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High repetition rate Q-switched microchip Nd:YVO_4 laser with pulse duration as short as 1.1 ns

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Abstract

We have demonstrated a compact and an efficient passively Q-switched microchip Nd:YVO_4 laser by using a composite semiconductor absorber as well as an output coupler. The composite semiconductor absorber was composed of an LT (low-temperature grown) $In_{0.25}Ga_{0.75}As$ absorber and a pure GaAs absorber. To our knowledge, it was the first demonstration of the special absorber for Q-switching operation of microchip lasers. Laser pulses with durations of 1.1 ns were generated with a 350 μm thick laser crystal and the repetition rate of the pulses was as high as 4.6 MHz. The average output power was 120 mW at the pump power of 700 mW. Pulse duration can be varied from 1.1 to 15.7 ns by changing the cavity length from 0.45 to 5 mm. Pulses with duration of 1.67 and 2.41 ns were also obtained with a 0.7 mm thick laser crystal and a 1 mm thick laser crystal, respectively.

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Keywords: Microchip laser; Q-switched; High repetition rate; Lt $In_{0.25}Ga_{0.75}As$; GaAs

Q-switching of diode-pumped lasers is an effective technique for generating pulses of nanosecond duration. Q-switched diode-pumped lasers have been realized actively, with an electro-optical modulator or passively, by using the self-Q-switching properties of Cr-doped solid-state lasers [1,2]. However, parameters of Cr^{4+}:YAG crystals such as recovery time and modulation depth cannot be modulated freely, which limits its application as an absorber. In 1999 [3], passively Q-switched Nd:YVO_4 with semiconductor saturable absorption mirror (SESAM) was performed and a pulse duration as short as 37 ps was demonstrated. Pure GaAs was first used for passive Q-switching by Kajava and Gaeta [4]. In their experiment, the pulse duration was as short as 3 ns. In mode-locking operations, passively Q-switched and mode-locked laser runs when the pump power is lower than the threshold of the continuous wave mode locking, the width of the Q-switching envelope is generally at the level of several hundred nanoseconds or several microseconds. In 2005, Pan et al. [5] removed the minor pulses inside the Q-switching envelope by the frequency selection technology and obtained pure Q-switching with a duration of 150 ns and

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a repetition rate of 76.3 KHz. In fact, pure Q-switching can be observed without the frequency selection technology when the mode locking was refrained in the cavity. In order to obtain a much shorter pulse, the thickness of the SESAM's absorption layer should be increased up to several tens of times of that of the normal SESAM for passively mode locking, the recovery time should be increased too, which will bring some difficulties in the manufacture and increase the insert loss of the device. The microchip laser, which is composed of a thin disk gain medium and a very short laser cavity, is extremely simple and compact. The extremely short cavity length of several hundred micrometers allows for pulse durations of 1 ns or even shorter in Q-switched operations. The $Nd:YVO_4$ crystal with its small possible absorption length and large emission cross-section is well suited for the microchip laser. In this paper, using the composite semiconductor absorber as the nonlinear absorber and a 350 μm thick $Nd:YVO_4$ as the laser crystal, we successfully achieved Q-switching pulse trains of the microchip laser. The shortest pulse duration was 1.1 ns with a high repetition rate of 4.6 MHz; the output power was 120 mW at the pump power of 700 mW. Such a high repetition rate Q-switching pulse laser may be useful for rapid-range finders or remote sensing.

The composite semiconductor absorber is fabricated mainly by the metal organic chemical vapor deposition (MOCVD) technique. First, a 500 nm GaAs buffer layer was deposited on the semi-insulating GaAs substrate with the thickness of 500 μm. Second, a single-quantum-well composed of GaAs (15 nm)/$In_{0.25}Ga_{0.75}As$ (10 nm)/ GaAs (15 nm) was grown on the buffer layer at a low temperature of 550 °C (for MOCVD, the normal temperature is from 600 to 750 °C). Third, the wafer was thinned to be about 100 μm from the other side of the wafer in order to decrease non-saturable loss and polished. Finally, both sides of the wafer were antireflection coated.

Fig. 1. shows the experimental configuration of the passively Q-switched microchip $Nd:YVO_4$ laser with the composite semiconductor absorber. The pump source was an 808 nm laser diode with a strip size of 200 μm. We controlled the diode work temperature by thermo-electric coolers so that we can adapt the pump wavelength to the maximum absorption by the laser crystal. Through a coupler system, a 90 μm pump spot was focused into the laser crystal. The laser crystal was a 3.0-at%, a-cut $Nd:YVO_4$ laser, with a thickness of 350 μm. One side of the crystal was coated for antireflection ($T > 98\%$) at the 808 nm pump wavelength and high reflection ($R > 99.8\%$) at the 1064 nm laser radiation, the other side was coated for antireflection ($T > 99.8\%$) at 1064 nm. To alleviate the thermal load, the crystal was attached to a copper block and cooled by thermo-electric coolers. The absorber was also attached

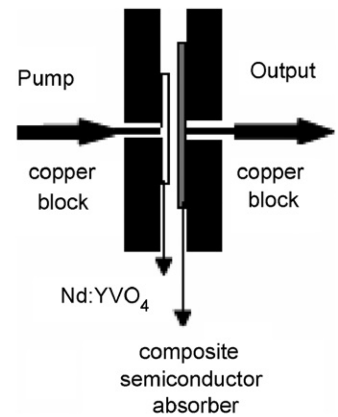

Fig. 1. Configuration of the Q-switched microchip $Nd:YVO_4$ laser.

