Characteristic of pulsed fiber laser induced by switching time

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Laser-diode pumped Q-switched ytterbium-doped fiber laser is studied experimentally by controlling the switching time of acousto-optic modulator (AOM). The characteristics of Q-switched pulses with different rise time of AOM regulated by the laser beam size along the window of AOM are presented. Meanwhile, the behaviors of Q-switched pulses are achieved by regulating the switching time of AOM. The single-repetition-rate and half-repetition-rate phenomena are described and discussed. The experimental results confirm that the fiber laser with lower level inversion population can be more easily operated for half-repetition-rate generation.

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Q-switched fiber lasers have attracted much interest in recent years for many potential ranges of sensing and material processing applications because of the good beam quality, excellent combination of high efficiency, and compactness. Acousto-optic fiber lasers with lower repetition rate and typically long pulse (several hundred nanoseconds)[1−3] are not suitable for the applications. In addition, several shorter acousto-optic Q-switched fiber lasers with high repetition rate (> 10 kHz) attract much attention[4]. Wang *et al.* presented a theoretical model in an acoustic-optic Q-switched fiber laser in detail, and discussed the contribution of switching time to Q-switched pulses[5,6]. The results implied a method to shorten the output pulse width in the acousto-optic Q-switched fiber laser. Up to now, such corresponding experimental results have not been achieved. In this letter, we demonstrate a method to adjust the rise time of acousto-optic modulator (AOM) in ytterbium-doped double-clad (YDDC) fiber laser. This offers a way to output shorter pulses or adjustable pulse width in acoustic-optic Q-switched fiber lasers.

As shown in Fig. 1, YDDC fiber laser with Fabry-Perot (F-P) cavity is pumped at 975 nm. The fiber used in the experiments is a 2.4-m-long fiber (Southampton University, UK). The fiber has a core of 30 μm (numerical aperture (NA) is 0.08) and a D-shaped inner clad of 400/450 μm. The pumping light is directed through a dichroic mirror (90% transmittance at near 975 nm, 99.5% reflectivity at 1080 nm) and focused into the double-clad fiber by the optical coupling system. The input end face of fiber is perpendicular to the fiber axis.

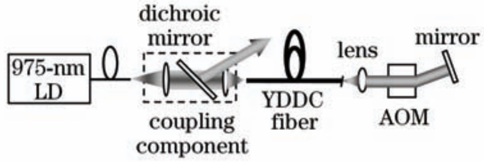

Fig. 1. Experimental setup.

The other end of the fiber is angle-cleaved to eliminate facet reflection. A lens with a focus length of f is adopted to collimate the light into an AOM (Gooch & Housego, UK). The AOM, having a driving radio frequency (RF) of 80 MHz and a diffraction efficiency of 80%, is operated at its first-order diffraction position. A high-reflectivity mirror is used to reflect the first-order beam back to the fiber core. A power meter (407A, Spectra-Physics, USA) and a 600-MHz oscilloscope (WR62XR, Lecroy, UK) with a fast photometer are adopted to measure the laser average output power and pulse trace.

It is known that acousto-optic rise time is determined by the acoustic wave transmission time across the optical beam diameter[7]. The acoustic wave time velocity of transmitting AOM is 153 ns/mm. According to the geometrical optics, the collimated beam diameter after the lens is $2nf$, where n is the NA of the fiber core. Here, two lenses with focal lengths of 6.3 and 12 mm are employed in the fiber laser cavity, leading to the acousto-optic rise time of about 133 and 293 ns, respectively. Figure 2 shows the optical pulse width as a function of the incident pump power at repetition rates of 20 and 50 kHz, respectively. It is evident that the fiber laser can produce shorter pulses using the 6.3-mm lens with lower pumping power. However, the difference of pulse width vanishes gradually with higher pumping power or lower repetition rate. The experimental results agree well with the theoretical analysis results given in Ref. [5].

