An acousto-optic Q-switched fiber laser using China-made double-cladding fiber

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A simple laser-diode pumped acoustic-optic Q-switched fiber laser is reported by using China-made large-mode-area ytterbium-doped fiber. Q-switched pulses with a beam quality factor of $M^2 \approx 2$ and several hundred nanoseconds pulse duration are achieved at the repetition rate of $1-50$ kHz. When the repetition rate is 1 kHz, the pulse energy is 0.93 mJ with the pulse duration of 132 ns. Meanwhile, the profile of laser pulses shows some mode-locking phenomena, the mechanism of the phenomena is discussed.

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In recent years there has been considerable interest in developing Q-switched rare-earth-doped fiber lasers because of the advantages of fiber such as high gain, excellent conversion efficiency, excellent beam quality, good compactness, and low propagation loss. With the adoption of double-clad pumping techniques, kilowatt peak power, millijoule energy high-brightness pulses are obtained.

There are many practical applications, including range finding, remote sensing, laser cutting and drilling or laser marking require short, and high-peak-power pulses. For these applications Q-switched double-cladding fiber laser is preferred. More recent works of Q-switched fiber laser to generate high-peak power and high-energy pulse have been reported[1−5].

In this letter, an acousto-optic Q-switched fiber laser using China-made Yb^{3+}-doped double-cladding (YDDC) fiber is reported. The configuration of the YDDC fiber-laser cavity is shown in Fig. 1. The YDDC laser is pumped by a continuous wave (CW) fiber-coupled laser-diode system (975 nm) with a fiber core diameter of 200 μm and a numerical aperture (NA) of 0.22. The pumping light is directed through a 45° dichroic mirror (90% transmittance at near 975 nm, 99.5% reflectivity at 1080 nm) and focused into the Yb^{3+}-doped double-cladding fiber by the optical coupling system with a coupling efficiency of 89% approximately. The large-mode-area dispersion compensation fiber (DCF) (fabricated by Fiberhome Telecommunication Tech Co., Ltd., China) has a Yb^{3+}-doped core of 40 μm and an inner-clad of 600/650 μm. The input end face of the fiber is perpendicular to the fiber axis. The other end of the fiber is cleaved at an angle of 10° to suppress feedback from Fresnel reflections. Then the laser out of the fiber end is collimated by a lens and sent into an acousto-optic modulator (AOM) which has a diffraction efficiency of 80% at a wavelength of 1.1 μm, a rise time of less than 150 ns, and a radio frequency of 80 MHz. A fast photometer and a 600-MHz digital oscilloscope (Lecroy WR62XR) are used to measure the pulse profile. A power meter (Spectra-Physics 407 A) is used to detect the output average power. A 2-m-long silica YDDC fiber is coiled by a 15-cm-diameter circle in order to get the high-quality mode output. The acousto-optic modulator operates in the zeroth-order diffraction mode with the deflected beam reflected back into the fiber by a high-reflection (99.5%, 1080 nm) mirror.

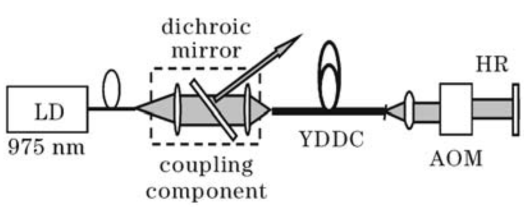

Fig. 1. Setup of Q-switched YDDC laser.

The average power and duration of the Q-switched pulse as functions of absorption power are given in Fig. 2. It is evident that the pulse duration decreases with increasing pumping power and decreasing repetition rate. The pulse profiles under the same pumping power are shown in Fig. 3 with the different repetition rates. At the repetition rate of 1 kHz, a 0.9-mJ, 132-ns pulse is achieved. The train of pulse is revealed in Fig. 4, and the pulse-pulse fluctuation is about 20%. It is found that with increasing modulation repetition rate of AOM, the

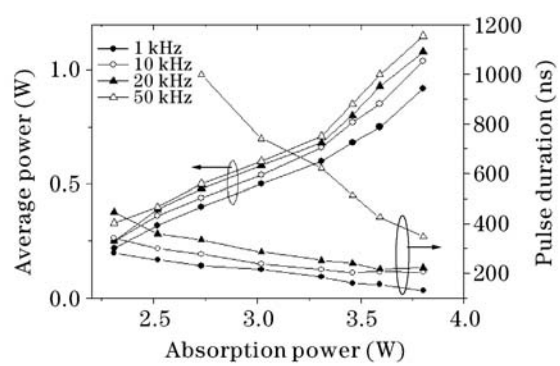

Fig. 2. Power and Q-switching pulse duration versus the absorption pumping power.

