Optik - International Journal for Light and Electron Optics 176 (2019) 630–635

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

High-peak-power short-pulse laser using a Yb:YAG/Cr^{4+}:YAG/YAG composite crystal

Jingzhao Li[a], Siqi Zhu[b,*]

[a] College of Electronics and Information Engineering, Shunde Polytechnic, Foshan, 528300, Guangdong, China
[b] Institute of Optoelectronic Engineering, Jinan University, Guangzhou, 510632, Guangdong, China

ARTICLE INFO

Keywords:
Solid-state laser
Composite crystal
Diode-pumped
Q-switched
Pulsed

ABSTRACT

A high-peak-power and short-pulse passively Q-switched laser at 1029 nm was obtained by using a Yb:YAG/Cr^{4+}:YAG/YAG composite crystal in a compact diode-end-pumped resonant cavity. With the saturable absorber of 85% initial transmission, the pulse peak power reaches up to 87 kW with a short pulse width of 3.14 ns at incident pump power of 7.2 W. Furthermore, the output performance and optical spectra were studied at different pump power and with different composite crystals, which reveal that both bonding nondoped YAG crystal and using low initial transmission can contribute to high-peak-power and short-pulse laser output.

1. Introduction

Short-pulse, high-peak-power, passively Q-switched solid-state lasers have a broad application prospect in the fields like optical communications, laser micromachining, laser ignition and nonlinear frequency conversion [1,2]. The passively Q-switched laser is generally composed of laser crystal and Cr^{4+}:YAG saturable absorber, which requires two temperature control modules for separate cooling of two crystals, thus increasing the cavity length and loss. In this regard, a viable solution has been developed in recent years [3–15], where the laser crystal is bonded with the homogenous saturable absorber by diffusion bonding technology [3]. Compared with separate crystals, the composite crystal can effectively decrease the length of resonant cavity, which not only reduces the cavity loss, but also compresses the pulse width, thus is conducive to producing narrow-pulse laser with high peak power.

Nd:YAG/Cr^{4+}:YAG composite crystals have long been used to generate pulsed 1 μm fundamental frequency laser [4,5], frequency doubled green laser [6] and Raman laser [7]. However, the severer heat generation by saturable absorber Cr^{4+}:YAG than Nd:YAG [8] exacerbates the thermal lens effect, which leads to resonant cavity instability at high power and ultimately results in difficulty of obtaining a larger output power [4,5,8,11]. To address this problem, a nondoped YAG crystal section can be bonded to the end of Cr^{4+}:YAG as a heat sink to accelerate the heat dissipation of Cr^{4+}:YAG, thereby effectively alleviating the thermal lens effect [9–15]. In 2013, we inserted a 65-mm-long Nd:YAG/ Cr^{4+}:YAG/YAG composite crystal rod into the diode-side-pumped system and used a KTP for frequency doubling to obtain a high-power pulsed green laser, which had an average output power up to 27.2 W under the pump power of 187.5 W, without showing instability or saturation [11]. This indicates that nondoped homogeneous crystals can greatly enhance the thermal properties of composite crystals, increase the output power and improve the beam quality. Nevertheless, most existing studies have focused on the Nd:YAG/Cr^{4+}:YAG/YAG composite crystals [9–14], while the Yb:YAG/Cr^{4+}:YAG/YAG composite crystals are seldom reported [16,17]. Compared with Nd:YAG, Yb:YAG has the advantages of wide absorption band, long fluorescence lifetime, large emission cross section and low quantum defect [18,19]. Therefore, it is necessary to study the laser

* Corresponding author.
E-mail address: tzhusiqi@jnu.edu.cn (S. Zhu).

https://doi.org/10.1016/j.ijleo.2018.09.132
Received 24 April 2018; Accepted 24 September 2018
0030-4026/

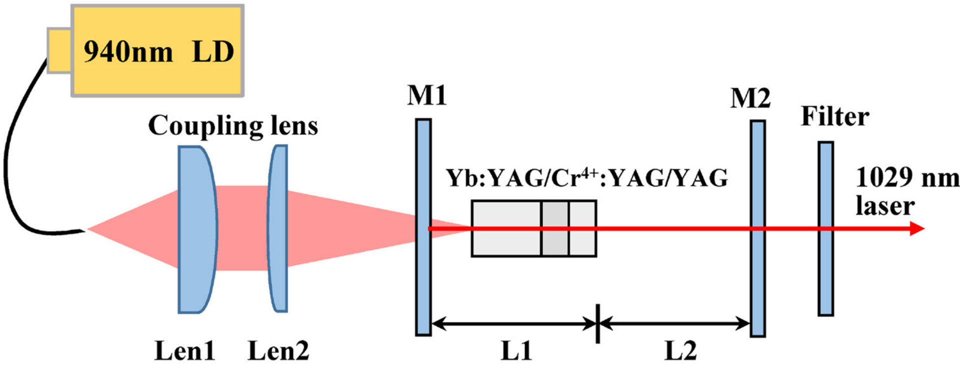

Fig. 1. Experimental configuration of the laser with a Yb:YAG/Cr^{4+}:YAG/YAG composite crystal.

performance of the composite crystal composed of Yb:YAG in depth.

