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Continuous-wave and Q-switched laser operation of Nd:$Gd_{0.18}Y_{0.82}VO_4$ mixed crystal

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ABSTRACT

Efficient continuous-wave (cw), passively Q-switched, and actively Q-switched laser operations are demonstrated with a mixed vanadate crystal of Nd:$Gd_{0.18}Y_{0.82}VO_4$ under diode pumping. In a cw operation, an output power of 8.25 W is obtained at a maximum available incident pump power (P_{in}) of 15 W, with a slope efficiency of 56%. Using a Cr^{4+}:YAG crystal of initial transmission of 62% as the saturable absorber for Q-switching, an average output power of 3.05 W is generated at pulse repetition frequency (PRF) of 16.7 kHz when the laser is pumped with the same maximum P_{in}. The pulse energy, pulse duration, and peak power are 183.3 μJ, 6.0 ns, and 30.6 kW, respectively. When actively Q-switched by an acousto-optic modulator, the laser produces an average output power of 5.5 W at PRF of 30 kHz with 16.2 W of pump power incident upon the laser crystal. The pulse energy, duration, and peak power are measured to be 183 μJ, 10.5 ns, and 17.5 kW, respectively.

1. Introduction

Neodymium (Nd) doped vanadates, Nd:YVO_4, Nd:$GdVO_4$, and Nd:$LuVO_4$, have become the most commonly used gain materials for continuous-wave (cw) diode-pumped solid-state lasers operating in the low-to-medium power regime. However, these crystals seem to be not very attractive for use in Q-switched lasers, because of their large stimulated emission cross sections (σ), which leads to limited energy storage capacities. To avoid such a drawback, *c*-cut crystals have been utilized to take advantage of a relatively low emission cross section in σ-polarization [1,2]. Unfortunately, *c*-cut crystals were found to suffer from stronger thermal lensing, by nearly three times than the *a*-cut ones, making them impractical in power scaling [3]. Additionally, the unpolarized laser radiation generated in this case is also inconvenient for some practical applications like frequency conversion through nonlinear optical interactions. To solve such problems, a class of mixed vanadate crystals of Nd:$Gd_xY_{1-x}VO_4$ were developed in 2003, demonstrating a significant enhancement in laser pulse energy as well as peak power [4,5]. Another class of mixed vanadates, Nd:$Lu_xGd_{1-x}VO_4$, were also developed lately showing a similar improvement in passively Q-switched performance [6,7]. Nearly all the detailed studies on Nd:$Gd_xY_{1-x}VO_4$ mixed vanadates that have been conducted so far are on one specific crystal, Nd:$Gd_{0.64}Y_{0.36}VO_4$ [5,8–10], which is seemingly the most desirable for Q-switched operation due to its low σ, nearing the minimum for the whole class [3]. In addition to Nd:$Gd_{0.64}Y_{0.36}VO_4$, pulsed laser performance was studied in detail only for Nd:$Gd_{0.51}Y_{0.49}VO_4$, using passively Q-switched operation with GaAs used as the saturable absorber [11]. A comprehensive study of the class of Nd:$Y_xGd_{1-x}VO_4$ mixed crystals emphasizing on their thermal properties and cw laser performance has also been conducted recently [12].

It is well known that in addition to the emission cross section, fluorescence lifetime, and resonator parameters such as the output coupling, the initial transmission (T_0) of the saturable absorber also plays a crucial role in a passively Q-switched operation. Consequently, it is interesting to evaluate the potential of different mixed vanadates for Q-switched operation under experimental conditions optimized for a specific crystal.

In this paper, we report efficient passively Q-switched laser operation obtained with Nd:$Gd_{0.18}Y_{0.82}VO_4$, another member of the Nd:$Gd_xY_{1-x}VO_4$ mixed vanadates class. The results from our current experiment show that by appropriate choice of T_0 of the saturable absorber, it is feasible to achieve pulsed laser performance comparable with that of mixed vanadates of lower emission cross sections. In addition to the passively Q-switched operation, the actively Q-switched laser performance of this mixed vanadate was also investigated by using an acousto-optic (AO) modulator. At pulse repetition frequencies (PRFs) around 30 kHz, this crystal turns out to be superior to others in the class of Nd:$Gd_xY_{1-x}VO_4$, producing the highest pulse energy in actively Q-switched operation [13].

