Cr,Nd:YAG laser with 7-W average output power

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We report a diode-pumped self- Q -switched 1064-nm Cr,Nd:YAG laser with pulse duration in the range of 16–18 ns. The maximum average output power up to 7 W, corresponding to a slope efficiency of 33%, is obtained in a simple and compact linear cavity by using a plane-concave output coupler with a transmittance of 15%. The laser operates at TEM₀₀ mode with a pump power of 14.2 W.

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Solid state lasers with high peak power and short pulses are widely used in laser communications, remote sensing, nonlinear optics, and so on. Diode-pumped self- Q -switched lasers can produce such pulses and have attracted great attention due to their compact and simple structure, high efficiency, and low cost. As a saturable absorber, Cr⁴⁺-doped crystals possess specific advantages such as good optical properties, photochemical and thermal stability, large absorption cross-section, and so on. In particular, Cr⁴⁺-doped YAG crystals can be co-doped with the gain medium Nd³⁺. Cr,Nd:YAG crystals combining the gain medium and the saturable absorber in a single crystal can be used to generate self- Q -switched laser with a highly compact resonant cavity^[1–4]. Experiments and numerical simulations about the self- Q -switched Cr,Nd:YAG lasers with lower average output power have been reported^[5–12]. In this letter, we present a diode-pumped Cr,Nd:YAG 1064-nm self- Q -switched laser with high average output power by using a Cr,Nd:YAG crystal as the gain medium as well as the saturable absorber. The performance of the laser is investigated under different experimental parameters such as variable pumping powers and different output couplers. Q -switched pulse trains are obtained under different pump powers. The average output power of the self- Q -switched 1064-nm laser is up to 7 W by using a simple linear cavity, corresponding to a slope efficiency of 33%. The width of the Q -switched pulses is in a range of 16–18 ns.

The experimental setup is shown in Fig. 1. A simple and compact linear cavity was used to produce the self- Q -switched pulse laser. The cavity length was as short as 19 mm. The pump source was a fiber-coupled continuous-wave (CW) laser diode (LD, Unique Mode) with a wavelength of 808 nm. The diameter of the fiber core was 400 μm with a numerical aperture (NA) of 0.22. The 808-nm pump light was collimated and focused into the Cr,Nd:YAG crystal with a diameter of 200 μm by two coupling lenses which gave a coupling efficiency of 90%. The co-doped Cr,Nd:YAG crystal used in our ex-

periment was 8 mm in length with a concentration of 0.8 at.-% for the Nd³⁺ ions. The pump surface of the crystal was polished and coated for high reflectivity at 1064 nm and high transmission at 808 nm. The other side of the crystal was coated for anti-reflection at 1064 nm. In order to remove the heat generated in the gain medium, the Cr,Nd:YAG crystal was wrapped with indium foil and mounted in a water-cooled copper heat sink which was directly cooled by flowing water. The temperature of the cooling water was set at 10 °C during our experiment. For optimizing the self- Q -switched laser, the performance of the laser was tested by using six different output couplers (OCs), i.e., three flat-flat mirrors with transmission of 20%, 25%, and 30%, and three plane-concave mirrors ($R = 50$ mm) with transmission of 15%, 20%, and 25% at 1064 nm. The output power was measured with a laser power meter behind the OC. The temporal shape of the output laser pulse was recorded by a photodiode whose rise time was less than 1 ns and a fast digital oscilloscope (Tektronix 3052B, 500-MHz bandwidth, 5.0 Gs/s).

In the experiment, higher output power and higher slope efficiency can be obtained by using the plane-concave mirrors. Figure 2 presents the average output power as a function of the incident input pump power with different OCs. The threshold pumping powers for all the six OCs were almost the same to be approximately 1.16 W. The maximum average output power was 7 W at the incident power of 22 W and the slope efficiency was 33% with the plane-concave OC of transmission $T = 15\%$. Figure 2 does not show any sign of saturation which

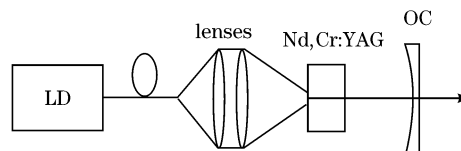


Fig. 1. Schematic of the LD-pumped self- Q -switched Nd,Cr:YAG laser.

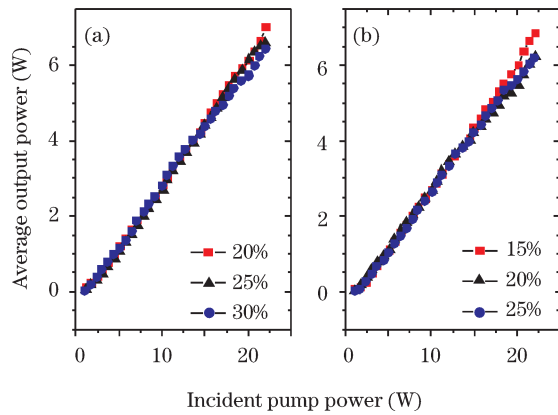


Fig. 2. Average output power as a function of the incident pump power with different OCs: (a) three flat-flat mirrors; (b) three plane-concave mirrors.