In this paper, Yb:YAG/Cr^{4+}:YAG/YAG composite crystals were used to get the short-pulse laser output with high peak power in a compact diode-end-pumped resonant cavity. The effects of pump power and initial transmission on the pulse performance were studied. Moreover, the optical spectra at different pump power were compared, as well as the spectra from different composite crystals.

2. Experimental setup

Fig. 1 presents the experimental setup of passively Q-switched laser with a Yb:YAG/Cr^{4+}:YAG/YAG composite crystal, which has a compact diode-end-pumped linear cavity structure. The pumping source is a semiconductor laser diode (LD) with fiber-coupled output, where the coupling fiber has a core diameter of 200 μm and a numerical aperture of 0.22, and the pump laser has a center wavelength of 940 nm that matches with the strong absorption peak of Yb:YAG [19–21]. The pump beam is focused to the gain medium in the cavity through a pair of convex lenses with an imaging ratio of 1:2. The resonant cavity consists of two plane mirrors M1 and M2. The input mirror M1 is coated with high-reflection (HR) film at 1030 nm ($R > 99.8\%$) together with high-transmission (HT) film at 940 nm ($T = 99.7\%$). The output mirror M2 is coated with partial-reflection (PR) film at 1030 nm ($R \approx 80\%$). The distances from the end side of the composite crystal to M1 (L1) and to M2 (L2) are 12 mm and 11 mm respectively. The plane filter mirror outside of the cavity is coated with HR film at 940 nm ($R > 90\%$) together with HT film at 1030 nm ($T > 99.5\%$), which is used to block the pump light and transmit 1 μm infrared laser.

The composite crystal Yb:YAG/Cr^{4+}:YAG/YAG has a cross-sectional area of 4×4 mm^2, and a total length of 9 mm, in which the gain medium Yb:YAG is 5 mm long, with a 5% ytterbium mass fraction. Meanwhile, the saturable absorber Cr^{4+}:YAG is a passive Q switch with a length of 2 mm and an initial transmission (T_0) of 85%. In addition, a 2-mm-long YAG crystal bonded at the end is used as a heat sink to improve thermal properties. In this way, the gain medium and saturable absorber can be cool simultaneously in the same temperature control module, which not only cuts the cost, but also tightens the cavity. According to the relationship between the absorption characteristics of Yb^{3+} ions and the temperature, the temperature of temperature control system is set at 12 °C [17,21,22]. To reduce the loss of pump light and fundamental laser, both end faces of the composite crystal are coated with HT film at 940 nm and 1030 nm.

3. Results and discussion

In the experiment, the average output power P_{av} of the laser is measured with the power meter at different pump power P_{ip}. As shown in Fig. 2, P_{av} increases linearly with the pump power, the slope efficiency is 16.5%, and the output power reaches 860 mW at 10-W incident pump power, without presenting saturation trend. This owes to the heat dissipation effect of nondoped YAG crystal at the composite crystal end [11].

The waveform and pulse sequence of a single pulse can be captured using an oscilloscope as shown in Fig. 3, based on which the repetition rate f_p and width τ_h of pulse are measured. Then, the energy E and the peak power P_{pk} of a single pulse can be calculated by the formula $E = P_{av}/f_p$ and $P_{pk} = P_{av}/(f_p{\cdot}\tau_h)$. It can be found from the pulse sequence in Fig. 3(b) that the pulse amplitude is instable because the resonant cavity contains multiple transverse modes, which results in uneven distribution of light spot intensity [12,17]. This way, the different points of saturable absorber on the cross section cannot be bleached simultaneously, thus forming unstable pulse [23].

Fig. 4 shows the relationship between the repetition rate of output pulse and the pump power. Clearly, the pulse repetition rate increases approximately linearly with the increasing pump power. This is because the increase of pump power accelerates the bleaching process of saturable absorber and shortens the interval of each bleaching, and thereby increases the repetition rate of pulse. When the incident pump power is increased to 10 W, the repetition rate reaches 2.8 kHz.

Fig. 5 displays the relationship between the pulse width and the pump power. The pulse width is very narrow, which is as short as 3.14 ns at the incident pump power of 7.2 W. This is precisely the result of the effective reduction of cavity length after using the