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Diode-side-pumped passively Q-switched Nd:YAG laser at 1123 nm with reflective single walled carbon nanotube saturable absorber

Y. Gao [a,b], T.Z. Zhao [a], C.Y. Li [c,*], W.Q. Ge [a], Q. Wu [a,b], Z.H. Shi [c], G. Niu [c], J. Yu [a], Z.W. Fan [a,c,*], Y.G. Wang [d]

[a] Academy of Opto-Electronics, Chinese Academy of Sciences, Beijing 100085, China
[b] Graduate University of Chinese Academy of Sciences, Beijing 100080, China
[c] National Engineering & Technical Center of Diode Pumped Lasers, Beijing GK Laser Technology Co., Ltd., Chinese Academy of Sciences, Beijing 100192, China
[d] Department of Applied Physics and Materials Research Center, HongKong Polytechnic University, HongKong, China

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ABSTRACT

We realized a LD-side-pumped passively Q-switched Nd:YAG laser at 1123 nm by using a single walled carbon nanotube saturable absorber (SWCNT-SA). The SWCNT film was prepared by a vertical evaporation method on quartz substrate. At the pump power of 98 W, a maximum output power of 680 mW for a stable Q-switching operation was obtained. The repetition rate varied from 15.1 kHz to 37.2 kHz with the increase of pump power. The highest single pulse energy of 12.29 μJ occurs at the repetition frequency of 24.4 kHz. The corresponding pulse width was measured to be 2.2 μs.

1. Introduction

As it is well known that laser emission around 1.1 μm has gained great attention in recent years since its wide applications in biotechnology, laser display, frequency conversion, etc. For instance, lasers near 1.1 μm are good candidates for pumping thulium up-conversion fiber laser to generate blue laser emission at 481 nm. The latter plays the essential role in laser display, printing and data recording. Lasers at 1123 nm can be used to generate yellow laser that holds great potentials in medical, laser guide star, public security, and military purposes [1,2]. To date, high power continuous wave (CW) and actively Q-switched 1123 nm lasers have been addressed. A 219 W 1123 nm laser in a short cavity configuration and a 106.5 W with good beam quality were reported [3,4]. By using a Nd:YAG ceramic, 247 W output at 1123 nm was also achieved [5]. On the basis of these high power CW lasers, acoustic Q-switched laser at 1123 nm with as high as 71 W output was acquired [6]. Moreover, in addition to their miniature, simplicity, compactness, high efficiency and low cost, etc, passively Q-switched lasers can offer high peak energy pulse and high repetition frequency that could meet the requirements of industrial processing. Unfortunately, to our knowledge, there are seldom addresses on passively Q-switched lasers around 1.1 μm.

Since the demonstration of saturable absorber based on SWCNT in 2004, this material opened up a new class of passively mode-locking or Q-switching approach in diode pumped lasers [6–14]. Among them passively mode locking lasers are dominantly studied. Here we should mention that the CNTs are promising Q-switching devices originated from their particular energy band structure [15]. They have been paid great attention on spreading the Q-switched laser wavelength beyond 1 μm. For the traditional Cr^{4+}:YAG crystal has only narrow Q-switched band at 1 μm [16]. Just recently, Gao et al. [17] reported a passively Er:YAG Q-switched laser at 1.645 μm using a graphene, they obtained maximum average output power of 251 mW. Wang et al. [18] reported a graphene based passively Q-switched 2 μm laser where 38 mW, 27.9 kHz was obtained. Furthermore, compared to the most prevalently used semiconductor saturable absorber mirrors (SESAM) [19], the CNT-SAs have many advantages e.g. short recovery time, easy fabrication, low cost, etc. In this study, we demonstrate a LD- side-pumped passively Q-switched Nd:YAG laser with a single walled carbon nanotube absorber (SWCNT). A single pulse of 2.2 μs, energy of 12.29 μJ at a repetition rate of 24.31 kHz was obtained. The maximum output power was 680 mW.

2. Experimental setup

The experimental setup was shown in Fig. 1. We adopted a short plano–plano symmetrical cavity configuration where a

* Corresponding authors. Tel.: +86 10 68966848.
E-mail addresses: zhaoyang2050@163.com (C.Y. Li), fanzw002@163.com (Z.W. Fan).

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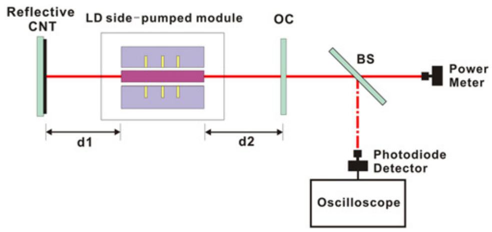

Fig. 1. Experimental setup of 1123 nm passively Q-switched laser.

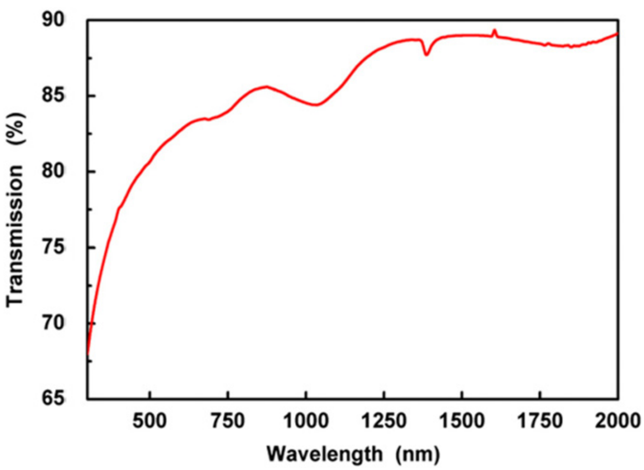

Fig. 2. Transmission spectrum of SWCNT.

