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Controllable high repetition rate gain-switched $Nd:YVO_4$ microchip laser*

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Abstract: We demonstrated a monolithic, compact, diode-pumped gain-switched $Nd:YVO_4$ laser at 1.064 μm wavelength with controllable repetition rate of 1 Hz to 25 kHz. Stable gain-switched pulse train with maximum repetition rate of 25 kHz and pulse width of 16 ns was obtained.

Key words: Laser technology, Gain-switching, Controllable repetition rate, High repetition rate
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INTRODUCTION

Monolithic, compact sources of controllable nanosecond pulses with high repetition rate are of great interest for applications such as laser ranging, photoelectric countermeasure, time-multiplexed fiber sensor systems, and MOPA systems (Larat *et al.*, 1994; 1996; Diettrich *et al.*, 2000; Sheng *et al.*, 2004). Combining the merits of short monolithic-cavity microchip laser with gain-switching technology, diode-pumped gain-switched microchip lasers are ideal sources for these applications. The outstanding advantages of this kind of laser are high stability and exact controllability in a large range of repetition rates of the output pulses. The $Nd:YVO_4$ laser crystal is the best choice for this kind of laser to supply short pulses with high repetition rate due to its short fluorescence lifetime and high emission cross-section.

Some reports have been published describing diode-pumped gain-switched $Nd:YVO_4$ lasers (Larat *et al.*, 1994; 1996; Sheng *et al.*, 2004). Larat *et al.* (1994; 1996) utilized a 1-mm-thick $Nd:YVO_4$ crystal to demonstrate a monolithic flat-flat laser cavity. The pump source was a fiber-coupled laser diode. The optical fiber was close-coupled to the $Nd:YVO_4$ crystal. They obtained gain-switched laser pulses with pulse width of 45 ns and constant repetition rate at 1 kHz.

We reported the first results of our work on a diode-pumped gain-switched $Nd:YVO_4$ laser (Sheng *et al.*, 2004). In our experiment, the fiber-coupled laser diode was driven by a current modulator with repetition rate of 1 Hz~4 kHz. The pump light from the optical fiber was collimated and focused into the $Nd:YVO_4$ crystal by two aspherical lenses. We obtained gain-switched laser pulses with pulse width of 60 ns~140 ns at 1.064 μm and controllable repetition rate of 1 Hz~4 kHz.

We report here the latest and best experimental results. In the latest experiment, the current modulator was replaced by an improved one with wider repetition rate range of 1 Hz~25 kHz. Instead of two aspherical lenses, we used a self-focus lens to focus the pump light. So Laser pulses at 1.064 μm with accurately controlled repetition rate of 1 Hz to 25 kHz and pulse width of 16 ns have been acquired. To our knowledge, this is the first report of gain-switched

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laser pulses with such a wide range of controlled repetition rate and small pulse widths.

EXPERIMENTAL SETUP AND PRINCIPLES

Fig.1 shows a schematic of our experimental setup. A 1 at.-% doped, a-cut Nd:YVO4 crystal with diameter of 20 mm and length of 1 mm, was utilized as laser medium. Both ends of the crystal were parallel, which created a flat-flat cavity. The input end was high-reflectivity (HR) coated at 1.064 μm and anti-reflectivity coated at 808 nm. The coating at the output end was HR at 808 nm and 92% reflectivity at 1.064 μm. The pump source was a fiber-coupled diode laser at 808 nm, which operates in either CW mode or pulsed mode. The output beam from the laser diode (LD) was delivered into an optical fiber and then focused by a self-focusing lens into the Nd:YVO_4 crystal. At the output side, a filter was used to absorb the remained pump light. The characteristics of the 1.064 μm laser pulses were sampled by a PIN diode whose output voltage was monitored by a TEK 3052 oscilloscope.

