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Q-switched ytterbium-doped fiber laser using graphene oxide as passive saturable absorber

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Abstract. A Q-switched ytterbium-doped fiber laser (YDFL) was demonstrated using Graphene Oxide (GO) as a saturable absorber (SA). Without SA, the ring cavity operates in a continuous wave laser at 1038 nm which is shifted to 1030 nm with the implementation of SA. The laser has a threshold pump power of 175 mW, a maximum repetition rate of 141 kHz and the shortest pulse width of 1.94 μs. The highest pulse energy of 5.65 nJ is achieved at the pump power of 175mW. A stable Q-switched ytterbium doped fibre laser was successfully achieved in this experiment as the pulses measured SNR of 56.52 dB.

1. Introduction

Pulsed laser has received tremendous focus among researchers within the field of laser because it plays crucial roles in wide selection of applications including optical communication, optical sensing, materials technology, life sciences, precision mechanics, national defense science and etc [1-3]. There are two techniques to realize pulsed laser which are active and passive. The latter is more favourable due to few advantages including ease of preparation, high flexibility and high efficiency. The generation of pulsed laser via passive means is highly dependent on the implementation of material as a saturable absorber inside a laser cavity. Recent years, many materials were implemented inside laser cavity to initiate pulsed laser such as semiconductor saturable absorber mirrors (SESAMs) [4] and carbon nanotubes (CNTs) [5].

For SESAMs, pulsing method require additional devices such as mirror, lenses and U-bench units which introduce extra losses to the cavity [6]. Therefore, researcher starts to use carbon-based materials to generate pulsed laser. CNTs, which seems very promising in terms of electron mobility exhibit ultra-fast recovery time (< 1 ps) and wide absorption spectrum (1-2 μm) [7]. However, tunability of wavelength for CNTs are dependable on it shapes and sizes, thus provide complexity for pulse generation. For instance, structural, morphological and alignment control needed to be establish for the purpose of band gap alteration for CNTs [8]. Thus, 2-dimensional carbon allotrope (graphene) is introduced due to excellent electronic and optical properties. In terms of saturable absorption ability, graphene provide significant improvement compare to CNTs. Hexagonal honeycomb lattice of graphene exhibit wide-band operation due to its ultrafast recovery time (~200 fs) and point band gap structure [8]. In fact, graphene oxide (GO), precursor of graphene offers easier sample preparation than it parents. This is attributed by hydrophilic properties of graphene oxide which makes it easier to dissolve in water [9]. On the other hand, most work in pulsed laser focused on the generation of Q-

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switched at 1.55 µm region [10] but only few works produced Q-switched at 1 µm regime. In this research, a stable Q-switched pulses is generated in ytterbium-doped fiber laser using graphene oxide as a saturable absorber.

2. Experimental setup

Figure 1 shows the experimental setup of the Ytterbium-doped fiber laser with Graphene oxide as a saturable absorber. The ring cavity consists of a 2 m long Ytterbium doped fiber (YDF) as the active medium, a 980/1050 nm wavelength-division multiplexer (WDM), an optical isolator, a GO based SA, and a 90:10 output coupler. The GO as a SA is sandwiched between two FC/PC fiber connectors and inserted into the fiber cavity. The insertion loss of the SA is measured to be around 2dB at 1030nm. It is pumped by the 980 nm laser diode via a 980/1050 nm WDM. Isolator is located between coupler and gain medium to allow light travel in a one direction. The output of the laser is tapped out of the cavity through a 90:10 output coupler, which allows 10% of the output to be extracted for analysis.

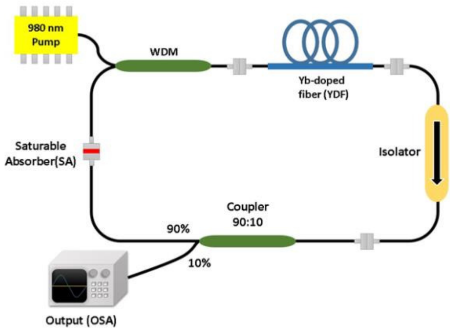

Figure 1. The experimental setup of the Ytterbium fiber laser with Graphene oxide as a passive saturable absorber.

