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Passively Q-switched and mode-locked laser performance of the mixed crystals with GaAs saturable absorber

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ABSTRACT

By using the mixed crystals Nd:$Lu_{0.33}Y_{0.37}Gd_{0.3}VO_4$, Nd:$Lu_{0.5}Y_{0.5}VO_4$ and Nd:$Lu_{0.15}Y_{0.85}VO_4$ as laser media, the LD pumped passively Q-switched and mode-locked (QML) lasers with GaAs saturable absorber are realized. The average output power, the pulse width and the repetition rates have been measured and compared. The experimental results show that the passively Q-switched and mode-locked Nd:$Lu_{0.33}Y_{0.37}Gd_{0.3}VO_4$ laser can generate shorter pulse width with higher peak power due to broader fluorescence line-width. By considering the Gaussian distribution of the intracavity photon density and the influence of the continuous pump rate, the coupled rate equations for QML lasers with GaAs saturable absorber are given. The theoretical solutions of the equations are in agreement with the experimental results.

1. Introduction

Simultaneously Q-switched and mode-locked (QML) lasers with high repetition rate, high peak power and moderate average power have found wide applications in the non-linear optics, remote-sensing, ranging, visible display applications, and UV materials-processing and so on. Diode-pumped passively Q-switched and mode-locked lasers can supply this kind of pulses and have the advantages of simplicity, compactness, low cost and high efficiency [1,2]. Semiconductor saturable absorber GaAs is an important saturable absorber and has been widely used as passive Q-switch owing to its thermal stabilities and the large optical nonlinearity which is related to the two-photon absorption [3,4]. Especially, because GaAs [5] has a high linear transmission at 1.06 μm and can form a Fabry–Perot (FP) cavity, the uncoated GaAs wafer can be used not only as a saturable absorber but also an output coupler.

The Nd-doped single vanadate crystals are the commonly used excellent laser gain media for the diode-pumped Q-switched and mode-locked lasers due to their broad absorption bandwidths, large absorption, emission cross sections and high chemical stability such as Nd:$GdVO_4$ [6], Nd:YVO_4 [7], and Nd:$LuVO_4$ [8–10] crystals. In order to improve the performance of Q-switched and mode-locked laser, the double-mixed Nd:$Gd_xY_{1-x}VO_4$, Nd:$Lu_xGd_{1-x}VO_4$ and Nd:$Lu_xY_{1-x}VO_4$ crystals were successfully grown [11–13]. Due to the inhomogeneous broadening in the fluorescence spectra, these double-mixed crystals have much broader fluorescence line-width than the single vanadate crystals. The passively mode-locked Nd:$Lu_xY_{1-x}VO_4$ laser with a semiconductor saturable absorber mirror (SESAM) and the passively Q-switched Nd:$Lu_xY_{1-x}VO_4$ laser with GaAs have been reported [14,15]. The experimental results show that both the Q-switched and mode-locked Nd:$Lu_xY_{1-x}VO_4$ lasers have shorter pulse width and higher peak power than the Nd:YVO_4 or Nd:$LuVO_4$ lasers at the same conditions. Moreover, a new triple-mixed vanadate crystal Nd:$Lu_{0.33}Y_{0.37}Gd_{0.3}VO_4$ was fabricated and grown by Fuzhou University. The central wavelength of the fluorescence band at 1064.1 μm has a half-maximum (FWHM) of 6.2 nm, which is even broader than that of Nd:$Lu_xY_{1-x}VO_4$. The related physical parameters are shown in Table 1. The diode-pumped passively Q-switched Nd:$Lu_{0.33}Y_{0.37}Gd_{0.3}VO_4$ lasers with a single-walled carbon nanotube and Cr^{4+}:YAG saturable absorber show that shorter pulse width and higher peak power can be generated [16,17]. However, there is no related report on the passively Q-switched and mode-locked laser characteristic comparison between the double-mixed and the triple-mixed crystals.

