



Diode-pumped doubly Q-switched Nd:Lu_{0.33}Y_{0.37}Gd_{0.3}VO₄ laser with an electro-optic modulator and a single-walled carbon nanotube saturable absorber

K. Cheng^a, S.Z. Zhao^{a,*}, K.J. Yang^a, G.Q. Li^a, D.C. Li^a, G. Zhang^a, B. Zhao^b, Y.G. Wang^c

^a School of Information Science and Engineering, Shandong University, Jinan 250100, PR China

^b College of Chemistry and Chemical Engineering, Fuzhou University, Fuzhou 350108, PR China

^c Research Center for Applied Sciences, Academia Sinica, Taiwan, China

ARTICLE INFO

Article history:

Received 22 August 2011

Received in revised form

16 September 2011

Accepted 3 October 2011

Available online 29 November 2011

Keywords:

Doubly Q-switched laser

Nd:Lu_{0.33}Y_{0.37}Gd_{0.3}VO₄ crystal

Single-walled carbon nanotube

ABSTRACT

By simultaneously using an electro-optic (EO) modulator and a single-walled carbon nanotube saturable absorber (SWCNT-SA) in the cavity, a diode-pumped doubly Q-switched Nd:Lu_{0.33}Y_{0.37}Gd_{0.3}VO₄ (Nd:LuYGDVO₄) laser is demonstrated. At the incident pump power 11.43 W and $f=2$ kHz, the minimum pulse width 17.6 ns and the maximum pulse peak power 19,886 W can be obtained. The experimental results show that this doubly Q-switched Nd:LuYGDVO₄ laser can generate shorter pulse width and higher peak power compared to the singly Q-switched Nd:LuYGDVO₄ laser with only EO or SWCNT-SA.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

Single-walled carbon nanotube saturable absorbers (SWCNT-SAs) have attracted much attention recently because of their simple and inexpensive fabrication process, broad wavelength range from 1 μm to 2 μm and high-speed third-order optical nonlinearity [1,2]. SWCNT-SAs have been successfully employed in mode-locking of Er-, Yb-, Cr-, Tm-, Nd-doped lasers from 1 μm to 2 μm wavelengths [3–7]. Moreover, we have successfully realized a passively Q-switched laser using SWCNT-SA [8], but the obtained minimum pulse width is 52 ns and the maximum peak power is only 62.5 W. The long pulse width and the quite low pulse peak power of the passively SWCNT-SA Q-switched laser will limit its applications. Double Q-switches technique is an effective method to compress pulse width and increase pulse peak power. Using both an electro-optic (EO) or acousto-optic(AO) modulator and a saturable absorber in the cavity simultaneously, known as double active-passive Q-switches, shorter pulses and higher peak power can be obtained [9–13]. Besides, the repetition rate of this double active-passive Q-switches can be controlled by EO or AO modulator. Therefore, in order to compress the pulse width and improve the peak power of the SWCNT-SA Q-switched laser, a doubly active-passively Q-switched laser with SWCNT-SA and EO or AO modulator is expected.

Since the Nd-doped vanadate mixed crystals such as Nd:Gd_xY_{1-x}VO₄, Nd:Lu_xGd_{1-x}VO₄ and Nd:Lu_xY_{1-x}VO₄ crystals were grown, they have been successively investigated [14–16]. Due to the inhomogeneous broadening in the fluorescence spectra, these double-mixed crystals have much broader fluorescence line-width than the single vanadate crystals such as Nd:GdVO₄, Nd:YVO₄ and Nd:LuVO₄. These researches prove that the double-mixed vanadate crystals are more suitable for Q-switched lasers than the single vanadate crystals. Recently, a new triple-mixed vanadate crystal Nd:Lu_{0.33}Y_{0.37}Gd_{0.3}VO₄ (Nd:LuYGDVO₄) was fabricated and grown in Fuzhou University. The central wavelength of the fluorescence band is 1064.1 μm with a full width at half-maximum (FWHM) of 6.2 nm, which is even broader than the double-mixed crystal [8]. In Ref. [8], Nd:LuYGDVO₄ crystal have been proved an excellent gain medium for Q-switched laser.

