Passively Q-switched $GdVO_4$/Nd:$GdVO_4$ and YVO_4/Nd:YVO_4 lasers using continuous-grown composite crystals using 879 nm direct pumping

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Abstract: Passively Q-switched $GdVO_4$/Nd:$GdVO_4$ and YVO_4/Nd:YVO_4 laser performance using direct 879 nm pumping was demonstrated for the first time., YVO_4/Nd:YVO_4 compared with $GdVO_4$/Nd:$GdVO_4$ is a more favorable gain medium if higher repetition rates are required.
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1. Introduction

Q-switched lasers with high repetition rate are widely used in numerous applications such as laser lidar, remote sensing, micro-machining, and microsurgery [1]. Passive Q-switching techniques have the advantages of lower cost, compactness and simplicity since they do not require external control. Neodymium ion-hosted crystals such as Nd:YAG, Nd:$GdVO_4$ and Nd:YVO_4 have been widely employed to build compact, high efficiency laser-diode pumped solid-state lasers in the near-infrared region. Both Nd:GVO_4 and Nd:YVO_4 crystals have excellent physical and optical properties. Nd:GVO_4 and Nd:YVO_4 compared with Nd:YAG, both have larger stimulated emission cross sections and moderate fluorescent lifetimes. The stimulated emission cross section at 1.06 μm of Nd:GVO_4 (10.3×10^{-19}cm^2) and Nd:YVO_4 (14.1×10^{-19}cm^2) are 4.5 and 6.1 times larger, respectively, than that of Nd:YAG (2.3×10^{-19}cm^2) [2,3]. The fluorescent lifetime of the $^4F_{3/2}$ level is 90 μs for Nd:$GdVO_4$ and Nd:YVO_4 is < 2.5 times that of Nd:YAG (230 μs) [4].

Both theoretical and experimental results have shown that thermal lensing effects of laser crystals result in a decrease of laser cavity stability and alter the TEM_{00} mode spot size, which impacts the performance of passively Q-switched lasers [5]. In this paper, for the first time to the best of our knowledge, we studied the passively Q-switched laser properties of continuous-grown composite $GdVO_4$/Nd:$GdVO_4$ and YVO_4/Nd:YVO_4 crystals using direct pumping. The performance of passively Q-switched $GdVO_4$/Nd:$GdVO_4$ and YVO_4/Nd:YVO_4 lasers were investigated by employing Cr^{4+}:YAG crystal as the saturable absorber.

2. Theory analysis

The repetition rate, *f*, for a passively Q-switched laser can be derived from the rate equations [5]

$$f = \frac{1}{-\tau \cdot \ln\left(1 + \dfrac{\ln(T_0^2 R_1 R_2)}{2\sigma l \eta \tau \alpha I_p}\right)}, \quad (1)$$

where τ is the fluorescence lifetime, T_0 is the initial transmissivity of the saturable absorber, σ is the stimulated emission cross section of the gain medium, l is the length of the cavity, α is the absorption coefficient, I_p is the incident pump intensity (in the number of photons per second and per surface unit), and R_1, R_2 are the reflection coefficients of the two respective cavity mirrors, η is an overlap efficiency factor (OEF) that represents the mode matching degree between the pump and the cavity beams as defined in the Ref. [6]

$$\eta = \frac{\left[\iiint_{\text{active}} \varepsilon(x,y,z) r(x,y,z) dv\right]^2}{\iiint_{active} \varepsilon(x,y,z)^2 r(x,y,z) dv}, \quad (2)$$

where $r(x,y,z)$ and $\varepsilon(x,y,z)$ are the normalized intensity distribution of pump beam and cavity beam respectively. The overlap efficiency factor varies with the pump beam waist radius ω_{p0} and its location z_0 where z_0 is the distance between the incident face of the crystal and the pump beam waist spot in the crystal.

