Optics Communications 335 (2015) 245–249

Contents lists available at ScienceDirect

Optics Communications

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

Enhancing extinction ratio of polarization and pulse stability simultaneously from passively Q-switched [100]-Nd:YAG/[110]-Cr^{4+}:YAG laser

Zhe Sun *, Qiutong Cheng, Yongling Hui, Menghua Jiang, Hong Lei, Qiang Li

Institute of Laser Engineering, Beijing University of Technology, Beijing 100124, China

ARTICLE INFO

Article history:
Received 18 June 2014
Received in revised form
20 August 2014
Accepted 1 September 2014
Available online 16 September 2014

Keywords:
Lasers
Diode-pumped
Q-switched
Polarization

ABSTRACT

Depolarization is one of important factor limits the output extinction ratio of polarization, pulse stability and energy of passively Q-switched Nd:YAG/Cr^{4+}:YAG laser, especially in high pump energy regime. We experimentally investigate the output extinction ratio of polarization, pulse stability and energy with different crystal cuts of Nd:YAG and Cr^{4+}:YAG. We demonstrate that linearly polarized, highly stable passively Q-switched output can be greatly enhanced by adopting [100]-cut Nd:YAG crystal as the gain medium and [110]-cut Cr^{4+}:YAG crystal as the saturable absorber. The output pulse energy is 8.5 mJ, repetition frequency is 100 Hz, pulse duration is 13 ns, extinction ratio of polarization is higher than 800:1 and pulse amplitude instability is 2.8%.

1. Introduction

Passive Q-switching is a significant method for short pulse and high peak power laser system since it does not require the additional complicated controllers [1]. Nd:YAG crystal is one of common gain medium, and Cr^{4+}:YAG normally used as saturable absorber of passively Q-switched solid-state lasers [2–4]. However, passively Q-switched Nd:YAG/Cr^{4+}:YAG lasers generally use [111]-cut Nd:YAG as the gain medium and [001]-cut Cr^{4+}:YAG as the saturable absorber. This generates a laser output with low energy and unstable polarization that is not suitable for applications.

Controlling the pump polarization [5,6] and using [110]-cut Cr^{4+}:YAG as the saturable absorber [7] instead of [001]-cut Cr^{4+}:YAG, have proven to be two effective way to improve the output pulse stability and extinction ratio of polarization for passively Q-switched Nd:YAG/Cr^{4+}:YAG laser. Bouwmans et al. [5] observed the linearly polarized output depends on the relative orientation of the pump polarization in passively Q-switched Nd:YAG/Cr^{4+}:YAG lasers. In another demonstration, Sun et al. [6] analyzed the output pulse stability and extinction ratio of polarization with different pump polarization directions. They demonstrated that the stable output with high extinction ratio of polarization can be obtained when the pump polarization direction was parallel to one of the crystallographic axes of [001]-cut Cr^{4+}:YAG crystal. On the other hand, Sakai et al. [7,8] investigated the dependence of the transmission of [110]-cut Cr^{4+}:YAG crystal on the polarization direction, and found that there is only one crystallographic axis on the plane perpendicular to the direction of incidence light. They demonstrated that the stable, linearly polarized output can be achieved by using the [110]-cut Cr^{4+}:YAG as the saturable absorber.

From all of the above passive Q-switch experiment results, we can see that the output pulse stability is improved by controlling pump polarization and using the [110]-cut Cr^{4+}:YAG crystal. For achieving high output power, the pump power needs to increase [9]. It will induce more heat deposit and leads to larger refractive index change in the laser crystal, which results in serious depolarization [10]. Unfortunately, the depolarization will limit the output extinction ratio of polarization in a low regime, even using the preferred two methods [5–7]. It can be seen that the output extinction ratio of polarization will be extremely degraded for further increasing the pump power [10,11]. In addition, the output pulse stability of pulse repetition frequency, pulse polarization and pulse amplitude will be inevitably reduced by the thermal effects [12,13]. Furthermore, the unstable, partially polarized output of a passively Q-switched laser will prevent further applications, such as efficient wavelength conversion [14,15]. Although the thermal effects can be reduced by adopting quasi-continuous-wave pumping [14,15], it still cannot intrinsically solve the problem of depolarization in high pump power regime.