In this paper, by simultaneously using EO modulator and SWCNT-SA in the cavity, a diode-pumped doubly Q-switched Nd:LuYGDVO₄ laser is presented. This doubly active-passively Q-switched laser can effectively compress the pulse width and improve the peak power compared to singly Q-switched laser with EO modulator or singly passively one with SWCNT-SA. Besides, compared with the singly SWCNT Q-switched laser, the doubly Q-switched laser can generate more stable pulse train with lower repetition rate. At the input pump power 11.43 W and $f=2$ kHz, the minimum pulse width and the maximum peak power of the doubly Q-switched Nd:LuYGDVO₄ laser are 17.6 ns and 19886 W, respectively.

* Corresponding author.

E-mail address: Shengzhi_zhao@sdu.edu.cn (S.Z. Zhao).

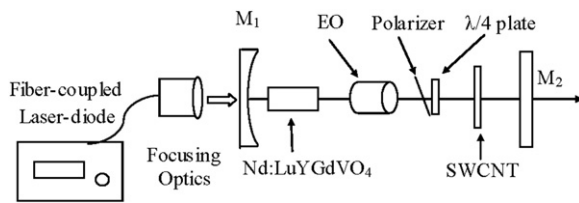


Fig. 1. Schematic of the experimental setup.

2. Experimental setup

The arrangement of the doubly Q-switched Nd:LuYGdVO₄ laser is shown in Fig. 1. The a-cut Nd:LuYGdVO₄ crystal (0.25 at% Nd-doped) has the dimensions of $3 \times 3 \times 6 \text{ mm}^3$ and is AR coated at 808 nm and 1064 nm on both the surfaces. The laser gain medium is controlled at 20 °C by a temperature controller in order to dispatch the deposited thermal efficiently. The mirror M₁ is a concave mirror with radius of 500 mm, which is anti-reflection (AR) coated at 808 nm on its outside surface and high-reflection (HR) coated at 1064 nm on its inside surface. The output mirror M₂ is a plane mirror with a transmission of 8.8% and HR coated at 1064 nm on both the surfaces. The cavity length is 22 cm. The EO modulator (BBO crystal) with a polarizer and $\lambda/4$ plate is used as an active Q-switch. The loss of EO modulator $\delta_E(t)$ can be expressed by $\delta_E(t) = \cos^2[(\pi/2)(V(t)/V_{\lambda/4})]$, where $V_{\lambda/4}$ is the quarter-wave voltage and equal to 3.8 kV and $V(t)$ is the voltage at EO modulator [17].

The SWCNTs were grown by electric arc discharge technique. The mean diameter of the SWCNTs is about 1.4 nm. At the first step, several milligrams of SWCNTs powder were poured into 10 ml 0.1% sodium dodecyl sulfate (SDS) aqueous solution. Hence, SDS was used as a surfactant. In order to obtain SWCNT aqueous dispersion with high absorption, SWCNT aqueous solution was ultrasonically agitated for 10 h. The dispersed solution of SWCNTs was then centrifuged to remove sedimentation of larger SWCNTs boundless. After decanting the upper portion of the centrifuged solution, several milligram PVA was poured into the solution and heated at 90°. The SWCNTs/PVA dispersion was then poured into a polystyrene cell. Finally, we inserted vertically a hydrophilic quartz substrate into the polystyrene cell and kept steady for gradual evaporation in the atmosphere. It took about two weeks for complete evaporation on the substrate. Then the quartz substrate coated with SWCNTs/PVA is ready for use as an absorber. Fig. 2 shows the transmission spectra of SWCNTs/PVA polymer film made from these solutions. The transmission is 78.1% at 1.064 μm .

The pump source is a fiber-coupled laser-diode (FAP-I system, Coherent Inc., USA) whose center wavelength is 808 nm. The output pump beam is focused into a spot with about 440 μm in diameter at focal plane. An EPM 2000 Energy/Power Meter (Moletron Detector Inc., USA) is used to measure the output powers. The temporal behavior of the laser pulse is recorded by a fast photo-electronic diode (New Focus 1623, wavelength range of 800–1700 nm and typical rise time 1 ns) and a TED 6208 digital oscilloscope (500-MHz bandwidth, Tektronix Inc., USA).

