Advances in Materials
2019; 8(4): 166-169
http://www.sciencepublishinggroup.com/j/am
doi: 10.11648/j.am.20190804.15
ISSN: 2327-2503 (Print); ISSN: 2327-252X (Online)

A Hybrid Q-switched Yb^{3+}-doped All-fiber Laser Based on the Acousto-optic Q-switch and SBS Effect

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To cite this article:

Lianju Shang, Hui Xu, Zhenzhong Cao, Mingsheng Niu. A Hybrid Q-switched Yb^{3+}-doped All-fiber Laser Based on the Acousto-optic Q-switch and SBS Effect. *Advances in Materials*. Vol. 8, No. 4, 2019, pp. 166-169. doi: 10.11648/j.am.20190804.15

Received: September 30, 2019; **Accepted**: October 18, 2019; **Published**: October 25, 2019

Abstract: In the past 30 years, the studies on Q-switched fiber lasers have made great progress in both theoretical and experimental fields. So far there have been many reports about the acousto-optic active Q-switched fiber lasers. At the same time, there are many reports about the passive Q-switched pulse output using SBS effect in optical fibers, and this Q-switched mechanism based on SBS effect has become a simple and feasible scheme to narrow the pulse width. However, there are few reports about the Q-switched all-fiber lasers which have the two advantages mentioned above simultaneously. Theoretically the active and passive hybrid Q-switch can make the laser pulse stable and narrow. In this paper, by using the acousto-optic Q-switch and the SBS effect, the operation of a hybrid Q-switched Yb^{3+}-doped all-fiber laser is realized. The pulse width 150ns is obtained at the repetition rate 50kHz. Furthermore, the output wavelength is 1083nm, with the pulse energy 0.02mJ and the peak power 133W achieved. In this experiment, the acousto-optic Q-switch and single-mode fiber play the role of Q-switching at the same time. The active acousto-optic Q-switch plays the role of frequency stabilization. The SBS effect in single-mode fiber plays the role of compressing pulse width. Hence the advantages of active and passive Q-switching modes are reflected.

Keywords: Hybrid Q-switched, Repetition Rate, Pulse Width, Acousto-optic Q-switch

1. Introduction

The Q-switched fiber lasers are very attractive sources because of their wide applications such as military affairs, surgical operation, laser machining, laser marking, nonlinear frequency conversion, range finding, remote sensing and optical time domain reflectometer [1-2]. Reviewing the development of the Q-switched all-fiber lasers, both the actively Q-switched all-fiber lasers [3-6] and the passively Q-switched all-fiber lasers based on the Stimulated Brillouin Scattering (SBS) effect are reported [7-13]. As is well known, at present, the pigtailed acousto-optic Q-switch (AOQS) is a kind of active, effective and fast-time fibered Q-switch which combines traditional acousto-optic Q-switch and modern optical fiber technology. AOQS is a kind of active Q-switch, and it is known that, all of the active Q-switches can control the pulse repetition rate and make the pulse train highly inerratic and steady [14-16]. Even so, for the pigtailed acousto-optic Q-switch, there will still be a limit to narrow the pulse width to nanosecond magnitude. In this case, certainly, reducing the fiber length is a good method to narrow pulse width; but it may decrease the cavity energy, with the pulse energy and the peak power both decreased. If increasing the doped concentration of the gain medium, which is a remedy for the above problems, the concentration quenching may happen because of the excited state absorption. Furthermore, it is not allowed to dope the high concentration of the active particles in the fiber. The earlier findings show that the SBS Q-switched mechanism has been a simple and feasible means to narrow down the pulse width [16-17]. In addition, by using the SBS in fiber, some researchers including our team [17] have reported the results of the Q-switched nanosecond pulse [7-13]. Therefore it should be an effective method to use the fibered acousto-optic Q-switch and the SBS effect of a single-mode fiber simultaneously. In this paper, an Yb^{3+}-doped all-fiber laser, which has a good performance, is realized by using the pigtailed acousto-optic Q-switch and the SBS effect in a single-mode fiber. The configuration of this source makes it very suitable in some kindred systems. This research is the continuity of our earlier works [17-23].