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2. Description of the experiment

The experimental setup employed to study the laser properties of the Nd:$Gd_{0.18}Y_{0.82}VO_4$ crystal is illustrated in Fig. 1, which was similar to that used in our previous work [4,5]. The 75-mm long resonator was formed by a concave reflector (M_1) of 200-mm radius-of-curvature, which was coated for high-reflectance ($R>99.8\%$) at 1.06 μm and high-transmittance ($T>97\%$) at 809 nm, and a plane output coupler (M_2). The *a*-cut crystal (0.5 at% of Nd concentration), 6 mm in length with an aperture of 3.5 mm × 3.5 mm, was anti-reflection (AR) coated at both 1.06 μm and 809 nm on its end faces. It was fixed in a water-cooled copper holder, and placed close to the reflector in the resonator. Three different Cr^{4+}:YAG crystals with initial transmissions at 1.06 μm of T_0=80%, 70%, and 62% were used as the saturable absorber for Q-switching. These crystals were also AR coated for 1.06 μm on their end faces. For effective Q-switching, the Cr^{4+}:YAG crystal was positioned near the plane coupler to take advantage of the smallest mode size. The pump source used in passively Q-switched operation was a fiber-coupled diode laser (fiber core diameter of 400 μm and N.A. of 0.22), capable of generating a maximum output power of 15 W at ~808 nm. Its output radiation was focused and delivered onto the laser crystal with a spot radius of ~0.2 mm. For active Q-switching, a 24-mm long AO modulator, whose faces were AR coated for 1.06 μm, driven at 70-MHz center frequency with 1.7 W of RF power, was inserted inside the resonator in place of the saturable absorber. The physical cavity length was increased to 80 mm to accommodate the Q-switch, which was of relatively large size. In the case of actively Q-switched operation, a second different fiber-coupled diode laser (fiber bundle core diameter of 1.5 mm and N.A. of 0.11) with a maximum output power of 30 W at ~807 nm was utilized as the pump source. The pump beam was focused onto the laser crystal with a spot radius of 0.26 mm. The laser pulse signal was detected by a fast photodiode, and monitored and measured with a 500-MHz oscilloscope.

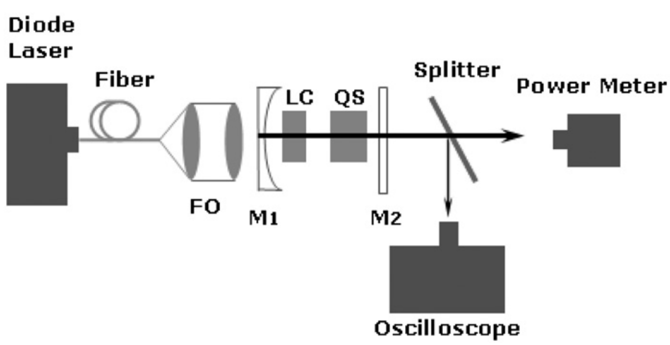

Fig. 1. Schematic diagram illustrating the experimental laser setup, FO: focusing optics; LC: laser crystal; and QS: Q-switch (saturable absorber or acousto-optic modulator).