3. Experimental results and discussion

In our experiment, if anyone of EO modulator and SWCNT-SA is removed, the doubly Q-switched laser will become the singly Q-switched laser. Both the doubly and singly Q-switched Nd:LuYGdVO₄ lasers are studied under the same cavity conditions. The threshold pump powers of the doubly Q-switched lasers are 1.35 and 1.24 W at an EO repetition rate $f=2$ and 4 kHz, respectively, while the singly Q-switched lasers for SWCNT and EO at $f=2$, 4 kHz are 0.98, 1.19 and 1.1 W, respectively. The scattered dots in Fig. 3 give

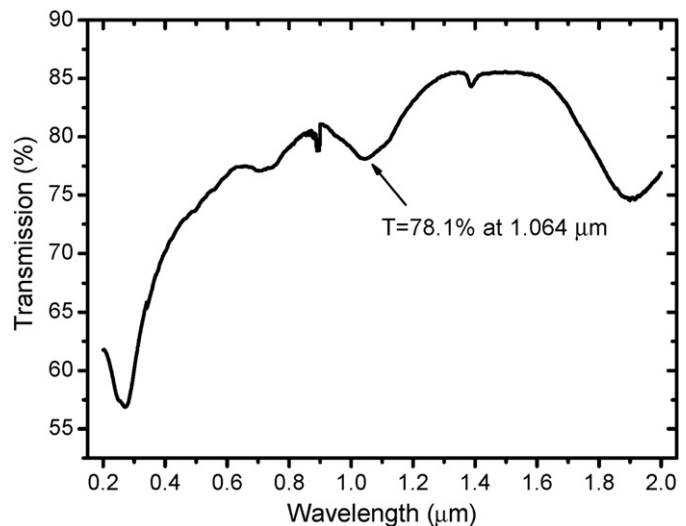


Fig. 2. Transmission spectra of the SWCNT.

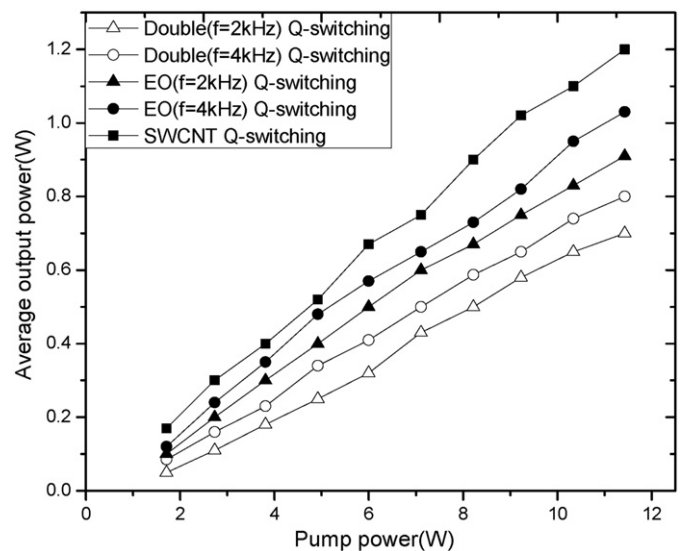


Fig. 3. Average output power versus incident pump power.

the average output powers P_A of the singly and doubly Q-switched Nd:LuYGdVO₄ lasers at $f=2$ and 4 kHz versus input pump power. Due to the dual-loss in the cavity, the doubly Q-switched lasers have lower conversion efficiencies than the singly Q-switched ones.

Fig. 4 shows the pulse width t_p of the singly and doubly Q-switched Nd:LuYGdVO₄ lasers on input pump power, in which a and b are for $f=2$ and 4 kHz, respectively. Fig. 4 indicates that the doubly Q-switched lasers can generate the shorter pulse width than the singly Q-switched ones. At the maximum incident pump power 11.43 W, the obtained pulse widths in the doubly Q-switched lasers for $f=2$ and 4 kHz are 17.6 and 21.3 ns, respectively, while the singly Q-switched lasers for SWCNT and two repetition rates of EO are 53.5, 28 and 32.2 ns, respectively. In comparison to the singly Q-switched laser with SWCNT or EO, the doubly Q-switched laser compressed the pulse width by 67.1%, 37.1%, 60.2% and 33.9%, respectively. Two typical pulse trains of the SWCNT and doubly Q-switched lasers are shown in Fig. 5. The pulse to pulse amplitude fluctuation of the SWCNT Q-switched laser is over 31%, while it is only about 6% in the doubly Q-switched laser. From Fig. 5, we know that the doubly Q-switched laser can obtain more stable pulse train and lower repetition rate than the singly passively Q-switched one.

Download English Version:

<https://daneshyari.com/en/article/732466>

Download Persian Version:

<https://daneshyari.com/article/732466>

[Daneshyari.com](https://daneshyari.com)