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Tm–Ho CO-DOPED FIBER SATURABLE ABSORBER BASED ALL-OPTICAL ACTIVE Q-SWITCHING

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Abstract

We build an all-optical, all-fiber actively Q-switched Er-doped fiber laser with a simple ring cavity. Active Q-switching is attained by saturating a section of 34 cm Tm–Ho co-doped fiber saturable absorber with a 1550 nm pulsed fiber laser. The repetition rate of the pulsed output is 30 kHz determined by that of the subsidiary pump. The maximum pulse energy generated is about 80 nJ with a pulse duration of 2.07 μs. The line width of the pulsed output is only 0.054 nm limited by the resolution capability of the spectrum analyzer.

Keywords: active Q-switching, Tm–Ho co-doped fiber, Er-doped fiber laser, fiber saturable absorber.

1. Introduction

Q-switched lasers have many applications in laser range finding, remote sensing, material processing, and medicine [1–4]. The all-fiber structure of the pulsed laser system is preferred in many practical applications [5], especially in space-based cases where small volume and little maintenance is a key concern [6]. Fortunately, various fiber-integrated modulators have been developed, including fiber-end mounted semiconductor saturable absorber mirror (SESAM) [7] and graphene [8, 9] and carbon nanotubes [10, 11]. However, these modulators are mostly used for passive mode locking and Q-switching. Although passively Q-switched lasers hold a lot of advantages, control of the repetition rate involves variation of other laser parameters [12].

For active Q-switching, one popular and simple choice is fiber Bragg grating (FBG)-based intensity modulator [13]. Usually, a piezoelectric transducer (PZT) is exploited to tune the central wavelength of the FBG, introducing periodical losses into the laser cavity and, consequently, active Q-switching is realized. However, this method involves the incorporation of bulky components, which would undermine the simplicity and robustness of the all-fiber configuration [14]. Thus, the development of all-optical, all-fiber pulsed laser systems draws much attention.

In 2010, utilizing an optically tunable FBG, an all-optical, all-fiber actively Q-switched fiber laser system was proposed and demonstrated in [14]. The FBG used was inscribed in an Yb-doped fiber, and

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wavelength tuning was realized by resonant optical pumping of the FBG. Later, in 2013, an actively Q-switched Er-doped fiber laser with a modulated Er-doped fiber saturable absorber (FSA) was designed in [15]. Taking advantage of the saturation characteristics of Er-doped FSA, it provides a novel approach for all-optical active Q-switching, although the laser structure is rather complicated.

In this paper, utilizing a section of Tm–Ho co-doped fiber as the FSA, exploiting a pulsed 1,550 nm fiber laser as the subsidiary pump which saturates the FSA periodically, we demonstrate an all-optical, all-fiber actively Q-switched Er-doped fiber laser system with a simple ring cavity.

2. Experimental Setup

The setup of this all-optical, all-fiber actively Q-switched Er-doped fiber laser system is shown in Fig. 1. In this laser system, there are two pump sources, namely, the main pump and the subsidiary pump. The main pump from a 980 nm CW LD is launched through a wavelength division multiplexer (WDM) to pump the Er-doped fiber for lasing, while the subsidiary pump from a 1,550 nm pulsed fiber laser is introduced into the cavity through a circulator to saturate the fiber saturable absorber for active Q-switching. A 9 m Er-doped fiber laser (EDFC-980-HP, Nufern) and a 34 cm Tm–Ho co-doped fiber (TH512, CorActive) are exploited as the gain fiber and the saturable absorber, respectively.

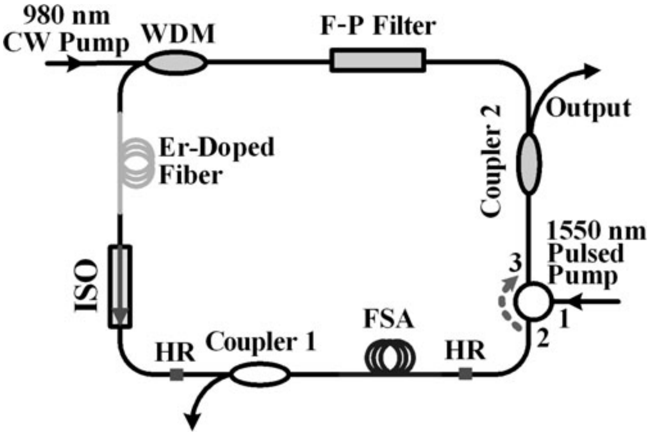

Fig. 1. Experimental setup for the all-optical, all-fiber active Q-switching laser system. Here, wavelength division multiplexer (WDM), highly reflective FBG (HR), and isolator (ISO).