To avoid the problem of depolarization, the influence of cutting direction of Nd:YAG crystal was analyzed in the former experiments [5–7]. Here, we make improvement in using [100]-cut Nd:YAG crystal as the gain medium instead of isotropic [111]-cut Nd:YAG crystal. The depolarization of the [100]-cut Nd:YAG crystal is evidently smaller than [111]-cut Nd:YAG crystal when the oscillation polarization

* Corresponding author.
E-mail address: allen-sun@163.com (Z. Sun).

http://dx.doi.org/10.1016/j.optcom.2014.09.005
0030-4018/

direction is parallel to one of [011], [0$\bar{1}$1], [01$\bar{1}$], and [0$\bar{1}\bar{1}$] orientation of the [100]-cut Nd:YAG crystal. The depolarization in Nd:YAG lasers can be intrinsically reduced by using the [100]-cut direction [16–20]. This effect is firstly found by Soms et al. [16] and theoretical demonstrate by Shoji et al. [17]. Thus, the [100]-cut Nd:YAG is more suitable to obtain high pulse energy, linearly polarized output than the [111]-cut Nd:YAG in passively Q-switched lasers. It will further improve the output extinction ratio of polarization and pulse amplitude stability with high pulse energy simultaneously, both in high and low repetition frequency.

In this paper, we enhance the output pulse stability and extinction ratio of polarization with high pulse energy by using the [100]-cut Nd:YAG as the gain medium and the [110]-cut Cr^{4+}:YAG as the saturable absorber. Different crystal cuts of Nd:YAG and Cr^{4+}:YAG are experimentally investigated in the high pump energy regime in order to intrinsically reduce the depolarization and improve the linearly polarized pulse stability.

2. Laser structure

Fig. 1 presents the schematic of the passively Q-switched Nd:YAG/Cr^{4+}:YAG laser structure with different combinations. The [111]- and [100]-cut Nd:YAG rod were used as the gain medium. Both Nd:YAG rods were 3 mm in diameter and 20 mm long and doped with 1.0 at% Nd^{3+} ions. Two Cr^{4+}:YAG crystals were used as the saturable absorber for passive Q-switching, one was [001]-cut Cr^{4+}:YAG with the initial transmission of 24.92% and the thickness of 3.86 mm, and the other was [110]-cut Cr^{4+}:YAG with the initial transmission of 24.88% and the thickness of 3.10 mm. The end-pump source was a fiber coupled 808 nm diode laser. The diameter of the fiber core was 400 μm with a numerical aperture of 0.22. The maximum peak power of the QCW pump light is 140 W. A half wave plate was installed behind the focus lens to vary the pump polarization. The pump beam radius was approximately 300 μm. The input coupling mirror was coated with anti-reflection at 808 nm and high reflection at 1064 nm. The Cr^{4+}:YAG crystal with copper heat sink was mounted on rotation mounts and rotated around the axis of laser propagation direction. The copper heat sink cooled by water at the temperature of 25 °C. A flat coupler with a transmission of 55% was used at the output. The cavity length is 185 mm. Average output power and polarization states were respectively measured with a power meter and polarization beam splitter cube (PBS). The Q-switched pulse profiles were recorded by using a photo detector and a Tektronix DPO4104B digital phosphor oscilloscope.

3. Experimental results and analysis

Four combinations of Nd:YAG and Cr^{4+}:YAG were used in the laser experiments to investigate the output performance of passively Q-switched Nd:YAG/Cr^{4+}:YAG lasers: No. 1, [100]-cut Nd:YAG+[110]-cut Cr^{4+}:YAG; No. 2, [111]-cut Nd:YAG+[110]-cut Cr^{4+}:YAG; No. 3, [100]-cut Nd:YAG+[001]-cut Cr^{4+}:YAG; No. 4, [111]-cut Nd:YAG+[001]-cut Cr^{4+}:YAG. To analyze the output characteristics in dependence of the Cr^{4+}:YAG crystal angle, we rotated the Cr^{4+}:YAG crystal to align the anisotropic transmission direction to the pump polarization. In our experiments, we made the pump polarization along the [011] orientation of [100]-cut Nd:YAG crystal. Under this operating condition, the pump frequency was 100 Hz, pump energy was 32 mJ and extinction ratio of the pump light was about 50:1.