2. Experimental Scheme

The experimental scheme is shown in Figure 1. In this experiment, only one of the six pump ports of the fiber combiner is used. The diode-laser with output-coupled fiber is made in China, and its parameters are as follows, fiber core diameter 200μm, NA 0.22, central wavelength 975nm, maximum output power 25W. In order to avoid shifting of the pump light wavelength, the temperature of the diode-laser is controlled by a TEC systems cooled by electricity, whose controlling precision is ±0.1℃. During the experiment, the pump port of the fiber combiner and the pigtailed fiber of the diode-laser are fused directly in order to realize the all-fiber scheme. The FBG has a high reflectivity (>98%) at the 1083nm, and its loss coefficient is less than 0.0015dB/m. The hybrid Q-switch operation is achieved by using the pigtailed acousto-optic Q-switch and the SBS effect in a single-mode fiber. The single-mode fiber, 2km long, has a core whose diameter is 10μm. Because of the difference between the single-mode fiber core and the signal port core of the combiner, the fusing loss here is larger than the loss at the other fusing points. But the sizes of the FBG, the AOQS pigtail fiber and the single-mode fiber are matched very well. The gain medium is an 11m long Yb^{3+}-doped double-clad fiber, which has an absorption coefficient of 1.2dB/m. With its parameters being 30μm core size with low NA (0.07), 350/400μm D-shaped inner cladding, and Large-Mode-Area (LMA) characteristic, the fiber is suitable in single-mode application. The output port of the all-fiber laser has the Fresnel reflectivity (0.04), and it is regarded as one of the reflector of the resonant cavity.

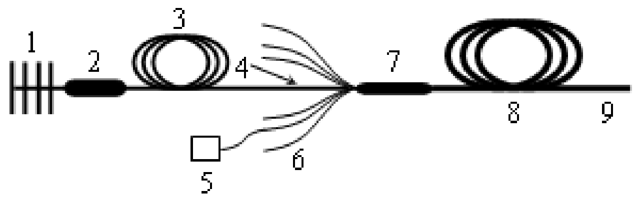

Figure 1. Schematic structure of the hybrid Q-switched Yb^{3+}-doped all-fiber laser: (1) FBG, (2) Pigtailed Q-Switch, (3) Single-mode fiber, (4) Signal port of fiber combiner, (5) LD, (6) Pump ports of fiber combiner, (7) Fiber combiner, (8) Yb^{3+}-doped double-clad fiber, (9) Output port.

3. Results and Discussions

(1) Figure 2 shows the pulse train of the hybrid Q-switched Yb^{3+}-doped all-fiber laser when the total pump power is 6.52W. In Figure 2, the pulse width is 150ns with the repetition rate 50 kHz, and the interval between two pulses is about 20μs.

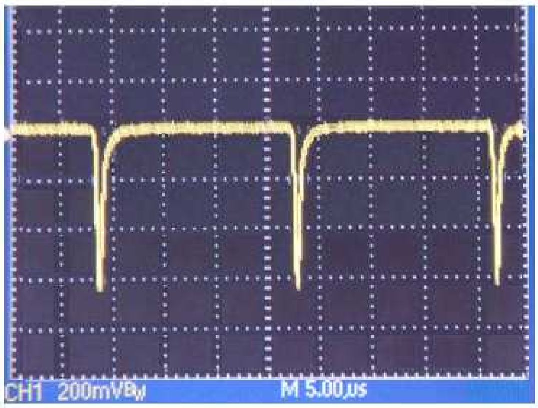

Figure 2. Pulse train of the hybrid Q-switched Yb^{3+}-doped all-fiber laser.