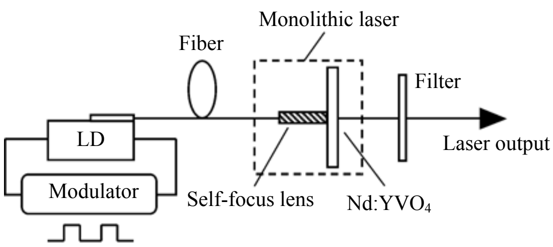


Fig.1 Schematics of gain-switched Nd:YVO_4 microchip laser

Using a current modulator designed ourselves, the diode laser was driven with rectangular pulses with a direct current off-set, as shown in the upper part of Fig.2. Correspondingly, the diode laser emitted rectangular pulses of light with a continuous light output base. The repetition rate of the output gain-switched laser pulses was equal to that of the pump light, which could be adjusted from 1 Hz to 25 kHz.

To produce gain-switched pulses, the Nd:YVO_4 microchip laser was pumped by the CW pump power below threshold. Some population inversion was accumulated but the intracavity photon density was very low. When the pump power was abruptly changed to many times higher than threshold, the gain of the cavity increased rapidly. A significant population inversion was produced during low intracavity photon density and consequently, the gain switched from low to high value. As the photon density eventually increased to significant levels, the gain was depleted and energy exited the cavity, which in turn produced rapid decay in the photon density. Provided the pump power was reduced to a low level before the threshold was exceeded again, the process produced a single short optical pulse. Different gain-switched pulses with different pulse widths, build-up times and repetition rates could be generated by altering the direct current base, the pulse current, the pulse width and the repetition rate from the current driver.

RESULTS AND DISCUSSION

Fig.2 shows the gain-switched pulse train with repetition rate of 25 kHz and the corresponding pump current i.e. driving current on the LD. The upper part is rectangular pulse current of 11.6 A with 17 μs pulse width added on a direct current of 5 A. The lower part is the output gain-switched pulse train with stable peak value and repetition rate. It is obvious that there is only one laser pulse in a pump pulse duration, which is called single-pulse output. The waveform of a single laser pulse with 16 ns duration from the laser pulse train is shown in Fig.3.

Fig.4a shows the laser pulse in one pump pulse duration for single-pulse output. Fig.4b shows the laser pulses in one pump pulse duration when the pump

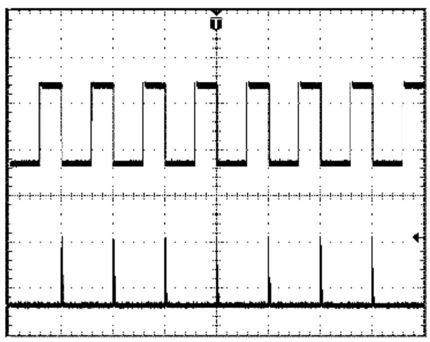


Fig.2 A 25 kHz gain-switched pulse train (lower part) and corresponding pump current (upper part), 40 μs/div

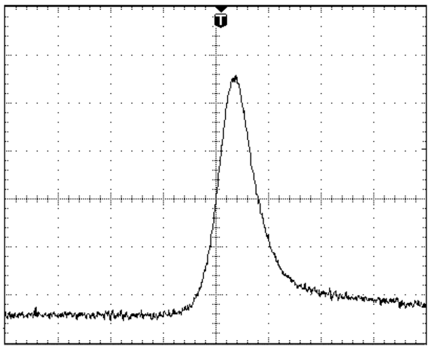
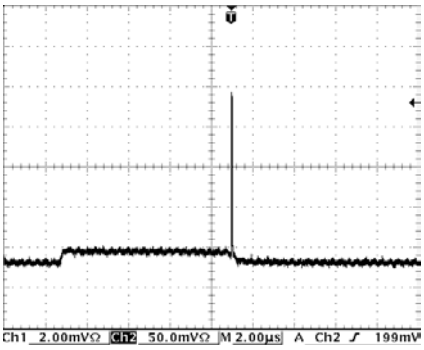
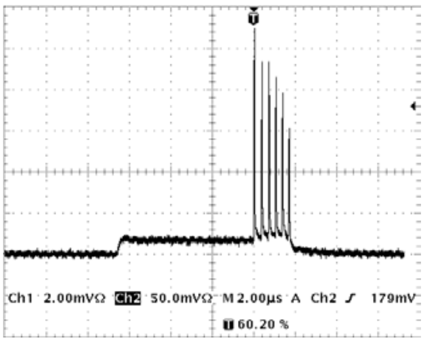