3. Results and Discussion

In the experiment, the YDFL started to generate pulse at threshold pump power of 154 mW. Figure 2 shows the comparison of the output spectrum of the proposed YDFL with and without using GO as a SA at the pump power of 175 mW. As seen, the operating wavelength of the laser shifts to the left from 1038nm to 1030 nm with the incorporation of the SA. The output spectrum with SA was measured at 1038nm. Without the SA, the ring cavity operates in a continuous wave method and output spectrum at 1030nm.

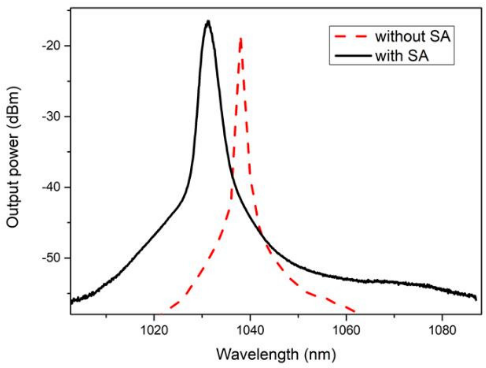

Figure 2. Output spectrum of the YDFL with and without GO as a SA at pump power of 175 mW

The stable pulse trains with the different of repetition rate were observed when the pump sources were progressively increased from 154 mW to 184 mW. The YDFL started to produce a Q-switched pulse at threshold pump power of 154 mW. Figures 3, 4 and 5 shows (a) typical oscilloscope trace of the Q-switched pulse train (b) a single envelop of the Q-switched at three different pump power which is 154 mW, 171 mW and 184 mW. The pulse trains have the pulse width of 3.72 µs, 2.44 µs and 1.94 µs, which is corresponds to the repetition rate of 88 kHz, 115kHz and 141 kHz, respectively.

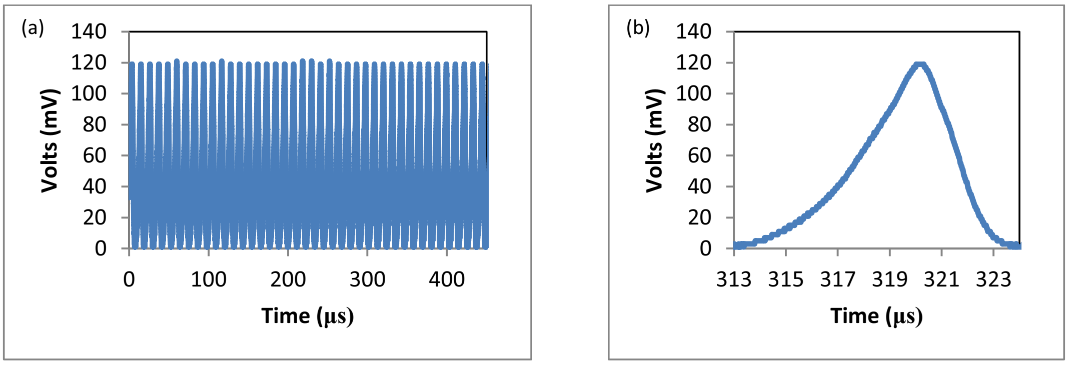

Figure 3. (a) Oscilloscope pulse train and (b) a single envelop of the Q-switched at power pump which is 154 mW.

