Black Phosphorus Saturable Absorber for Pulse Generation Using Q-Switched Teachnique

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ABSTRACT

This paper reported a passive Q-switched erbium doped fiber laser (EDFL) using two-dimensional (2D) material of black phosphorus saturable absorber (BP-SA). The maximum output power reached is 3.54 mW, which is generated by pump power of 42.327 mW. The results show that a stable pulse was generated with repetition rate starts at about 9.606 kHz and ends at about 44.72 kHz and very narrow pulse width between 40.01 µs and 9.84 µs and pulse energy 80 nJ. Clearly, the stability of the Q-switched pulse train was achieved because the BP-SA film was inserted in the laser ring cavity

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1. INTRODUCTION

According to the compactness, simplicity and flexibility design, passive technique of acquiring Q-switched pulses have more attention compared to active technique. Pulses can be found using various kinds of saturable absorbers including graphene oxide, Transition metal dichalcogenides (TMDs) such as molybdenum disulfide (MoS2), Semiconductor Saturable Absorption mirrors (SESAMs), and Carbon Nano-Tube (CNT) [1-3]. However, these saturable absorbers have a number of drawbacks in terms of their fabrications and compatibility with some optical fiber applications, it also suffers low pulse energy with a wide band gap between layers.

Too many works have been reported on intensive advancements in the fields of photonics based on (2D) materials based photonics including ultrafast recovery time and broadband saturable absorption of graphene saturable absorber. However, the absence of band-gap limited its applications in some applications. As the result of graphene limitations, transition-metal dichalcogenides have been studied due to their result of special absorbing and relying on bandgap thickness. BP saturable absorber has joined the family of 2D material with more efficient than the above-mentioned SA in terms of band gap filling [1-4].

Recently, we had a large increase in the number of practical applications requiring Erbium-doped fiber (EDF) laser as the gain medium due to the possibility of more output power at higher gains and their flexible in usage and design [1-3]. Ismail et al. demonstrated Q-switched pulse using EDFL as a gain medium and BP [1]. Ultra-short pulse generation using multi-layer black phosphorus SA based on erbium doped active fiber [2]. Ahmed et al. [3] proposed passive mode-locked pulse with BP saturable absorber. However, a loss of the average output power has shown, while the pulse energy and peak power are decaying. Hence, large quantities of stable few layer black phosphorus dispersions occurred. Moreover, exfoliated BP saturable absorber was fabricated mechanically for resulting dual-wavelength Q-switched fiber laser [4]. Where the signal to noise ratio recorded was about 57 dB since the pulse repetition rate range from 9.606 kHz to 44.72 kHz. However, the average output power linearly increased to 50 mW as the result of huge increase input pump power of 1133 mW and the average pulse energy is around about 1.05 µJ.

Chen et al [5] made an attempt to show that BP is a promising narrow direct band gap two-dimensional material which fills the gap between the semi-metallic graphene and wide-band gap TMD. This work assures the simplicity to secure either the passive Q-switching or mode-locking pulse laser with pulse width down to 946 fs. Q-witched pulse laser for Ytterbium doped fiber laser (YDFL) is experimentally obtained as the gain medium using BPSA, along with the high pulse energy gained from the experiment, it is highlighted that the repetition rate suddenly decreases as the pump power is raised up in number before the Q-switched pulse operation becomes unstable [6]. A distinctive feature configuration of Q-switched EDFL with graphene based SA is tested. The measured pulse energy was at 43.7 nJ. The observed results indicate that the EDFL is easy to implement and low cost. However, the thicker graphene layer takes a lot of time because of more difficult absorption [7]. It is worth to note that Sadovnikova et al. [8] used a thulium-doped fiber laser with heavily holmium-doped fiber as SA acquiring low pulse energy. A passively Q-switched pulse of Brillouin fiber laser (BFL) is reported using multi-walled carbon nanotubes (MWCNTs) by Arman Zarei et al [9] with 0.13 nJ pulse energy.

In this work, we propose passively Q-switched configuration, an erbium doped fiber laser with two dimensional (2D) material BP saturable absorber to achieve high pulse energy and filling the band gap between layers.

2. EXPERIMENTAL SETUP

Figure 1 highlights the proposed configuration of a Q-switched pulse laser, where consist of the wavelength pump (980 nm) and wavelength (1550 nm) are connected to wavelength divisions multiplexer (WDM) and the out pot joined to 2.8 m of EDFL. An isolator is placed between the EDFL and the splitter to generate Q-switched pulses to prevent the back power. By using the coupler 80% of splitter output will circulate through the cavity repeatedly and the rest 20% will be monitored by optical spectrum analyzer (OSA) Yokogawa, AQ6370B because the maximum power inter to OSA should not more than 10 dB. Finally, digital Oscilloscope (GDS-3352) with 350 MHz was used to detect the output pulse trains, repetition rate and pulse duration. The input pump power controlled by the current in a range 0 to 290 mA.