Fig.3 Waveform of single gain-switched pulse, *FWHM*=16 ns, (20 ns/div)



(a)



(b)

Fig.4 The output laser pulses in one pump pulse duration of 8 μs at different pump current
(a) Single-pulse output at pump current of 16.2 A;
(b) Multi-subpulse output at pump current of 18 A

current was raised. It can be seen that the laser oscillation builds-up fast and that the laser pulse occurs earlier with the increase of pump current as shown in Fig.4b. In this situation, after the first laser pulse was shot, the exhausted population inversion of gain material will be pumped and exceed the threshold again, and then a new laser pulse will be shot. When the pump current or pump pulse duration was raised, it could be observed that more laser pulses were shot in one pump pulse duration, as shown in Fig.4b. The situation is called multi-subpulse output and all the laser pulses in one pump pulse duration are subpulses. The number of subpulses could be controlled by the pump current and pump pulse width. The multi-subpulse output is also useful, for example, as a double subpulse output can be desirable in micro-machining.

To ensure single laser pulse output in one pump pulse duration, we increased the pulse current and decreased the direct base simultaneously at constant pump pulse width of 12 μs. Gain-switched pulses with different pulse width and delay time, and the time interval between the start of a laser pulse and its pump pulse, were obtained. Figs.5 and 6 show the variations of pulse width and delay time with total pump current respectively. As seen, the pulse width and delay time decreased with the sum of the base current and the pulse current. The reason is as follows: the cavity loss and laser threshold are constant during the gain-switching process. The bigger the pump current, the higher the pump power and pump rate. The increase of pump rate increases the net intracavity gain and accelerates photon density increase and population inversion depletion. So the ascending and descending of the optical output pulse are steeper and the pulse width consequently becomes smaller. Before a gain-switched pulse is produced, the population inversion accumulates faster and reaches the threshold earlier as the pump rate is increased. This results in a shortening of the delay time of gain-switched

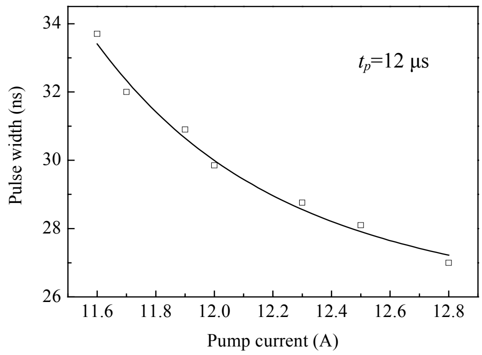


Fig.5 Variation of pulse width with total pump current

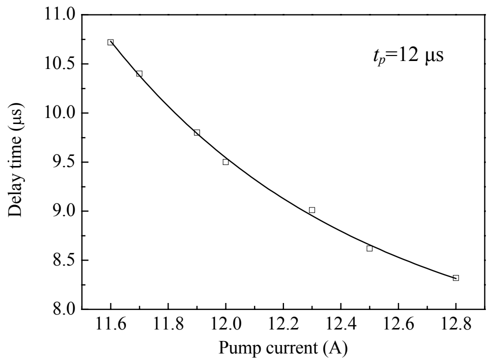


Fig.6 Variation of delay time with total pump current

pulses. This is why more subpulses will be produced with increased pump current or pump pulse duration.

Therefore, an effective method to achieve single pulse output is applying direct current close to threshold combined with high pulse current with small pump pulse width on the laser diode.

CONCLUSION

In conclusion, a diode-pumped gain-switched Nd:YVO_4 laser at 1.064 μm, formed with a monolithic flat-flat cavity has been demonstrated. Stable and controllable laser pulse sequences in a single longitudinal mode are obtained with repetition rate of 1 Hz~25 kHz and pulse width of 16 ns. Choosing suitable pump current and pump pulse width, single pulse or multi-pulse output can be obtained. This capability has used in many applications.

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