In this paper, by using Nd:$Lu_{0.33}Y_{0.37}Gd_{0.3}VO_4$, Nd:$Lu_{0.5}Y_{0.5}VO_4$ and Nd:$Lu_{0.15}Y_{0.85}VO_4$ mixed crystals as laser media, the diode-pumped passively Q-switched and mode-locked lasers with GaAs saturable absorber are presented. The average output power, pulse width and pulse repetition rates are measured and compared. In comparison with the double-mixed crystals, due to broader fluorescence line-width, the passively Q-switched and mode-locked Nd:$Lu_{0.33}Y_{0.37}Gd_{0.3}VO_4$ laser with GaAs can generate shorter pulse width with higher peak power. Meanwhile, the rate equations under Gaussian approximation for Q-switched and mode-locked

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Table 1
Related physical parameters among Nd:$Lu_{0.15}Y_{0.85}VO_4$, Nd:$Lu_{0.5}Y_{0.5}VO_4$ and Nd:$Lu_{0.33}Y_{0.37}Gd_{0.3}VO_4$ crystals.

	Crystals		
	Nd:$Lu_{0.15}Y_{0.85}VO_4$	Nd:$Lu_{0.5}Y_{0.5}VO_4$	Nd:$Lu_{0.33}Y_{0.37}Gd_{0.3}VO_4$
Fluorescence line-width (nm)	5.1	5	6.2
Fluorescence lifetime (μs)	96	98	102
Absorption cross-section at 0.80 μm ($\times 10^{-20}$ cm^2)	15	16	13
Stimulation cross-section at 1.06 μm ($\times 10^{-20}$ cm^2)	64	63	60

lasers are given. The theoretical solutions of the equations are in agreement with the experimental results.

2. Experimental setup and results

2.1. Experimental setup

The experimental setup is shown in Fig. 1, in which a V-typed folded cavity is employed. The pump source is a fiber-coupled laser-diode (FAP-I system, Coherent Inc., USA) whose center wavelength is 808 nm at 22 °C. The output pump beam from the fiber bundle end, which is 800 μm in diameter, is focused into the laser crystal with a spot of about 440 μm in diameter at focal plane by a focusing optics. The mirror M_1 is a spherical concave mirror with radius of 150 mm, which is AR-coated at 808 nm on its outside surface and HR-coated at 1064 nm on its inside surface. M_2 is also a spherical concave mirror with a 500 mm radius, which is high-reflection coated at 1064 nm on the surface. The different arm lengths (L_1 and L_2) are set as 60 cm and 46 cm, respectively. The whole length of the folded cavity is approximately 106 cm, corresponding to a roundtrip transmit time of about 7 ns. Three a-cut mixed crystals Nd:$Lu_{0.15}Y_{0.85}VO_4$ (2.5 at.% Nd-doped, 3 mm × 3 mm × 10 mm), Nd:$Lu_{0.5}Y_{0.5}VO_4$ (2.5 at.% Nd-doped, 3 mm × 3 mm × 10 mm) and Nd:$Lu_{0.33}Y_{0.37}Gd_{0.3}VO_4$ (2.5 at.% Nd-doped, 3 mm × 3 mm × 6 mm) are used as laser media. These crystal are AR coated at 808 nm and 1064 nm on both surfaces, respectively, and controlled at 20 °C by a temperature controller in order to dispatch the deposited thermal efficiently. A 700 μm thick uncoated GaAs wafer with the small-signal transmission $T_0 = 92.6\%$, which is optically polished on both sides, is used as saturable absorber. The output mirror M_3 is a plane mirror with a transmission of 10%. For the three kinds of passively Q-switched and mode-locked lasers, the cavity has the similar parameters. The EPM 2000 Energy/Power Meter (Molectron Detector Inc., USA) is used to measure the average output power and the DPO7104C digital oscilloscope (1 GHz bandwidth and 20G samples/s sampling rate, Tektronix Inc., USA) is used to measure the pulse width and the pulse repetition rate.

