A self-seeded fiber laser incorporated with a fiber Bragg grating external cavity semiconductor laser

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A self-seeded fiber laser incorporated with a fiber Bragg grating external cavity semiconductor laser (FBG-ECL) and a Mach-Zehnder interferometer (MZI) were reported in this paper. The MZI provided a Q-switching with response time in the order of micro-seconds. The FBG-ECL provided narrow pulses as seeds to shorten the Q-switched pulses. Experimentally, pulse width of 0.8 μs was measured, which was one fifth of the pulse width without self-seeding.

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High-peak-power, Q-switched fiber lasers in the 1.55-μm wavelength region are very attractive sources in many applications such as range finding, optical time domain reflector (OTDR), and distributed fiber sensor systems[1]. For a number of these systems, the pulse duration sets the spatial resolution limit and hence short pulses of high power are required. The first Q-switched fiber laser was achieved by Alcock in 1986. Since then, several types of Q-switched fiber lasers have been proposed by using bulk optic modulator, such as acoustic-optic modulator (AOM)[2] and electro-optic modulator (EOM)[3]. Bulky optical modulators suffer the same critical issue, that is, to couple laser beam between the modulator and the fiber, and result in extra loss and instability. In order to overcome the problem, recent years some all-fiber modulators such as MZI[4], Mickelson interferometer[5] and fiber loop mirror based on FBG[6] have been reported. The pulse width of these fiber lasers is limited by the response time of piezoelectricity PZT, which is used to modulate the optical path of the interferometers mostly. In this paper, we report a new method of reducing Q-switched pulse width by incorporating a fiber Bragg grating external cavity semiconductor laser into the Q-switched laser as a self-seeding component. The response time of the FBG-ECL is much shorter than that of PZT intrinsically. Furthermore it also gives an effective wavelength selection.

A 10-m-long erbium doped fiber, a 980-nm pump, a MZI used as a Q-switch, and a FBG-ECL connected by a circulator comprised a unidirectional ring-cavity fiber laser, as shown in Fig. 1. The MZI, with a section of one beam stuck on a PZT, could be modulated by applying a sinusoidal voltage signal on the PZT and provided a loss modulation of the laser. The FBG-ECL consists of a fiber Bragg grating and a laser diode (LD) chip. A 2-cm-long uniform fiber Bragg grating was used to form the external cavity. Its center wavelength and reflectivity were 1551.2 nm and 70% respectively. The threshold current of the ECL was 30 mA. The output of the fiber laser was measured through a coupler by an optical spectrum analyzer with resolution of 0.07 nm, an optic power meter and a PIN detector.

Since the response of a LD is in the order of nanosecond, it is reasonable to use the LD pulse as a seed of the fiber laser to shorten the pulse width. And the FBG-ECL has some obvious advantages, such as stable narrow spectral line operation, and tunability.

In this scheme several facts should be taken into careful consideration.

(1) The pulsed LD signals must be synchronized with the sinusoidal wave applied on PZT.

(2) The phase difference between LD signals and PZT signals should be adjusted to get the best effect. That is to say, the seeding pulse should be injected into active fiber exactly at the time of Q-switch turned on.

(3) The LD should be biased near threshold and be gain-switched with short pulse signals. Small output of the ECL is enough to play a role of seed for the Q-switched fiber laser. The high output of the fiber laser should rely on high gain of erbium doped fiber (EDF).

When a sinusoidal signal was applied on the PZT and a same frequency short pulsed current was applied on the LD chip of ECL, a pulsed waveform was observed on an oscilloscope, as shown in Fig. 2(a). The upper trace in the photo was the modulation waveform on PZT. There were two peaks seen in the waveform. The small peak, circled in the waveform photo, came from the ECL output, with pulse width of about 0.6 μs. The higher one was attributed to the signal on PZT, which indicated Q-switching effect of the fiber laser. But the expected self-seeding had not yet come into force because the two effects did not occurred at the same time. Figure 2(b)

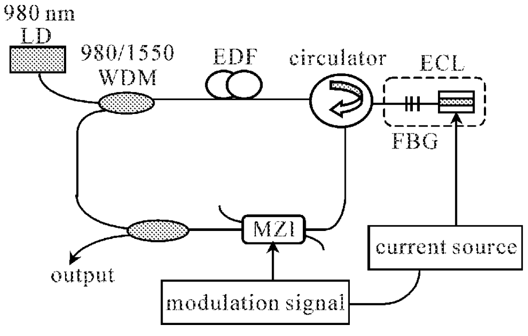

Fig. 1. Configuration of the self-seeded Q-switched fiber laser.

shows the waveform trace of MZI switched output, giving a pulse width of 4 μs.

When the phase difference between the two signals on PZT and ECL was carefully adjusted by using a delay circuit so that the two peaks came to be overlapped each other, a single pulse was observed, as shown in Fig. 3(a). The pulse amplitude increased five times and the pulse width decreased to below 0.8 μs, as shown in Fig. 3(b).

The spectral line width was measured to be below 0.07 nm (limited by the resolution of the spectrum analyzer), as shown in Fig. 4, and a side mode suppression ratio (SMSR) of 48 dB was obtained under 180-mW pump power. From the repetition frequency of 5 kHz and the measured average output power of 20 mW, the peak power of the fiber laser could be calculated to be 5 W.

The experiment indicated that the self-seeding given by the FBG-ECL reduced the pulse width and raised the peak output power. The Q-switch fiber laser could steadily work for three hours without another adjusting in the laboratory environment.

