

Compact and efficient diode-pumped passively Q -switched Nd:GdVO₄ laser at 1.06 μm

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Diode-pumped passively Q -switched Nd:GdVO₄/Cr⁴⁺:YAG lasers with a simple flat-flat cavity were demonstrated. The maximum average output power at 1.06 μm was 1.25 W. The highest peak power and pulse energy were 7.56 kW and 75 μJ , respectively, with the pulse repetition rate of 11.1 kHz and pulse width of 10 ns at the incident pump power of 8 W.

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Passively Q -switched all-solid-state lasers have attracted a great deal of attention for scientific, industrial, and military applications. Compared with actively Q -switched devices that require high-voltage switching electronics, passive techniques can significantly simplify the operation, reduce the cost, and improve the reliability. In recent years, interest has been concentrated on the use of Cr⁴⁺:YAG as a saturable absorber because of its high thermal conductivity, high damage threshold, large absorption cross section near 1.06 μm , and better stability, especially at high repetition rates.

Diode-pumped passively Q -switched Nd:YVO₄ and Nd:YAG have been successfully demonstrated^[1-4]. Nd:GdVO₄ is also a laser material, its space group is the same as that of Nd:YVO₄. Some experiments have shown that Nd:GdVO₄ crystal is also an efficient diode-pumped solid-state laser crystal^[5]. The thermal conductivity along the $\langle 110 \rangle$ direction is comparable with that of Nd:YAG crystals, and it is almost two times greater than that of Nd:YVO₄^[6]. Nd:GdVO₄ has a larger absorption cross section and an emission cross section at 1.06 μm . Therefore Nd:GdVO₄ is a very efficient laser material for diode pumping and has been receiving considerable attention in recent years. Nd:GdVO₄ crystal is the promising substitute for Nd:YVO₄ and Nd:YAG in diode-pumped laser products.

Because of the early work on Nd:GdVO₄ lasers at 1.06 μm , passively Q -switching operation has been realized with Cr⁴⁺:YAG^[7,8]. An active Nd:GdVO₄ Q -switching laser at 1.06 μm with a flat-flat cavity has been reported^[9]. The device however, was complicated. The reported output peak powers of the passively Q -switched Nd:GdVO₄ lasers were smaller (625 W), and obtained in a folded cavity^[8]. In this paper, we present our results on the high-peak-power passively Q -switched Nd:GdVO₄ lasers with a Cr⁴⁺:YAG crystal as the saturable absorber in a simple flat-flat cavity. Several characteristics of the passively Q -switched lasers, including the output power, the variation of laser pulse width and repetition rate with the incident pump power using different initial transmissions of Cr⁴⁺:YAG, have all been investigated in detail.

The schematic of the passively Q -switched Nd:GdVO₄ laser is shown in Fig. 1. The length of the flat-flat cavity was approximately 58 mm. The Nd:GdVO₄ crystal was pumped by a fibre coupled semiconductor laser at

808 nm with the maximum output power of 10 W and a numerical aperture of 0.12. A 1.3 at.-%, a -cut Nd:GdVO₄ crystal with dimensions of $3 \times 3 \times 4 \text{ mm}^3$, was utilized as laser medium. The output from the semiconductor laser was focused onto the Nd:GdVO₄ crystal with a coupling optics system. The left side of the Nd:GdVO₄ crystal was coated to be highly reflecting (HR) at 1.06 μm , and anti-reflecting (AR) at 808 nm pumping wavelength. It also acts as the input mirror (M_1). The other side of the crystal was coated for AR at 1.06 μm . M_2 was a flat mirror with transmission at 1.06 μm of 20% or 40%. Two pieces of Cr⁴⁺:YAG crystals with the initial transmission of 70% and 85% at 1.06 μm , respectively, were used to test the properties of the passively Q -switched Nd:GdVO₄ lasers. We found in our experiments that such a flat-flat cavity could satisfy the Q -switching criteria and mode-matching condition as discussed in Refs. [1] and [8]. The pulse temporal behavior was recorded by a fast photodiode detector (NEW FOCUS 1623) and a 500 MHz oscilloscope (Tektronix TDS620A).