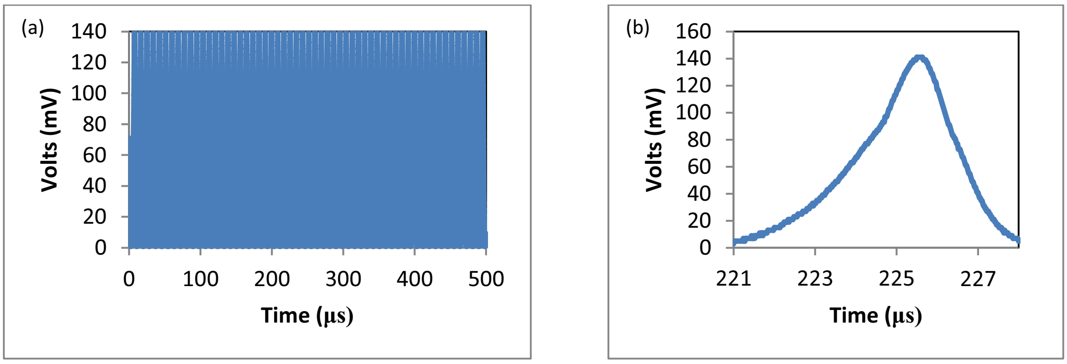

Figure 4. (a) Oscilloscope pulse train and (b) a single envelop of the Q-switched at power pump which is 171 mW.

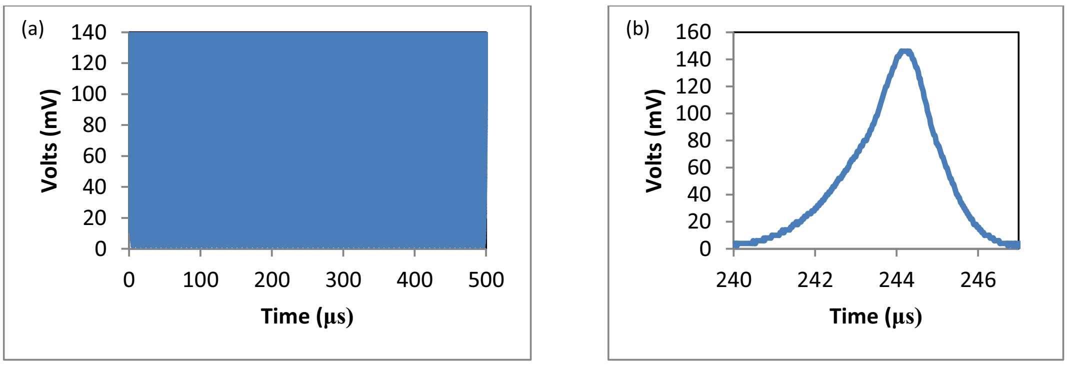

Figure 5. (a) Oscilloscope pulse train and (b) a single envelop of the Q-switched at power pump which is 184 mW.

Figure 6 shows the relationship between the repetition rate and the pulse width versus the pumping sources. The repetition rate of the proposed YDFL can be changed from 88 kHz to 141 kHz when the pump was gradually increased from 154 mW to 184 mW. From that, the pulse width reduces from 3.72 µs to 1.94 µs as the pump increased.

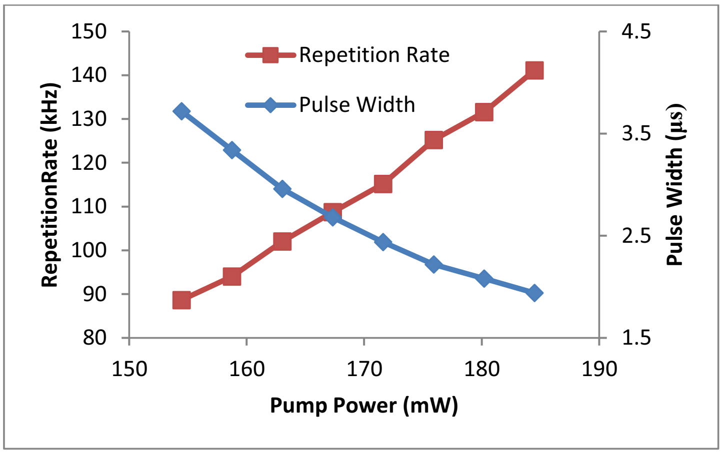

Figure 6. Repetition rate and pulse width of Q-switched YDFL within 154 mW to 184 mW

Figure 7 shows the repetition rate and the average output power as the function of the pump power. As seen, it shows both of repetition rate and the average output power was increased as the pumping sources increased. The highest pulse energy obtained was 5.65 nJ at the power pump of 184 mW. From that, the constructed laser is working under passively Q-switched. The slope efficiency of 1.3% is obtained.