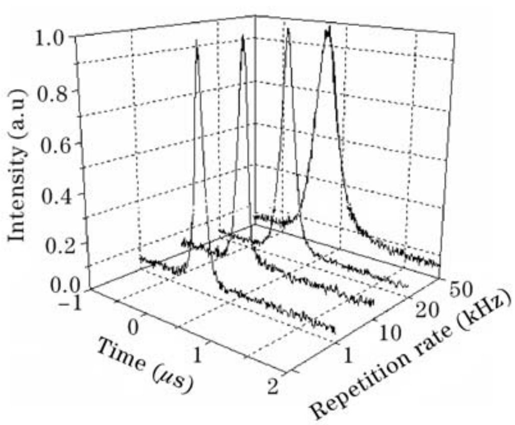

Fig. 3. Pulse profiles at different repetition rates of 1, 10, 20, and 50 kHz.

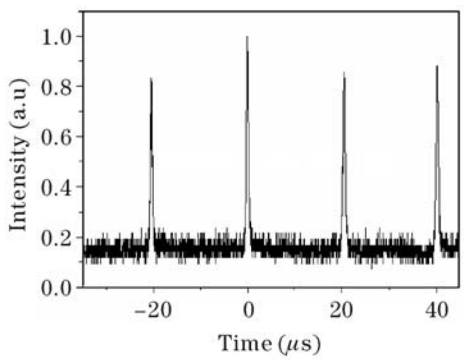

Fig. 4. Pulse train at 50-kHz repetition rate.

output laser pulses become unstable, even some pulses vanish. Subsequently, the pulse-pulse stability is improved greatly by lengthening gate time of AOM or increasing pumping power in our experiment. It can be thought that the short energy-extracted time and limited energy stored in the fiber lead to pulse-pulse instability. The output beam quality factor M^2 measured by conventional knife edge method is about 2.

It should be pointed out that in the experiment, interesting mode-locking sub-pulses parasitizing Q-switched pulse are observed, as shown in Fig. 5. The time between two sub-pulses is $1/2T_{\rm r}$ ($T_{\rm r}$ is the round trip time of cavity), and sub-pulse duration is about 1 ns, The mode-locking pulses do not get clearer or stronger with increasing the pumping power. The similar phenomena have been reported in Q-switched rare-earth-doped fiber laser for several times[3,6].

It is well known that mode-locking in the fiber is often associated with the laser gain nonlinear effect, self-phase modulation (SPM), and cross-phase modulation (XPM)[6]. The laser does not operate under the perfect mode-locking conditions since there is no change of mode-locking in Q-switched pulse by enhancing the nonlinear effect with increasing the pumping power. Here is the beating caused by a set of longitudinal modes coupling[6], which are unstable self-mode-locking pulses. The periodic of the sub-pulses is equal to the round trip time of

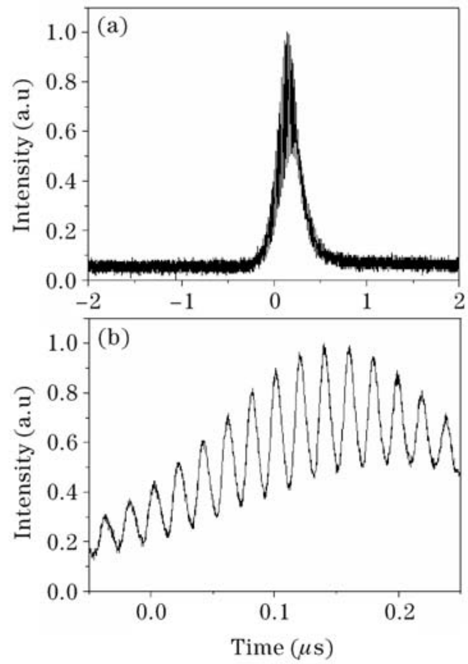

Fig. 5. (a) Q-switching pulse parasitized by sub-pulses; (b) sub-pulses of Fig. 5(a).

cavity, when the adjacent longitudinal modes couple[7]. Only when the longitudinal modes are assayed all in phase, or nearly so, can sub-pulses be strengthened into stable mode-locking pulses[8].

In summary, several hundred nanosecond pulses with average power of 1 W from a Q-switched Yb^{3+}-doped double-cladding fiber laser are observed. A 0.9-mJ, 132-ns laser pulse is obtained at 1 kHz.

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