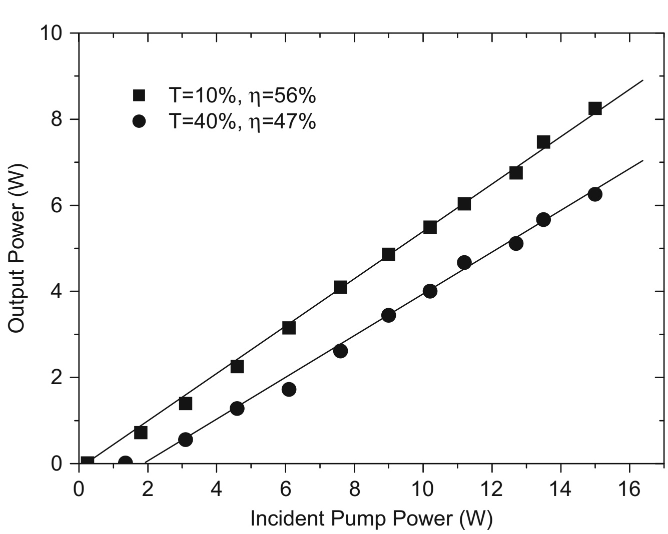

Fig. 2. Continuous-wave output power as a function of P_{in} for T=10% and 40%.

3. Results and discussion

The cw laser performance of the Nd:$Gd_{0.18}Y_{0.82}VO_4$ crystal was studied using the first diode laser, with a group of output couplers of transmissions in the range $T=5-50\%$. The most efficient operation was obtained with output couplings of $T=5-15\%$. Fig. 2 shows the output power as a function of incident pump power (P_{in}) for T=10% and 40%. In the case of T=10%, an output power of 8.25 W with a slope efficiency of 56% was generated at the highest available pump power (P_{in}=15 W). While in the case of T=40% (the optimal for Q-switching), the output power obtained at the same pump level decreased to 6.26 W, with the slope efficiency being 47%.

For passively Q-switched operation, the output coupler of T=40% was used, which was found to be the optimal in producing efficient, stable, short-duration pulsed laser radiation. Fig. 3 shows the average output power versus incident pump power generated with different Cr^{4+}:YAG saturable absorbers of T_0=80%, 70%, and 62%. One sees that the pump power required for reaching threshold increases rapidly with T_0; it was measured to be 6.8 W in the case of T_0=62%, in contrast to 3.5 and 4.6 W measured for T_0=80% and 70%, respectively. On the other hand, nearly equal slope efficiencies, $\eta=37-38\%$, were determined for the three cases, which amount to a factor of 0.8 of that for the cw operation generated with the same coupler of T=40%, indicating efficient Q-switching action. The maximum average output power, produced at the highest available P_{in}=15 W, was measured to be 4.0, 3.7, and 3.05 W for T_0=80%, 70%, and 62%, respectively, with the corresponding optical-to-optical efficiency being 26.7%, 24.7%, and 20.3%.

One common feature of passively Q-switched operation is the increase of pulse repetition frequency (PRF) with pump power. With the pump power rising from P_{in}=6.1 W (9 W in the case of

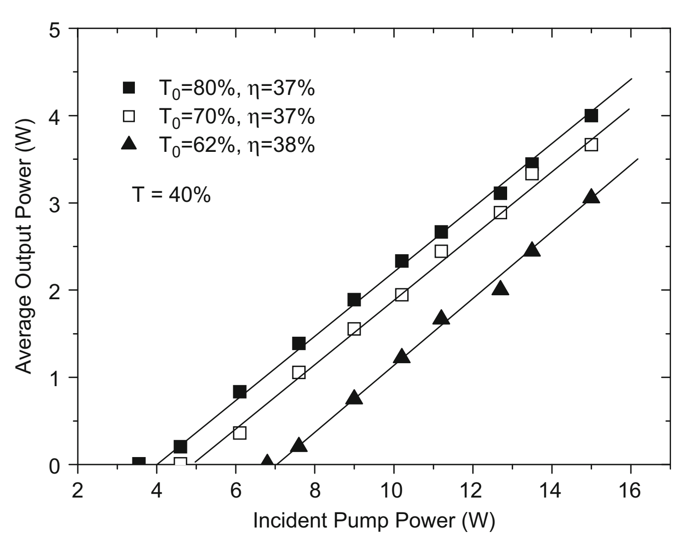

Fig. 3. Average output power as a function of P_{in} generated with three saturable absorbers of T_0=80%, 70%, and 62%.