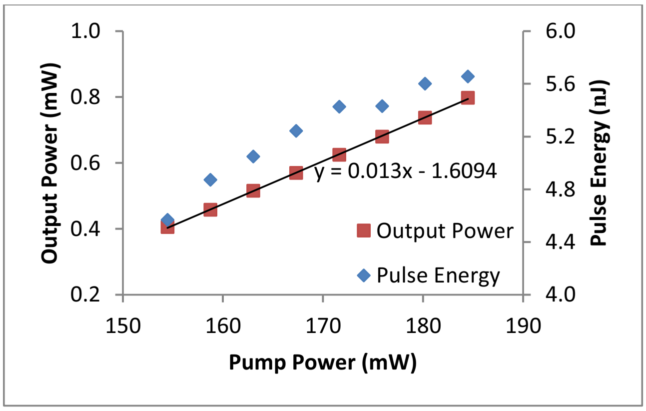

Figure 7. Repetition rate and output power as a function of 980nm of pump power.

The radio frequency (RF) spectrum analyser at pump power of 171 mW was measured. Figure 8 shows the RF spectrum of the Q-switched laser output of the pumping sources. It shows a stable repetition rate of 115.2 kHz and peak to background ratio of about 56.52 dB. This indicates stable pulses are produced by our laser cavity.

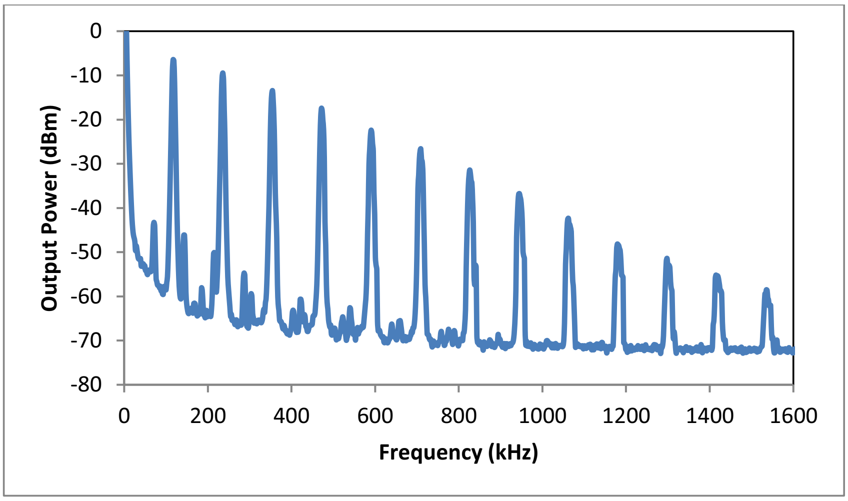

Figure 8. RF spectrum at pump power of 171 mW (SNR: 56.52 dB)

4. Conclusions

A YDFL is proposed and demonstrated using graphene oxide as a passive saturable absorber (SA). GO film is sandwiched between two FC/PC fiber connector to analyze the performance of Ytterbium doped fibre laser based on Graphene Oxide as a saturable absorber. Without SA, the ring cavity operates in a continuous wave regime with output spectrum at 1038 nm. By inserting SA, the YDFL operates at 1030nm. Stable Q-switched starts at the threshold pump power of 154 mW producing pulse with the repetition rate of 88 kHz and the pulse width of 3.72 µs. At maximum pump power of 184 mW, we achieved the maximum pulse energy of 5.65 nJ and the shortest pulse duration of 1.94 µs. A passively Q-switched ytterbium doped fibre laser was successfully achieved in this experiment.

5. Acknowledgements

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