We firstly study the extinction ratio of output polarization in dependence of angle θ for four combinations. θ is the rotation angle of the Cr^{4+}:YAG crystal. The extinction ratio of output polarization periodically changed with the angle θ in Fig. 2(a) and (b). All four combinations exhibit linearly polarized output and the maximum extinction ratio of polarization is greater than 800:1 for No. 1 combination. The extinction ratio of output polarization of other

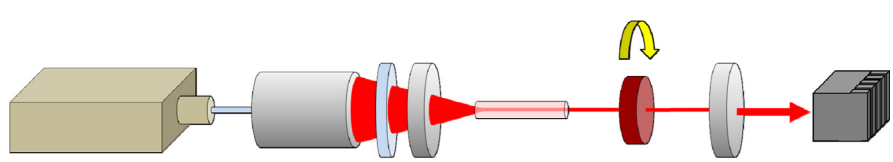

Fig. 1. Experimental setup of passively Q-switched laser. (1. Laser diode; 2. Focus lens; 3. Half wave plate; 4. High reflection coating, HR@1064 nm, AR@808 nm; 5. [111]- and [100]-cut Nd:YAG rod; 6. [001]- and [110]-cut Cr^{4+}:YAG crystal; 7. Mirror, transmission is 55%; 8. Power meter. [111]- and [100]-cut Nd:YAG rod are used as the gain medium, [001]- and [110]-cut Cr^{4+}:YAG crystal are used as the saturable absorber, respectively.).

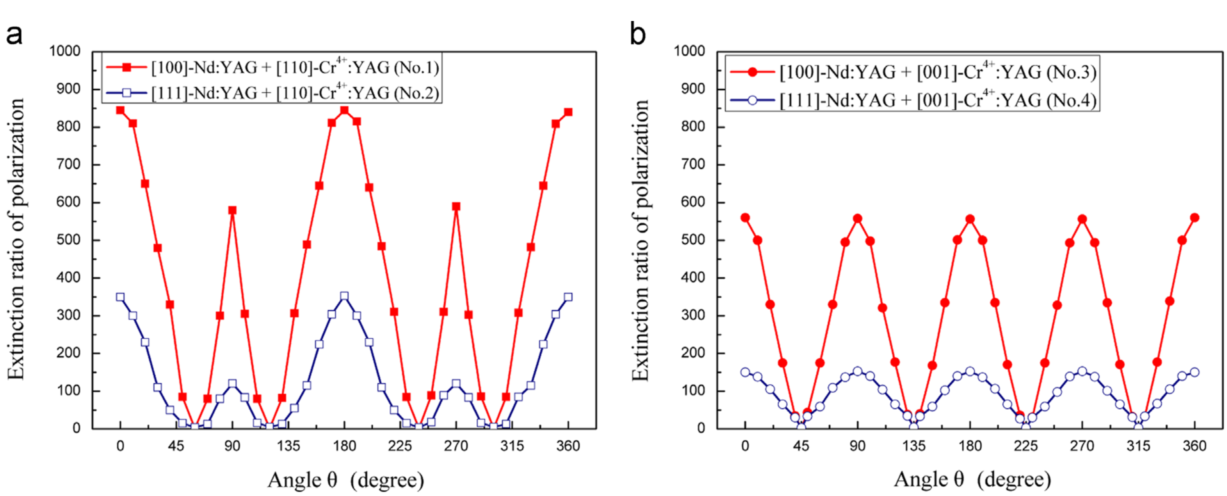

Fig. 2. The extinction ratio of output polarization as a function of angle θ for of passively Q-switched Nd:YAG/Cr^{4+}:YAG lasers four combinations. (a) [100]-Nd:YAG+[110]-Cr^{4+}:YAG (No. 1) and [111]-Nd:YAG+[110]-Cr^{4+}:YAG (No.2); (b) [100]-Nd:YAG+[001]-Cr^{4+}:YAG (No. 3) and [111]-Nd:YAG+[001]-Cr^{4+}:YAG (No. 4).