3. Experimental setup

The experimental configuration of passively Q-switched $GdVO_4$/Nd:$GdVO_4$ and YVO_4/Nd:YVO_4 lasers using 879 nm laser-diode end-pumping is shown in Fig. 1. The dimensions of composite $GdVO_4$/Nd:$GdVO_4$ and

$YVO_4/Nd:YVO_4$ crystals were 3×3×10 mm^3 respectively, and the undoped caps were 2 mm long. The composite crystal was wrapped with indium foil and placed into water-cooled copper heat sink. Two plano-plano mirrors were used to construct the laser cavity. The output coupler M_2 had a transmissivity of 35% at 1064 nm. The saturatable absorber Cr^{4+}:YAG crystal has an initial transmission of 80% at 1064 nm. The length of l_1 was ~ 5 mm and the length , l_3 was ~ 45 mm. For such a laser architechture, the total cavity length was ~ 60 mm.

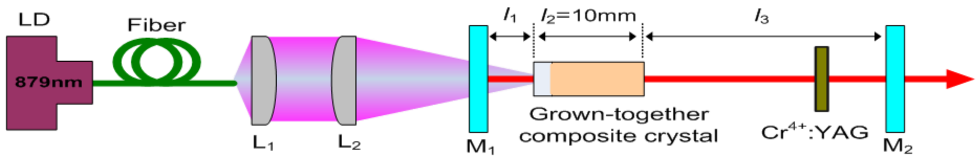

Fig. 1. Experimental setup of passively Q-switched $GdVO_4/Nd:GdVO_4$ and $YVO_4/Nd:YVO_4$ lasers

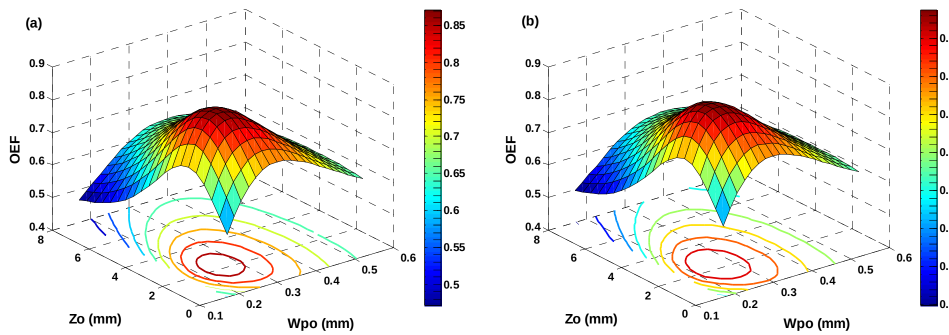

Fig. 2. The overlap efficiency factor (OEF) varies with the pump beam waist radius ω_{p0} and the location of pump waist spot z_0: (a) $GdVO_4/Nd:GdVO_4$ laser; (b) $YVO_4/Nd:YVO_4$ laser

The numerical results based on Eq. (2) of the overlap efficiency factor for our experimental setup with an incident pump power of 10 W are shown in Fig 2. The numerical results for $GdVO_4/Nd:GdVO_4$ and $YVO_4/Nd:YVO_4$ lasers are shown in Fig.2 (a) and Fig. 2(b), respectively. The highest value of overlap efficiency factor 87.1% for $GdVO_4/Nd:GdVO_4$ laser and 88.6% for $YVO_4/Nd:YVO_4$ laser was obtained when the LD pump beam waist radius ω_{p0} is ~ 0.265 mm and the location of pump waist spot z_0 is 2.5 mm. By adjusting the two coupling lenses L_1 and L_2, the pump beam was fixed at ω_{p0}=0.265 mm and z_0=2.5 mm in the experiments.