According to the propagation of Gaussian beam through a paraxial optical $ABCD$ system, the feedback focal spots of the two lenses coupling onto the fiber end are approximately the same. In theory, there is no additional difference in fiber laser loss. In experiment, the two fiber lasers have similar output average power. Therefore, the difference of the Q-switched pulses is mainly determined by the variety of rise time of the AOM. It will be helpful for the application of controlling pulse width in the fiber cavity. Because of the limited optical window size (2 mm), the results with longer rise

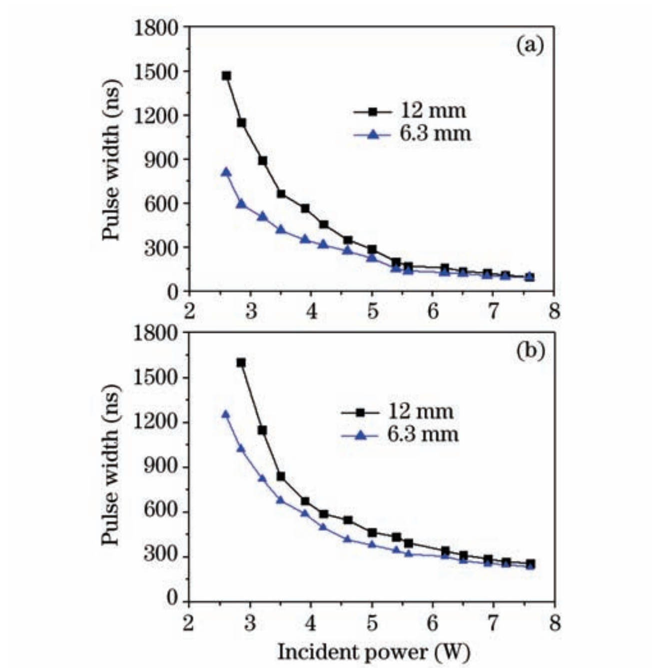

Fig. 2. Output pulse width as a function of incident pump power for different lens focus lengths for the repetition rates of (a) 20 kHz and (b) 50 kHz.

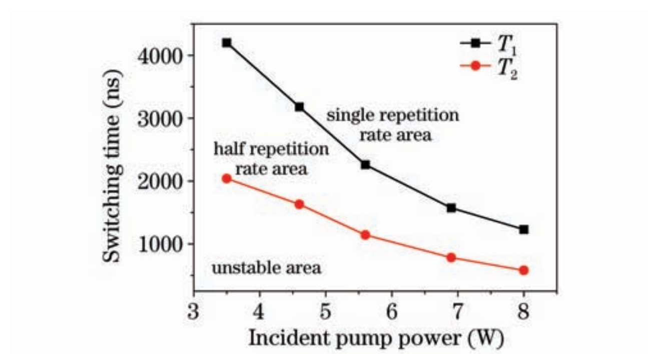

Fig. 3. Behaviors of optical pulses influenced by the switching time and incident power for the 100-kHz repetition rate of AOM.

time cannot be included here.

Using the 6.3-mm lens, the behaviors of optical pulses influenced by the switching time of AOM and the incident power at the 100-kHz repetition rate of AOM are shown in Fig. 3. Firstly, the characteristic of normal Q-switched pulses is caught during a long switching time. We consider that these Q-switched pulses are entirely oscillated and released. Then the repetition rate of output optical pulses is turned into a half of that of AOM by shortening the switching time. It is found that the shorter half-repetition-rate Q-switched pulses have higher peak power and higher stability than the single-repetition-rate ones.

Further shortening the switching time of the AOM, the output pulse trains appear unstable. Finally, the Q-switched fiber produces single-repetition-rate optical pulses again, but with shorter compressed pulses. The short pulses have been discussed in Refs. [8,9]. The very short switching time destroys the whole and energic Q-switched pulse oscillation. However, the rest of the energy stored along the long fiber provides the amplification of the weak and partial Q-switched pulse. Figure 4 depicts the behaviors of optical pulses influenced by the switching time of AOM for a 4.6-W incident power with the optical repetition rate from 25 to 160 kHz.