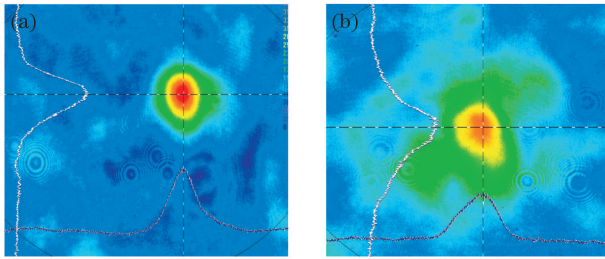


Fig. 3. Far-field beam spatial profiles at the pump powers of (a) 11.8 W and (b) 14.2 W with the flat-flat OC of $T = 25\%$.

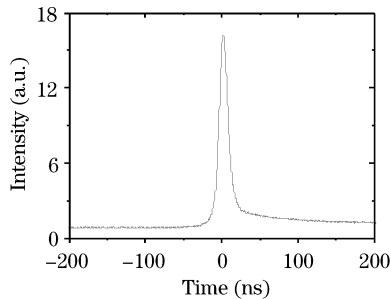


Fig. 4. Pulse shape of the self- Q -switched 1064-nm Cr,Nd:YAG laser.

indicates that higher average output power is achievable at higher pumping power.

The far-field beam spatial profile of the self- Q -switched pulses was measured using a charge-coupled device (CCD) at a distance of about 40 cm from the OC. Figure 3(a) shows the beam spatial profile of the laser pulses corresponding to the flat-flat OC of $T = 25\%$ at the pump power of 11.8 W. The Gaussian curve indicates that the laser nearly oscillates in the fundamental transverse mode. The M^2 factor was about 1.3 under this pump power. As the pump power increases, the quality of the fundamental transverse mode declines. Figure 3(b) shows the beam spatial profile of the laser at the pump power of 14.2 W. This is the critical condition for the fundamental transverse mode. The high-quality fundamental transverse mode can be preserved under the pumping power of 14.2 W with this OC during the experiment. When the pump power is higher than 14.2 W, the mode

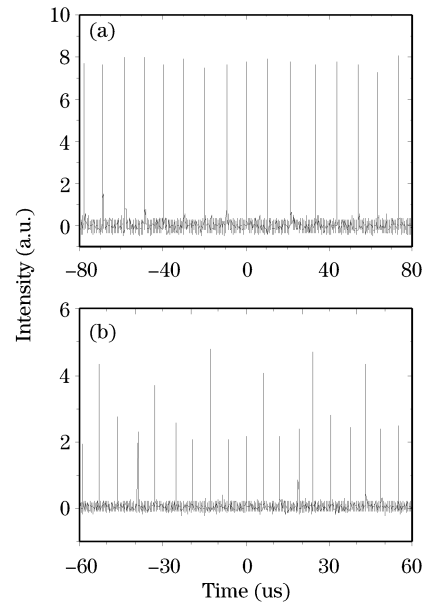


Fig. 5. Oscilloscope traces of Q -switched pulse trains at incident pump powers of (a) 7.95 W and (b) 14.2 W.

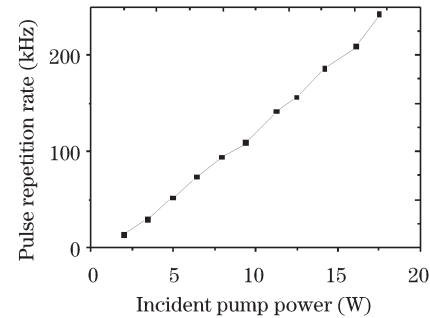


Fig. 6. Repetition rate of the pulse as a function of the incident pump power.

becomes bad because higher pump power leads to oscillations of the high-order transverse modes.

The Q -switched pulse temporal behavior was recorded by a photodiode. Figure 4 shows a typical Q -switched laser pulse with a duration of 16 ns, which is obtained at the pump power of 6.4 W with the plane-concave OC of $T = 25\%$. In the experiment, the pulse duration was in the nanoseconds temporal regime, in the range of 16–18 ns full-width at half-maximum (FWHM), depending only slightly on the pumping power, similar to those observed by Kalisky *et al.*^[13] and Dong *et al.*^[14]

Figure 5 presents an oscilloscope trace of 1064-nm Q -switched pulses at the incident pump powers of 7.95 and 14.2 W with the plane-concave OC of $T = 25\%$. We can see that the self- Q -switched pulses are stable at lower pump power, as shown in Fig. 5(a). The pulse-to-pulse amplitude fluctuation is more apparent with the increased pumping power and the antiphase state is observed at the incident pump power of 14.2 W, as shown in Fig. 5(b). This phenomenon is due to the spatial hole burning (SHB) effect when the gain region is at one end of the laser cavity. Although there are hundreds of longitudinal modes within the gain curve, the system selects only a few of them to lase due to the SHB effect. With the pump power increasing, the number of lasing modes increases. These modes compete for the gain and make use

of the inversion particles in different longitudinal spatial positions of the laser crystal, and then the modes with higher gain go to oscillate. These lasing modes generate self-organized dynamics such as antiphase dynamics^[15]. In our experiment, the pulse repetition rate of the self-*Q*-switched pulse train increases with the increasing pump power, as shown in Fig. 6. At the pumping power of 17.5 W, the repetition rate reaches 242 kHz.

In conclusion, we have presented a high average output power in the self-*Q*-switched 1064-nm Cr,Nd:YAG laser using a LD as the pump source. The maximum output power reaches 7 W and the slope efficiency is 33%. The pulse width is in a range of 16–18 ns in the fundamental transverse mode and remains constant with the pump power increasing. The pulse repetition rate increases almost linearly with the incident pump power.

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