4. Results and discussions

As shown in Fig. 3, the repetition rate increased with increasing of the incident pump power. For an incident pump power of 10W, the maximum repetition rate were 121 kHz and 218 kHz for $GdVO_4/Nd:GdVO_4$ and $YVO_4/Nd:YVO_4$ lasers, respectively. Using Eq. (1) and Eq. (2), we calculated the theoretical repetition rates for various incident pump powers of $GdVO_4/Nd:GdVO_4$ and $YVO_4/Nd:YVO_4$ lasers, respectively. The repetition rate for a $YVO_4/Nd:YVO_4$ laser was higher than that of a $GdVO_4/Nd:GdVO_4$ laser. According to Eq. (1), three possible reasons may contribute to this result. First, the stimulated emission cross section σ of $YVO_4/Nd:YVO_4$ ($14.1\times10^{-19}cm^2$) is higher than that of $GdVO_4/Nd:GdVO_4$ ($10.3\times10^{-19}cm^2$). Second, the measured absorption coefficient α of $YVO_4/Nd:YVO_4$ ($0.26mm^{-1}$) is higher than that of $GdVO_4/Nd:GdVO_4$ ($0.24mm^{-1}$). Third, as shown in Fig.4, the η (OEF) of the $YVO_4/Nd:YVO_4$ laser is higher than that of the $GdVO_4/Nd:GdVO_4$ laser. The thermal conductivity is 10.5W/m·K and 12.1W/m·K for $Nd:GdVO_4$ and $Nd:YVO_4$, respectively [7]. This high thermal conductivity is effective for heat conduction which is advantageous for minimizing thermal lens effects and improving the mode matching degree. As shown in Fig.4, comparing a non-composite crystal, a composite crystal produced weaker thermal lensing effects and higher overlap efficiency factors under the same conditions owing to the undoped end acting as an effective heat diffuser. Therefore, it can be predicted that the laser with the composite crystal will have a higher repetition rate and superior beam quality in comparison to that of a non-composite crystal laser.

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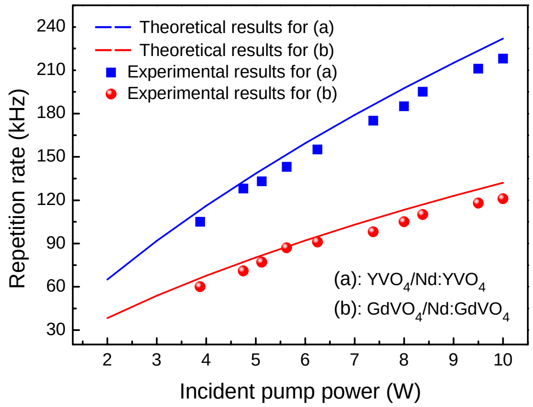

Fig. 3. Repetition rate as a function of incident pump power

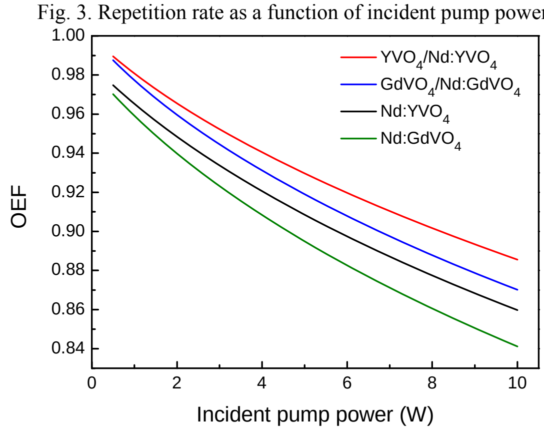

Fig. 4. The overlap efficiency factor (OEF) as a function of incident pump power

5. Conclusions

A comparison of the performance of passively Q-switched laser properties of continuous-grown composite $GdVO_4$/Nd:$GdVO_4$ and YVO_4/Nd:YVO_4 crystals operated at 1.06 µm using direct 879 nm diode laser pumping was demonstrated. Continuous-grown composite crystals and direct pumping were proved to be effective methods to reduce the thermal lens effect. YVO_4/Nd:YVO_4 compared with $GdVO_4$/Nd:$GdVO_4$ is a more effective gain medium due to its physical and optical properties (higher stimulated emission cross section and absorption coefficient) when higher repetition rates are required.

6. References

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