In order to describe the output half-repetition-rate optical pulses in detail, the performances of normal single-repetition-rate optical pulses with a longer switching time and the corresponding half-repetition-rate pulses are presented in Fig. 5. Meanwhile, according to Fig. 4, there are two long switching time (T_1, T_2) for the normal single-repetition-rate and half-repetition-rate fiber laser operation. The switching time as a function of the optical repetition rate under the conditions of 4.6- and 6.9-W pump power is shown in Fig. 6. It is clearly shown that the pulses with the same repetition rate have close curves (pulse width, switching time) by using two different methods.

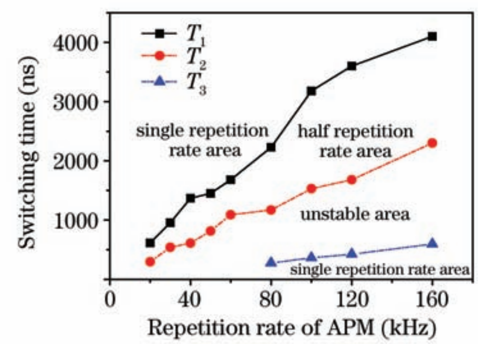

Fig. 4. Behaviors of optical pulses influenced by the switching time and optical repetition rate for a 4.6-W incident power.

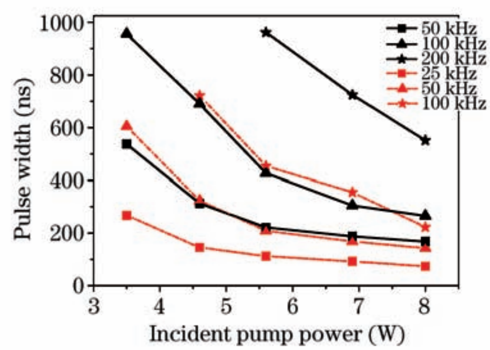

Fig. 5. Optical pulse width versus incident pump power for different repetition rates of optical pulses. Solid curves for normal single-repetition-rate case, dashed curves for half-repetition-rate case.

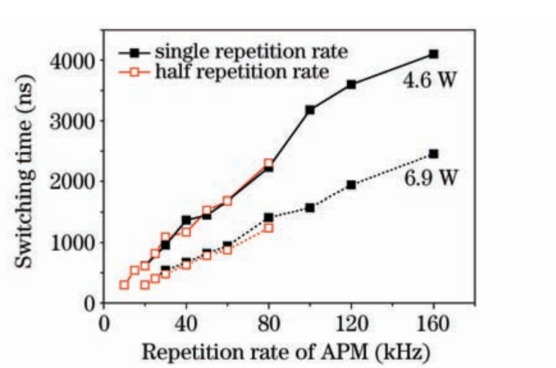

Fig. 6. Switching time versus repetition rate of optical pulses under 4.6- and 6.9-W pump power.

These results imply that the shorter switching time regulates the fiber laser into another normal Q-switched laser with half repetition rate. Because of the lower upper inversion population, the Q-switched optical pulse is suppressed by the shorter switching time. However, the fiber laser output an optical pulse in the next period of switching time after much more upper inversion population is obtained. Therefore, fiber laser with lower level inversion population can be easily operated for half-repetition rate generation. On the one hand, the Q-switched pulse needs longer switching time to build up with lower inversion population and higher repetition rate modulator. On the other hand, the Q-switched pulse forming requires more closing time of AOM to accumulate inversion population. This conflict between the switching time and closing time causes the perturbation of optical pulses. The half-repetition-rate phenomena relax the restriction between Q-switched pulse forming period and energy storing period for the lower pumping power or higher repetition rate. As a result, stable half-repetition-rate optical pulses can be observed.

In conclusion, we have demonstrated an acousto-optic Q-switched fiber laser by adjusting the switching time of the AOM. A method of regulating the rise switching time is given. The dependences of pulse width on the pump power and rise time of AOM are experimentally presented. The half-repetition-rate optical pulses can be obtained by an accurate shorter switching time of AOM. The lower upper inversion population of fiber laser is the main reason of the half-repetition-rate phenomena.

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