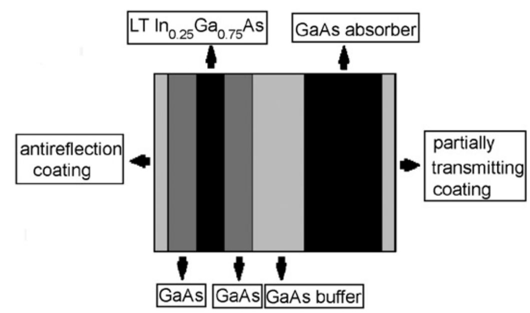

Fig. 2. Structure of the composite semiconductor absorber.

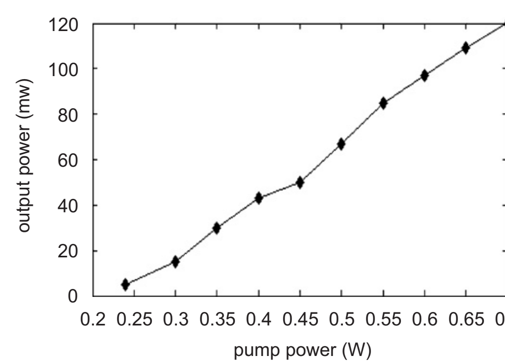

Fig. 3. Output power as a function of the pump power.

to a copper block, but not temperature controlled. The flat–flat cavity was formed from one side of the $Nd:YVO_4$ and from one side of the absorber (Fig. 2).

In the first part of the experiment, we used the 350 μm thick $Nd:YVO_4$ as the laser crystal. First, we designed the laser cavity to be about 0.45 mm. The laser oscillation threshold was about 240 mW, the output average was 120 mW at the maximum pump power of 700 mW. In Fig. 3, the laser output power was plotted as a function of the pump power. The temporal behavior of the laser pulses was recorded by a fast-response InGaAs

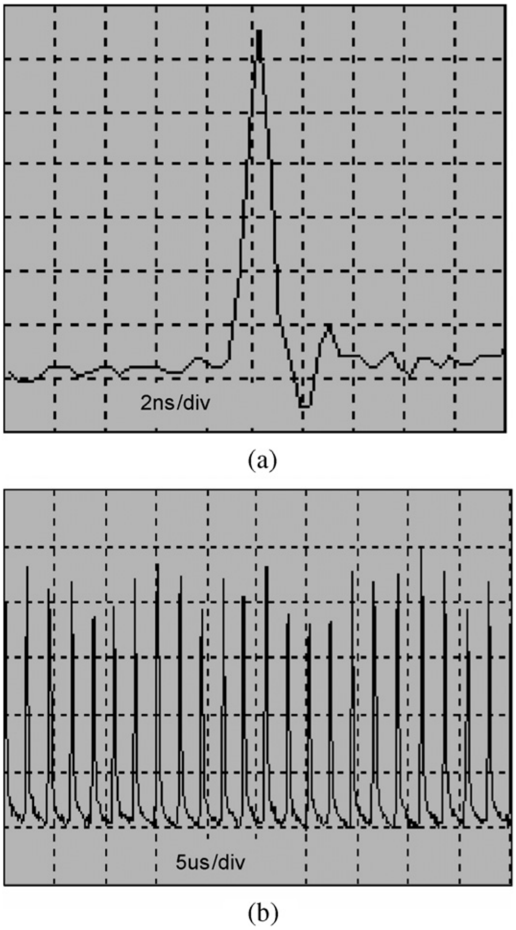

Fig. 4. Q-switched laser pulses with the composite absorber and the 350 μm thick Nd:YVO_4: (a) single laser pulse with a pulse duration of 1.1 ns and (b) laser pulse train with a repetition rate of 4.6 MHz.