Ten percent of the unabsorbed subsidiary pump is leaked through Coupler 1 (10 : 90) for monitoring, and 30% of the laser signal is extracted through Coupler 2 (30 : 70). A wide-band isolator (ISO) around 1,550 nm with a minimum isolation of 35 dB is inserted to dump the unabsorbed subsidiary pump, at the same time ensuring unidirectional operation of the ring cavity. Two highly reflective FBGs at 1,998 nm are deployed to confine the 2,000 nm signal inside the FSA cavity as shown in Fig. 1. Lasing wavelength of the system is determined by an F–P filter at 1,555 nm.

The subsidiary pump and the laser signal are monitored with a fast InGaAs detector (DET01CFC, Thorlabs) and a 4 GHz oscilloscope. An optical spectrum analyzer (Agilent 86140B) is used to measure the spectrum of the laser signal.

3. Results and Discussion

The repetition rate of the pulsed subsidiary pump is set to be 30 kHz with a pulse duration of 100 ns, and the peak power of the subsidiary pump pulse is 10 W.

Output signals with repetition rates of 10, 15, and 30 kHz are observed successively with increase in the pump power of the 980 nm main pump, as shown in Fig. 2.

It can be found that, with a low main pump, the repetition rate of the laser signal is one nth of that

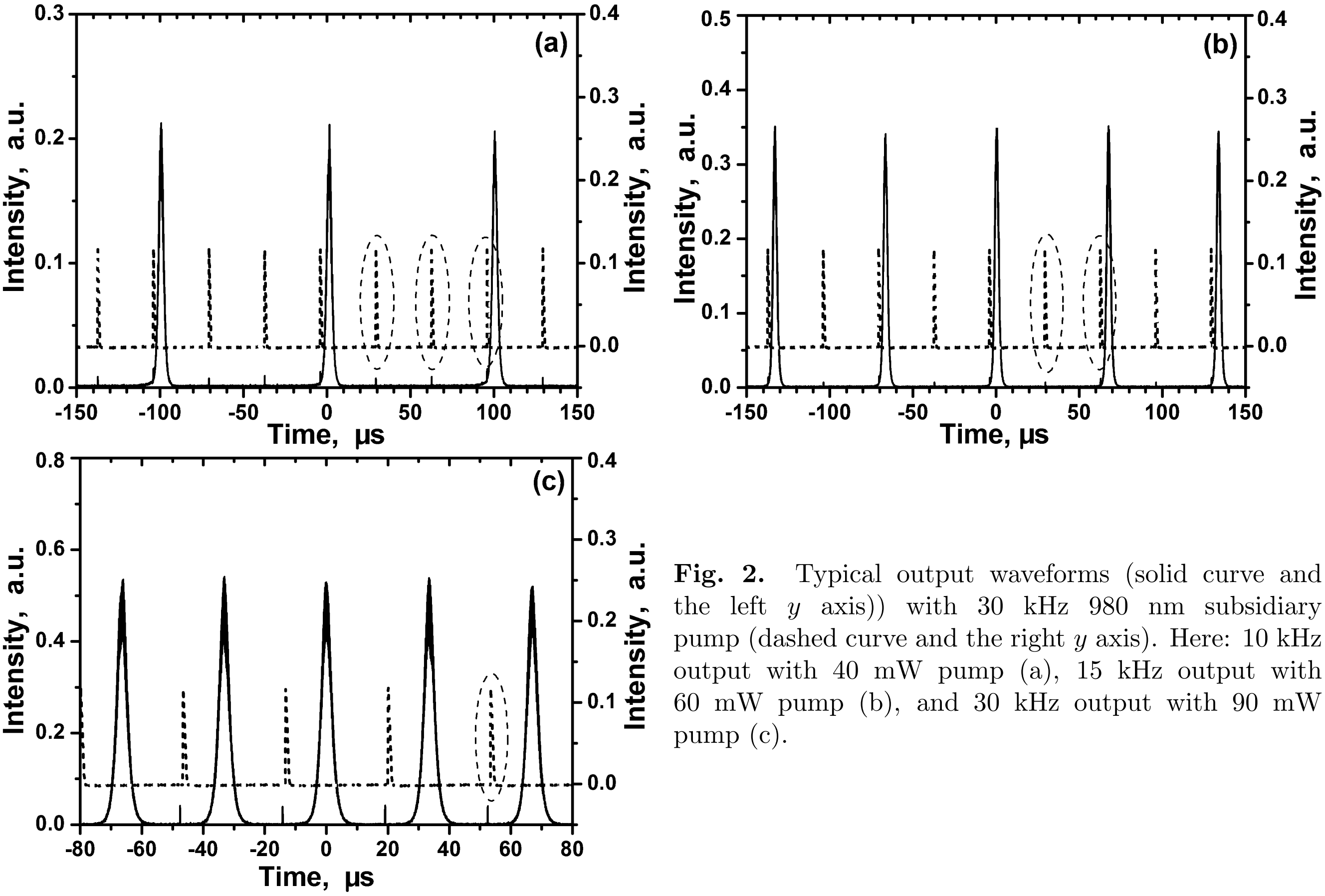

Fig. 2. Typical output waveforms (solid curve and the left y axis)) with 30 kHz 980 nm subsidiary pump (dashed curve and the right y axis). Here: 10 kHz output with 40 mW pump (a), 15 kHz output with 60 mW pump (b), and 30 kHz output with 90 mW pump (c).