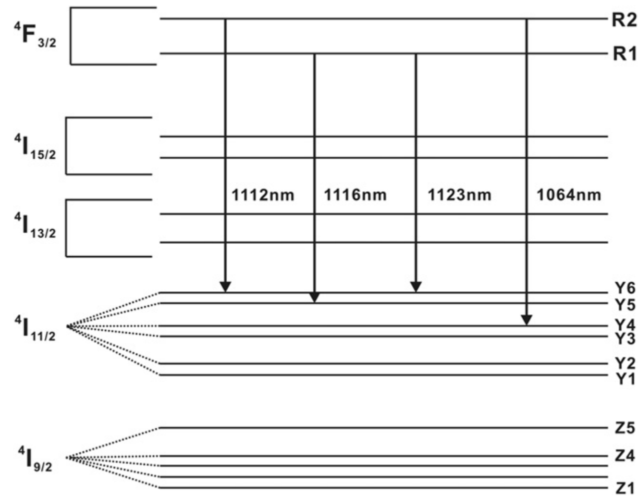

Fig. 3. Typical energy level of the Nd:YAG crystal.

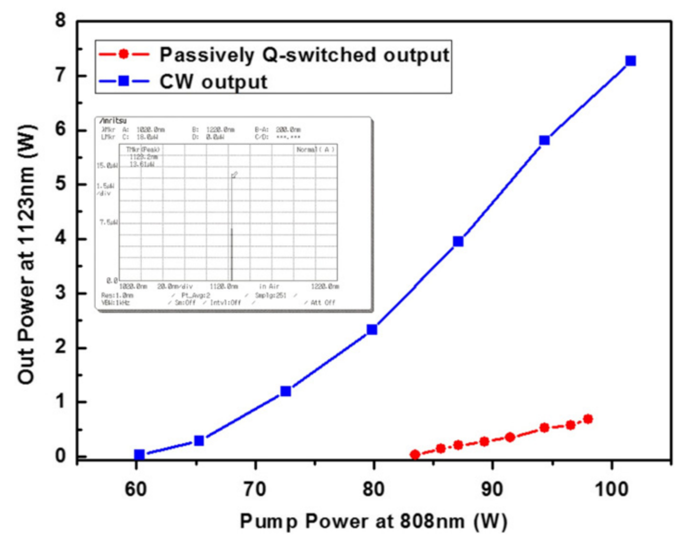

Fig. 4. Output power as the function of pump power both for passively Q-switched operation and CW oscillation at 1123 nm. The inset is spectrum of passively Q-switched laser at 1123 nm in the range of 1020–1220 nm.

threefold symmetry arranged LD side-pumped module was used (GKPMY-50, Beijing GK laser Co. Ltd). The laser medium was a 60 mm Nd:YAG rod in length and 3 mm in diameter. The Nd doping concentration was 0.7 at%. The centre emission wavelength of LD array was carefully adjusted to 808.5 nm with water cooled at 22 °C. The total pump power of LD arrays was 160 W. In our work, a reflective SWCNT with 1100–1150 nm high reflection (HR) coated on the back surface was used as the rear mirror. The output mirror (OC) was a partial transmission mirror with 5% transmission ratio at 1122.7 nm that was identical to our previous work [6]. We have proven that only 1123 nm laser line can oscillate via the coating technology. L1 and L2 were the distance from the SWCNT to the left Nd:YAG rode end surface and OC to the right Nd:YAG rod surface, respectively. Both of them were set to 50 mm that form a symmetric resonator.

The SWCNT employed here was similar to that in [13]. First, we fabricated the transmission type of SWCNT absorber on quartz by vertical evaporation method. Both sides of the quartz were SWCNT film. Fig. 2 was the transmission spectrum of used SWCNT. The transmission ratio was 85.8% at the wavelength of 1123 nm. The SWCNT on one side of the transmission type of SWCNT absorber was rubbed off and coated with high reflection film and the SWCNT on the other side was remained to form the reflective SWCNT absorber. The modulation depth of the reflective absorber is 2–3%. The output power was measured by an Ophir power meter. The wavelength characteristic was monitored by an Anritsu MS9710B optical spectrometer. The pulsed property was recorded by a fast photodiode (Thorlabs Inc., DET200). The pulsed waveforms were traced by a 4 GHz Tektronix DPO 4104 oscilloscope.

3. Results and discussion

Under normal conditions, the Nd:YAG laser operates at the lowest threshold laser line 1064 nm, corresponding to the $^4F_{3/2}(R2)\rightarrow{}^4I_{11/2}(Y4)$. It is possible to obtain other low gain laser wavelengths by coating technology. Around 1.1 μm region for Nd:YAG crystal, there have three transitions that are 1112, 1116, and 1123 nm, respectively [20]. Fig. 3 shows the typical energy level diagram of Nd:YAG. To obtain single 1123 nm oscillation, 1064 nm laser line as well as the 1112 nm, 1116 nm should be restrained. Fortunately, thanks to the precise coating, they could be distinguished absolutely.

We monitored the emission spectrum over the full range of the pump power that was shown in the inset of Fig. 4. It could be seen clearly that only 1123 nm oscillation existed in the band range of 1020–1220 nm. The 1112 and 1116 nm transitions nearby did not appear, that meant the wavelength selectivity was achieved through elaborate coating. The 1112 nm and 1116 nm components were restrained effectively due to the minor transmittance difference. The 1123 nm line had the lowest threshold at current transmittance ratio.

To evaluate the Q-switched performance of SWCNT, firstly we investigated the CW operation property by using a HR mirror at 1123 nm as the rear mirror. The CW output power versus the pump power was shown in Fig. 4. The lasing threshold occurs at 60.3 W and the output power reaches to 7.27 W at 101.6 W pumping. Following,