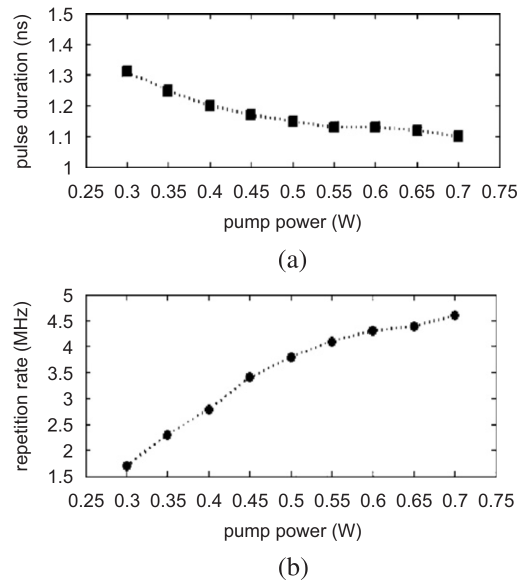

Fig. 5. Variation of the repetition rate and the pulse duration as a function of the pump power: (a) pulse duration and (b) repetition rate.

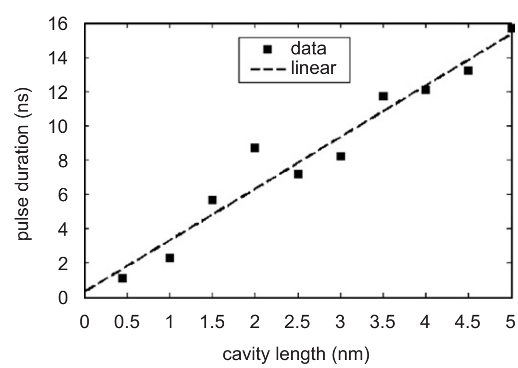

Fig. 6. Pulse duration as a function of the cavity length.

photodiode with a time resolution of 0.3 ns and a LeCroy oscilloscope (9361C). The pulse repetition rate increased from 1.7 to 4.6 MHz as the pump power increased from 300 to 700 mW. The oscilloscope trace of the 4.6 MHz pulses train is shown in Fig. 4(a). However, the pulse duration decreased from 1.31 to 1.1 ns as the pump power increased from 300 to 700 mW. The single laser pulse with a pulse duration of 1.1 ns is shown in Fig. 4(b). Fig. 5 showed the variation of the repetition rate and the pulse duration as a function of the pump power. Second, at the 700 mW pump power, we changed the cavity length from 0.5 to 5 mm, and the pulse duration increased from 1.1 to 15.7 ns. In Fig. 6, the pulse duration was plotted as a function of the cavity length.

In the second part of the experiment, we used the other two Nd:YVO_4 chips as the laser crystals, the thickness of one was 0.7 mm (2 at%) and the other was 1 mm (1 at%). The film coating of the two crystals was the same as the 350 μm thick crystal, and the pump source was not changed. Using the 0.7-mm thick crystal, we designed the cavity length to be about 0.8 mm and studied the performance of the laser. The pulse duration achieved at the maximum pump power was about 1.67 ns. The repetition rate was about 3.7 MHz. Using the 1 mm thick crystal, we designed the cavity length to be about 1.1 mm, the pulse duration was about 2.41 ns and the repetition rate was about 3.2 MHz at the maximum 700 mW pump power.

The principle for undoped (or pure) semi-insulating GaAs as a Q-switching absorber is shown [6]. Differently, the LT GaAs/$In_{0.25}Ga_{0.75}As$/GaAs absorber has some characteristics similar to those of SESAM. Carriers in $In_{0.25}Ga_{0.75}As$ excited from valence band to conductor band and the absorption for 1.06 μm laser are 10^4 times that in LT GaAs or pure GaAs wafers. In addition, LT $In_{0.25}Ga_{0.75}As$ as well as LT GaAs can act as rapid recombination centers for carriers as pure GaAs wafers. The density of As_{Ga} in LT GaAs ($\sim 10^{19}\,cm^{-3}$) is much higher than that in pure GaAs wafers (generally less than $10^{15}\,cm^{-3}$). Therefore, the number of As_{Ga} traps in several tens of nanometers of LT GaAs or LT $In_{0.25}Ga_{0.75}As$ can compare with that in several hundreds of micrometers of pure GaAs wafer, which relates to recovery time and saturable loss. LT $GaAs/In_{0.25}Ga_{0.75}As/GaAs$ as well as couplers can act as absorbers for mode locking [7,8]. We believe that the additional pure GaAs wafer does not play a major role in mode locking in these experiments. However, in this paper, Q-switching pulses with short duration and high repetition rate were observed when the laser cavity and pump power do not satisfy the conditions for mode locking. We believe that both the absorbers play an important role in the Q-switching stage.

In conclusion, using the new composite semiconductor absorber as the Q-switched device and output coupler, we have demonstrated compact and simple Q-switched microchip lasers. Short pulses with durations of 1.1 ns were achieved with the 350 μm thick $Nd:YVO_4$ laser crystal. The repetition rate of the pulses was as high as 4.6 MHz. Such a high repetition rate Q-switching pulse laser was useful for rapid range finders or remote sensing. The maximum average output power was 120 mW at a pump power of 700 mW, which corresponded with an optic-to-optic conversion efficiency of 17%. The inexpensive and robust composite absorber was suited for generating short duration and high repetition rate pulses.

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