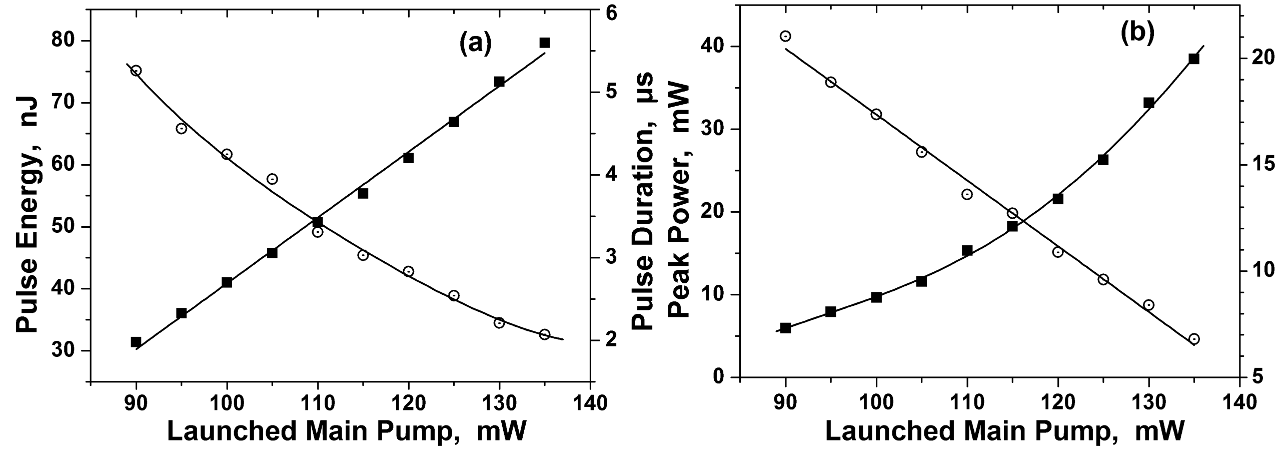

Fig. 3. Output characteristics of the all-optical, all-fiber actively Q-switched fiber; here, pulse energy (■) and pulse duration and building time (○).

of the subsidiary pump, where $n = 2$ or $n = 3$. When the main pump power is above a certain value, which is 80 mW in this experiment, the repetition rate of the laser signal becomes the same as that of the subsidiary pump. In this operation mode, the output characteristics of the laser system are shown in Fig. 3.

As can be found in Fig. 3 a, in contrast to Tm-doped FSA-based passive Q-switching [16, 17], the pulse energy rises with the launched main pump almost linearly with a slope of 1.06 nJ/mW in the laser system under investigation. This can be explained by the fact that, in actively Q-switched laser systems, the repetition rate of the laser signal remains constant at high main pump powers, while in passively Q-switched systems, the repetition rate increases with the pump power. The pulse duration of the output pulses shortens monotonously with the main pump power and, consequently, the pulse peak power shows an exponential growth as illustrates Fig. 3 b. The buildup time in Fig. 3 b is defined as the interval between the subsidiary pump pulse and the signal pulse. A monotonous reduction is witnessed, which is similar to that in gain-switched laser systems [18, 19].