Figure 2 shows the CW operation (without the Cr⁴⁺:YAG) of the different output couplings ($T = 20\%$ and $T = 40\%$). At the incident pump power of 8 W, the CW output powers of 3 and 2.4 W were obtained with the output couplings of $T = 20\%$ and $T = 40\%$, respectively. Thresholds of 1.2 and 1.7 W, slope efficiencies of 44% and 38% were obtained. To optimize the laser performance of Q -switched operation, we used the output couplers with transmissions of 20% and 40%. The best results for all the absorber crystals were achieved for the highest output coupling ($T = 40\%$).

Figure 3 shows the average output power of stable operation as a function of incident pump power with different Cr⁴⁺:YAG saturable absorbers and different

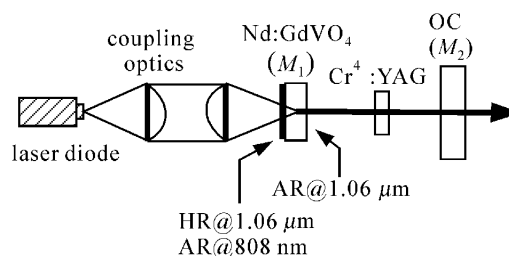


Fig. 1. The schematic of the passively Q -switched Nd:GdVO₄ laser.

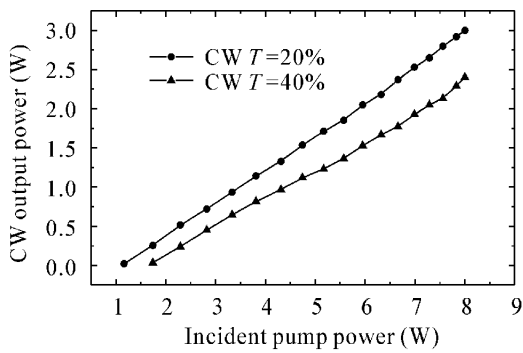


Fig. 2. The CW output power of Nd:GdVO₄ lasers as a function of incident pump power.

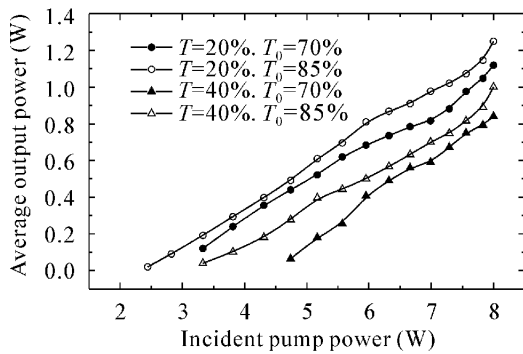


Fig. 3. Averaged output power versus the incident pump power for Cr⁴⁺:YAG saturable absorbers of initial transmission $T_0 = 70\%$ and $T_0 = 85\%$. The transmission of the output coupler is $T = 20\%$ and $T = 40\%$.

output couplings. The initial transmissions T_0 of Cr⁴⁺:YAG were 70% and 85%. It is obvious that the thresholds for Q -switched operation are higher than those for CW operation and increase as T_0 decreases. The oscillation threshold pump power was 2.4 W for the output coupling of 20% and Cr⁴⁺:YAG initial transmission of 85%. However, for 40% output coupling and 70% Cr⁴⁺:YAG, the threshold was much higher, up to 4.7 W. The most efficient operation was achieved with the 20% output coupling and 85% Cr⁴⁺:YAG. At the incident pump power of 8 W, the maximum average output power of 1.25 W was obtained, giving an optical conversion efficiency of 15.6%, and the averaged slop efficiency of 22.5%. The maximum slop efficiency of 25.8% was obtained with the 70% Cr⁴⁺:YAG and the 40% output coupling, in spite of its lower average output power. We can see that the decrease of the initial transmission of the Cr⁴⁺:YAG crystal will not only increase the threshold power, but also increase the slop efficiency of the passively Q -switched lasers.