It is worth to discuss the mechanism of the fiber laser in detail. The short pulse output of ECL provides an injection seed for the fiber laser, while in the dark time of ECL, it will bring about a loss to the fiber laser. Therefore two modulated loss mechanisms play similar Q-switching effects. In case of only MZI switch, it is not easy to reduce the pulse width because of the slow response of PZT. On the other hand, if only ECL self-seeding incorporated the laser cannot be shut off thoroughly and high energy storage cannot be obtained.

Although the response time of semiconductor laser chip is in the order of nanoseconds, the pulse width of ECL self-seeded fiber laser in this work was only in the range of sub-micro seconds. It may be attributed to some facts, such as fiber connection loss, gain efficiency of EDF, and others. But there should be an intrinsic fact, that is, the photo lifetime of the fiber laser as a whole is the last determinant fact. Reference [7] reported that assuming rapid switching compared to the pulse build up time, an expression for pulse duration can be written as

$$\Delta t \approx \frac{r\eta(r)}{r-1-\ln(r)}\cdot\tau_c, \tag{1}$$

where r is the pump rate relative to threshold for the switch open; $\eta(r)$ is gain medium energy extraction efficiency, which is a function of r; and τ_c is the photon lifetime. From Eq. (1) we see that for short pulse, r must be maximized while τ_c is minimized. In this work, a relatively longer EDF (lower erbium doping) was used, and the fiber lengths in the MZI and between components were not cut to the minimum, resulting in a longer photo lifetime. It is necessary to optimize the parameters of the laser, especially minimize the photo lifetime, in order to get shorter pulse width and higher peak output power.

A new type of Q-switched fiber laser with a FBG-ECL incorporated as a self-seeding element is described. Experiment showed that, in comparison with the PZT modulated fiber interferometer switch, the ECL self-seeding could reduce the pulse width and increase peak power greatly, for example five times in this work. And the FBG-ECL was also an effective element for wavelength-selection at the same time.

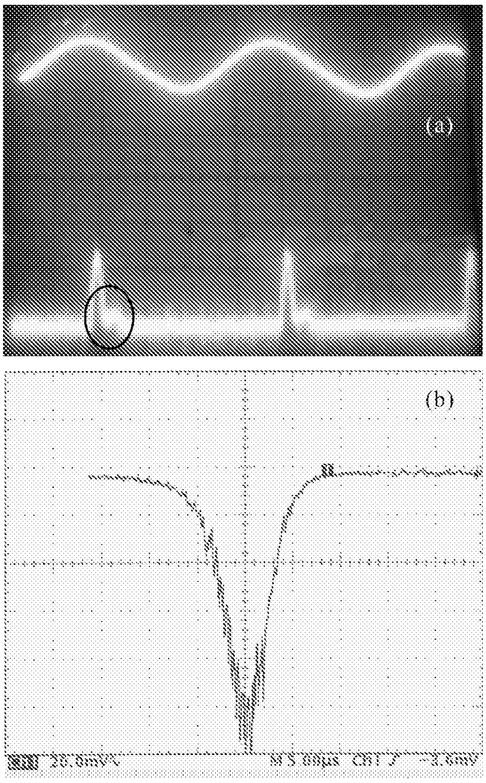

Fig. 2. (a) Waveform of the fiber laser output when the two modulation signals were not overlapped; (b) trace of the MZI Q-switched pulse.

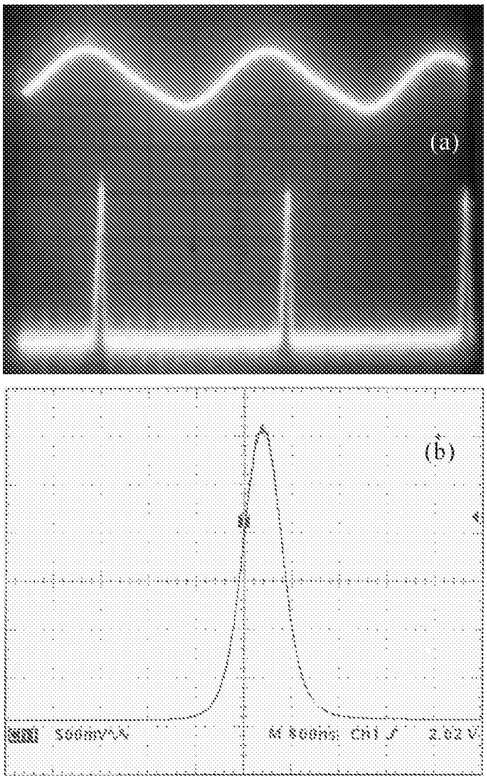

Fig. 3. (a) Waveform of the fiber laser output when the two modulation signals were overlapped; (b) trace of the output pulse from the self-seeded Q-switch fiber laser.

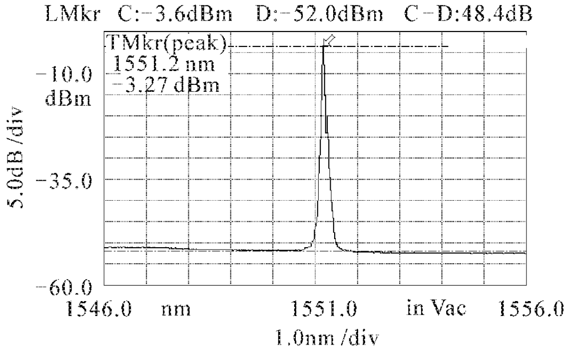

Fig. 4. The spectrum of the FBG-ECL self-seeded Q-switched fiber laser.

The mechanisms of the self-seeded Q-switched laser is discussed. Further improvements are expected after optimization of the device designing and the componant performances. It is believed that this simple configuration represents one of important steps towards the development of an all-fiber Q-switched short pulse fiber laser source.

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