2.2. Experimental results

The threshold pump power for the diode-pumped passively Q-switched and mode-locked lasers of Nd:$Lu_{0.33}Y_{0.37}Gd_{0.3}VO_4$, Nd:$Lu_{0.5}Y_{0.5}VO_4$ and Nd:$Lu_{0.15}Y_{0.85}VO_4$ mixed crystals with GaAs saturable absorber are found to be 0.68, 0.65, 0.64 W, respectively.

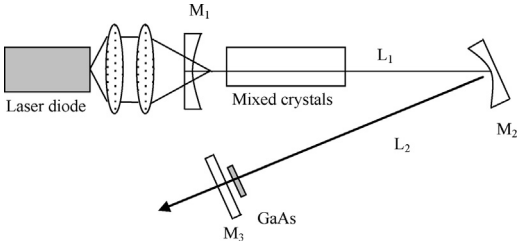

Fig. 1. Schematic of the experimental setup.

The average output powers versus the incident pump power are shown in Fig. 2. The output powers increase with the incident pump power. At the incident pump power of 6.75 W, the maximum average output pump powers for Nd:$Lu_{0.33}Y_{0.37}Gd_{0.3}VO_4$, Nd:$Lu_{0.5}Y_{0.5}VO_4$ and Nd:$Lu_{0.15}Y_{0.85}VO_4$ lasers are 613, 651, 678 mW, respectively.

Fig. 3 shows the relationship between the repetition rates of the passively Q-switched pulses and the incident pump power. As we can see, when the incident pump power increases from 1.028 W to 6.75 W, the repetition rates increase from 21 kHz to 128.34 kHz for Nd:$Lu_{0.33}Y_{0.37}Gd_{0.3}VO_4$ laser, from 31.15 kHz to 150.7 kHz for Nd:$Lu_{0.5}Y_{0.5}VO_4$ laser and from 50 kHz to 187 kHz for Nd:$Lu_{0.15}Y_{0.85}VO_4$ laser, respectively.

The pulse energy of Q-switched envelope is estimated based on the average output power and the repetition rate, which is shown as dots in Fig. 4. The pulse energy increases with the incident pump power, and reaches 4.78, 4.32 and 3.62 μJ for Nd:$Lu_{0.33}Y_{0.37}Gd_{0.3}VO_4$, Nd:$Lu_{0.5}Y_{0.5}VO_4$ and Nd:$Lu_{0.15}Y_{0.85}VO_4$ lasers, respectively.

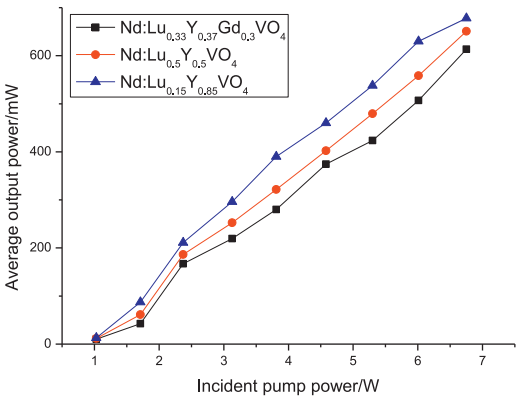

Fig. 2. Dependence of the average output power of the Q-switched pulse train on the incident pump power.

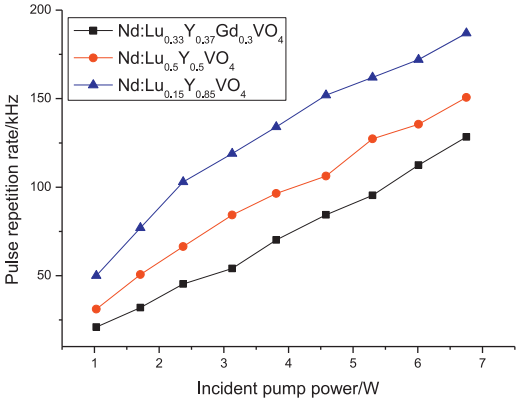

Fig. 3. Dependence of the repetition rates of the Q-switched pulse train on the incident pump power.