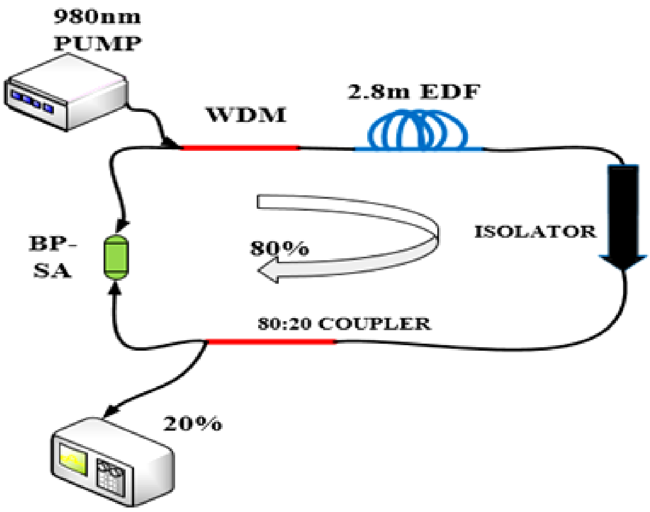


Figure 1. Configuration of Q-switched Setup

Figure 2 explains the shows the relation between the power and the time to calculate the pulse energy and prepetition rate.

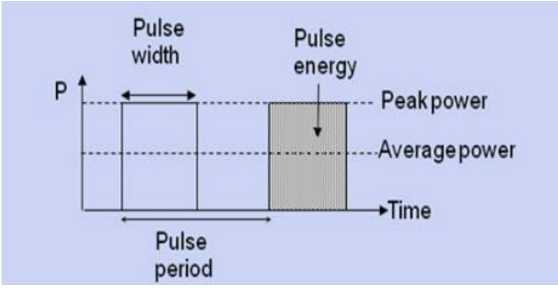


Figure 2. Relation between the Power and the Time

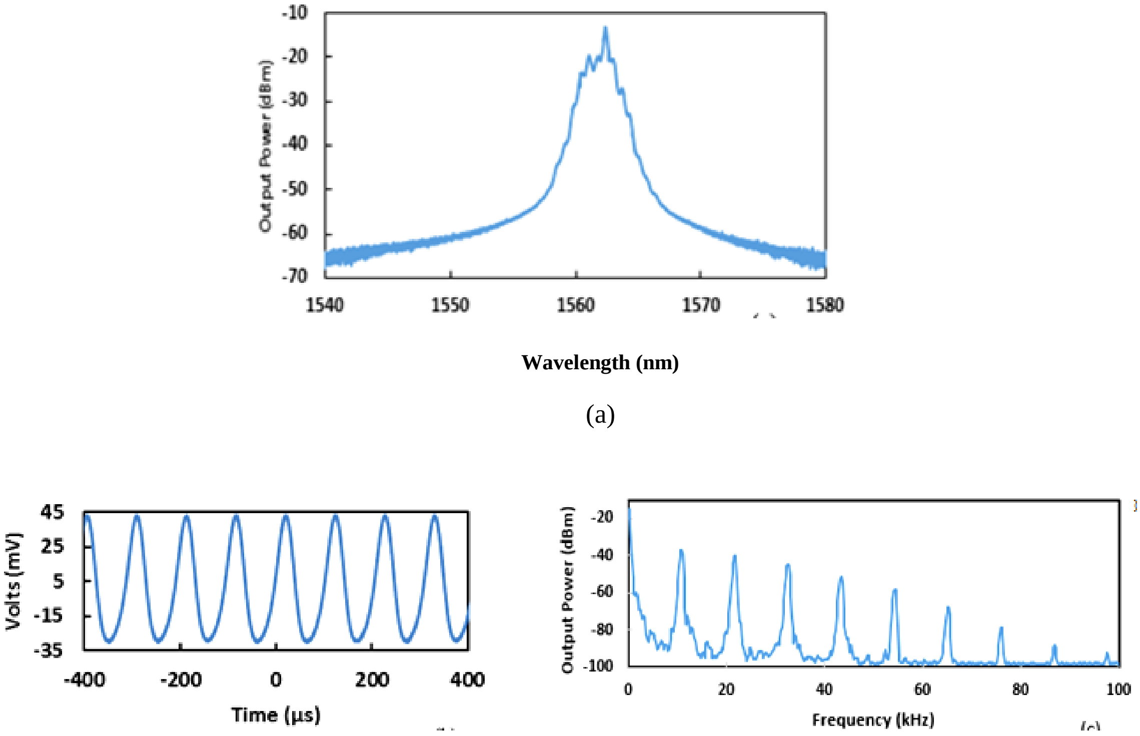
By using the figure above we can calculate both pulse energy and pulse prepetition rate as following;