(2) Figure 3 shows the output spectra of the hybrid Q-switched Yb^{3+}-doped all-fiber laser. The central wavelength of the output light is 1083nm, and the linewidth is about 2nm. In addition, the light near 975nm is the pump light remained.

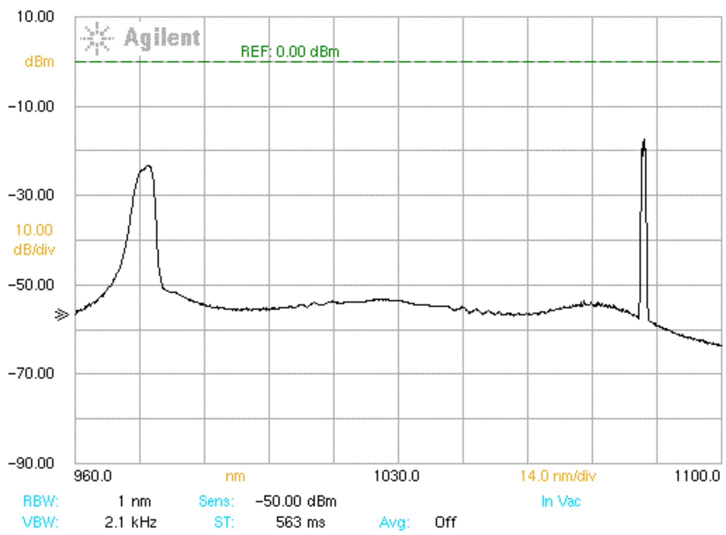

Figure 3. Output spectra of the hybrid Q-switched Yb^{3+}-doped all-fiber laser.

(3) The average output power, which is measured by the power meter, is 1.02W. By using the above results, after calculating, it is known that the pulse energy is 0.02mJ, and the peak power is 133W. Also, within a certain range, if the pump power is reduced properly, the pulse width will narrow slightly. So in this experiment, a relatively low pump power may well keep the pulse width narrow.
(4) In this experiment, the acousto-optic Q-switch and single-mode fiber play the role of Q-switching at the same time. Respectively, the active acousto-optic Q-switch makes the frequency stable, and the SBS effect in single-mode fiber makes the pulse width narrow. So the advantages of the active and passive hybrid Q-switching ways are shown here, and this hybrid Q-switching is the innovation of this experiment.
(5) Another advantage of this experiment is that the laser is all fiber structure. Comparing this experiment with references [16, 24], the results are satisfying. In references [16, 24], the body Q switch is used, and other optical components of the resonator are also split bulk components. Because the coupling efficiency of bulk Q-switch with optical fiber and cavity mirror is low, and optical lenses are needed in the coupling process, the experimental device of this kind of Q-switched fiber laser is relatively complex. Not only the optical path is sensitive to collimation error, but also the misalignment sensitivity of the system is relatively high. So a good way to avoid these problems is to research and develop Q-switched all fiber lasers.

4. Conclusions

From above, by using the pigtailed acousto-optic Q-switch and the SBS effect of single-mode fiber simultaneously, the experimental study of the hybrid Q-switched Yb^{3+}-doped all-fiber laser is accomplished, and a stable 150ns pulse width is obtained at the repetition rate of 50kHz. Furthermore, the output wavelength is 1083nm, with the pulse energy 0.02mJ and the peak power 133W achieved. In this experiment, the pulse output with stable repetition frequency and narrow pulse width can be obtained by hybrid Q-switching with intracavity high gain provided by acousto-optic Q-switch and SBS effect in single-mode fiber. From the mechanism of Q-switching, this method of obtaining pulsed laser can be regarded as a special Q-switching technique of amplifying the narrow seed pulse generated by the SBS effect.

Acknowledgements

This research is supported by The National Natural Science Foundation of China (number: 11705101), and The Key Research & Development Project of Shandong Province (number: 2017GSF17125).

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