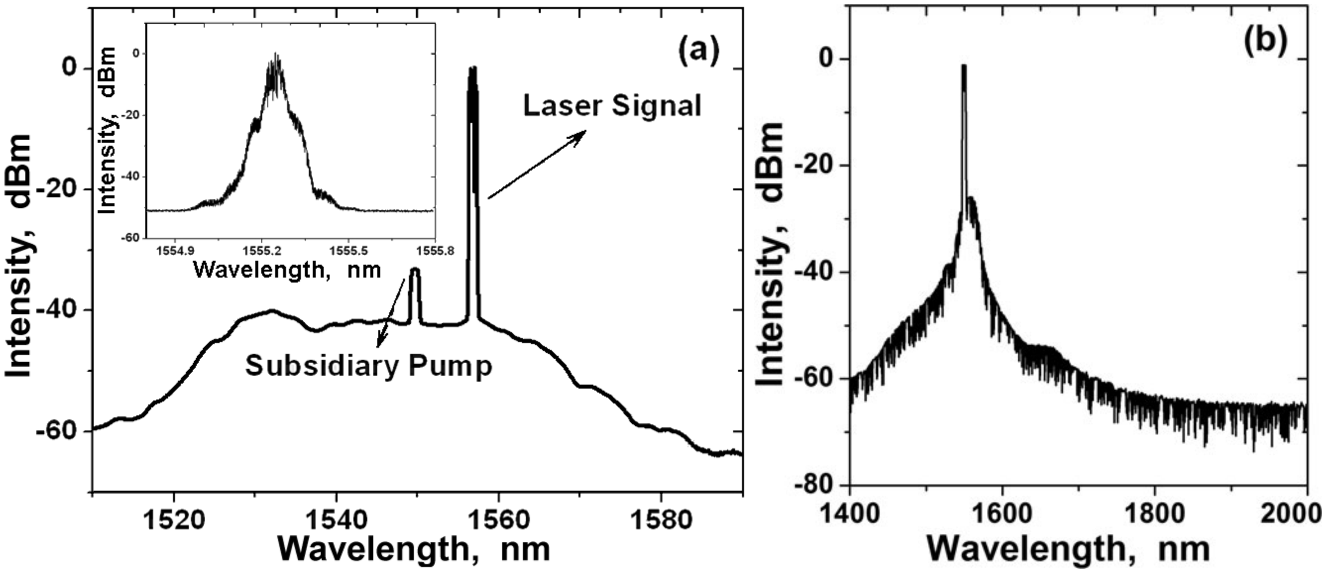

Fig. 4. Spectra of the all-optical, all-fiber actively Q-switched fiber laser system. Here: spectrum around 1,550 nm with a resolution of 1 nm (a). Inset is the spectrum of the laser signal at 1,555.25 nm with a resolution of 0.06 nm. Broadband laser spectrum from 1,400 to 2,000 nm with a resolution of 5 nm (b).

Spectra of this laser system are presented in Fig. 4, where Fig. 4 a demonstrates the laser spectrum around 1,550 nm. As can be found, the intensity of the laser signal is much higher than that of the subsidiary pump. The inset shows that the line width of the signal laser is only 0.054 nm, which is beyond the resolution capability of the spectrum analyzer. Figure 4 b shows the broadband laser spectrum from 1,400 to 2,000 nm.

No signal around 2,000 nm is detected at the 10% port of Coupler 1 with an HgCdTe detector (Vigo PVM-2TE-10.6-2) demonstrating that there is no lasing inside the FSA cavity. This result is further confirmed with the laser spectrum at the 30% port of Coupler 2, as can be seen in Fig. 4 b.

Compared with the Er-doped FSA-based active Q-switching [15], the laser system elaborated boasts not only a simpler laser configuration but also much higher repetition rate and pulse energy and relatively shorter pulse duration.

4. Conclusions

We demonstrated Tm–Ho co-doped FSA-based, all-optical, all-fiber active Q-switching of an Er-doped fiber laser with a simple laser configuration. In contrast to that in Tm–Ho co-doped FSA-based passively

Q-switched fiber lasers, the Tm–Ho co-doped FSA is actively saturated by 1,550 nm pulse injection. We obtained the repetition rate at tens of kHz pulse duration of several μs. As Tm ions have three major absorption bands [20], subsidiary pump within 780–800 nm band and 1,100–1,250 nm band should also be feasible. Moreover, since mode-locking with a repetition rate in the MHz range can be achieved with Tm–Ho co-doped FSA [21], we believe that this active Q-switching mechanism holds potential to operate at much higher frequencies than 30 kHz, and active mode-locking should be possible.

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