Pulse prepetition rate = 1/pulse period

Pulse energy = Peak power * Pulse Width

3. RESULTS AND DISCUSSION

The EDF cavity produces continuous wave (CW) mode operation at the threshold pump power of 6 mW with BP saturable absorber is placed in the cavity. The Q-switched erbium-doped fiber laser is achieved at the pump power of 7.2198 mW and pump power increased up to 42.327 mW. The result from the experiment a stable pulse trace with an increasing repetition rate was detected. This is a normal feature of passive Q-switching. Fig. 3 (a) shows the output spectrum of 1562 nm. While the Fig. 3 (a, c) representative the RF spectrum signifies the Q-switched laser having the repetition rate of 9.606 kHz, pulse period of 40.1 µs, the output power of 0.163 mW and signal to noise ratio (SNR) is about 51 dB.



(b) (c)

Figure 3. (a) Output Spectrum at 1562 nm Wavelength, (b) Pulse Period of 40.1 µs, (c) RF Spectrum of the Output Power at SNR of 51dB

Since the maximum pump power is 129.20 mW of the laser source, the pulse train disappeared at 42.327 mW. Thus, at this point, the repetition rate of the pulse increased to 44.72 kHz. Similarly, the pulse duration had expanded to 9.84 µs as shown in Fig. 4 which also indicates that the repetition rate of the Q-switching pulses linearly increased from 9.606 to 44.72 kHz as the pump power is increased from 7.2198 to 42.327 mW. Meanwhile, the pulse duration significantly enlarges from 40.1 to 9.84 µs.

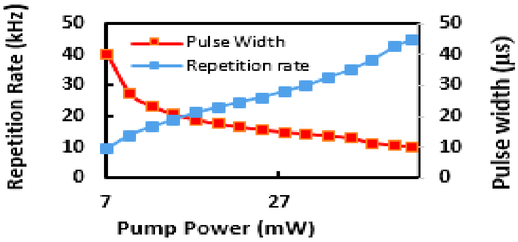


Figure 4. The Repletion Rate and Pulse width of the Proposed Q-Switched Fiber Laser.

It is noted in Fig.5, the pulse energy has linearly increased as the pump power increases. The highest output power and pulse energy are 3.54 mW and 80 nJ respectively.

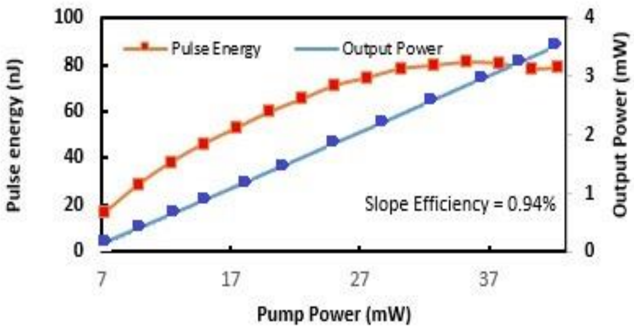


Figure 5. Output Power and Pulse Energy of Q-Switched Pulse versus the Pump Power

The experiment is also repeated at different times to obtain optimum RF spectrum. The output frequency spectrum of the laser is also analyzed with the RF spectrum analyzer at the output power of 3.54 mW as shown in Fig. 6, the maximum repetition rate of the pulse is 44.72 kHz while the gained signal to noise ratio is about 67 dB, which reflects the efficiency of the system.

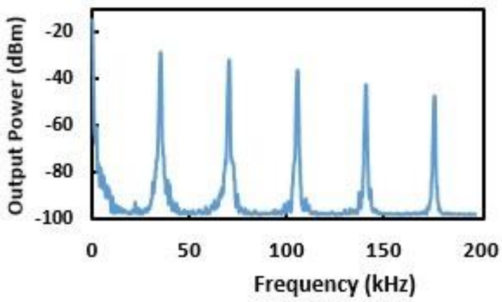


Figure 6. The RF Spectrum of the Highest Pump Power against Output Power

4. CONCLUSION

In this paper, we have experimentally demonstrated Q-switched pulse laser using EDFL as the gain medium, with the assistant of BP-SA in the cavity. A stable Q-switched pulse train is self-started at the input pump power of 7.2198 mW, the highest pulse energy of 80 nJ is obtained at an output power of 3.54 mW which assures the stability of the pulse laser. The repetition rate of the Q-switched laser increases from 9.606 kHz to 44.72 kHz, whereas the pulse width stretches from 40.1 µs to 9.84 µs, the received signal to noise ratio at the radio frequency spectrum is about 67 dB.

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