Figure 4 summarizes the pump power dependence of the pulse width, the pulse repetition rate, and the peak power for the two Cr⁴⁺:YAG saturable absorbers with $T_0 = 70\%$ and $T_0 = 85\%$ at different output couplings. It can be seen that the pulse width of 70% Cr⁴⁺:YAG crystal is insensitive to the pump power. When the incident pump power was 8 W, we obtained the shortest pulse width of 10 ns, and the highest pulse repetition rate of 33.3 kHz. Clearly, the saturable absorber of lower transmission exhibits a shorter pulse-width and

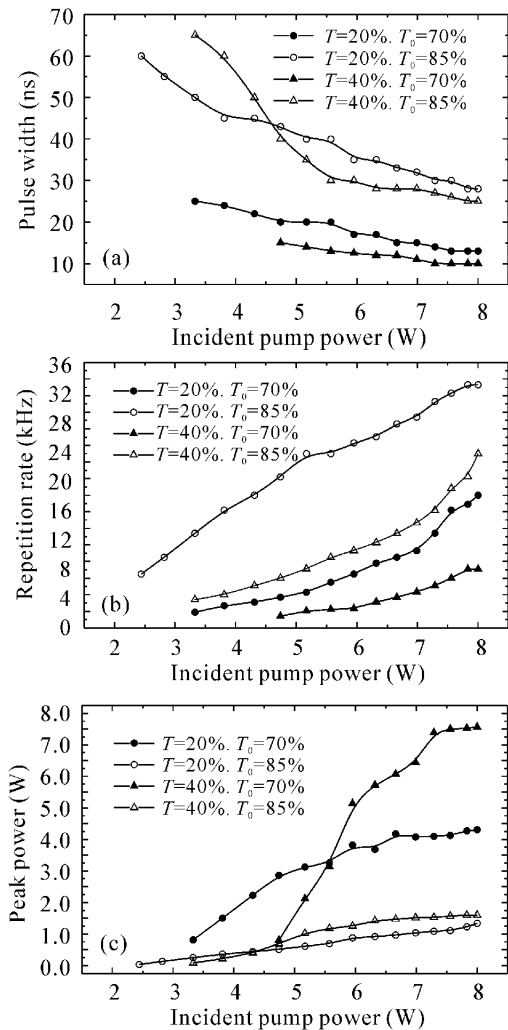


Fig. 4. Pulse parameters versus incident pump power for Cr⁴⁺:YAG saturable absorbers of initial transmission $T_0 = 70\%$ and $T_0 = 85\%$. The transmission of the output coupler is 20% and 40%. (a) Pulse width; (b) repetition rate; (c) peak power.

lower repetition rate. In the case of passive Q -switching, increase in repetition rate for a specific laser setup requires an increase in pump power, resulting in a parallel reduction of the pulse width. We found that the highest pulse peak power of 7.56 kW and the maximum pulse energy of 75 μ J were obtained when the Cr⁴⁺:YAG crystals with the initial transmission of 70% and the output coupling of 40% were used, in spite of its lower average output power. The pulse width was 10 ns, which is much narrower than that when the 85% Cr⁴⁺:YAG crystal was used. We also found that the slopes of the peak power tend to decrease when the incident pump power increases. Such a phenomenon can be attributed to the amplified spontaneous emission that occurred in the Nd:GdVO₄ lasers under intense pumping. Experimental results for different output couplings and different initial transmissions of Cr⁴⁺:YAG are summarized in Table 1.

In summary, we have demonstrated compact and efficient diode-pumped passively Q -switched Nd:GdVO₄ lasers. A maximum average output power of 1.25 W was obtained with an optical conversion efficiency of 15.6%,

Table 1. Experimental Results for Passively Q-Switched at the Incident Pump Power of 8 W

Cr ⁴⁺ :YAG: T_0 (%)	70	85	70	85
OC(M_2): T (%)	20	20	40	40
Output Power (W)	1.12	1.25	0.84	1.00
Pulse Width (ns)	13	28	10	25
Repetition Rate (kHz)	20	33.3	11.1	25
Pulse Energy (μ J)	56	37.5	75	40
Peak Power (kW)	4.31	1.34	7.56	1.6

the averaged slop efficiency was 22.5%. At the incident pump power of 8 W, the highest single pulse energy and peak power were 75 μ J and 7.56 kW, respectively. The shortest pulse width of 10 ns was observed at the repetition rate of 11.1 kHz. The highest pulse repetition rate was 33.3 kHz. In addition, this inexpensive and compact device can apply to a variety of applications for which high peak power in nanosecond pulse width and high-repetition-rate operation are required.

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