

APPLICATION OF MULTI-WALLED CARBON NANOTUBES-BISMUTH (III) TELLURIDE (MWCNTS-Bi₂Te₃) BASED PASSIVE SATURABLE ABSORBER IN PASSIVELY Q-SWITCHED FIBER LASER

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ABSTRACT

Q-switching fiber lasers based on 1-dimensional (1D) and 2D material have been extensively reported over the past few years. Saturable absorbers (SAs) like Multi-Walled Carbon Nanotubes (MWCNTs) and Topological Insulators (TIs) are gaining more attention for their unique and intrinsic properties, well suited in optical applications. While many have reported individual works on the SAs, this work demonstrates a saturable absorber based on a combination of 1D and 2D materials, MWCNTs-Bi₂Te₃, in Q-switched regime. The proposed work revealed that the laser oscillated about 1558 nm at threshold input pump power of 18.31 mW. The pump power is tunable up to 73.79 mW, yielding a maximum repetition rate of 59.88 kHz. The pulse energy obtained is 111.85 nJ, with corresponding 13.71 mW of peak power. The stability of the pulse generated is proven by the obtained signal-to-noise ratio (SNR) of 60 dB. The SA shows promising potential in high energy and broadband optical applications.

Keywords: MWCNTs; topological insulators; saturable absorber; q-switching; high energy

INTRODUCTION

Fiber laser plays a vital role in satisfying a range of applications, may it be for scientific purposes, medical solutions or industrial supplies. In Q-switching, active and passive technique is the two approaches taken in generating pulsed laser of which the latter is more preferred for its' simplicity and compactness. Unlike active Q-switching which requires external control element, the passive approach uses saturable absorber (SA) to modulate the intracavity loss. This resulted in lower cost and less component requirement, thus the compactness and simplicity mentioned before. The numerous SA

used in realizing Q-switched technique have their own intrinsic properties, but research is still on-going to find the ideal SA for specific applications.

In optical fiber laser, many works have been reported on Multi-Walled Carbon Nanotubes (MWCNTs) and Topological Insulators (TIs) (Bi_2Se_3 , Bi_2Te_3 , Sb_2Te_3) based SA. Both of the materials show great potential in Q-switching as well as mode-locking lasers [3-5]. MWCNTs have been demonstrated in Q-switched fiber laser, mostly incorporated with host polymer such as polyvinyl alcohol (PVA) or polyethylene oxide (PEO). MWCNTs-PVA based SA demonstrated by Tiu et al. [6] produces a maximum repetition rate of 48.2 kHz and shortest pulse width of 5.3 μs at 65.3 mW pump power. Peak power and pulse energy of 0.24 mW and 99.75 mW is obtained. Kasim et al. [7] utilizes MWCNTs polymer composites using PEO as SA yielding a maximum of 143.5 nJ of pulse energy.

On the other hand, TIs based SA such as Bismuth Selenide (Bi_2Se_3), Bismuth Telluride (Bi_2Te_3) and Antimony Telluride (Sb_2Te_3) are gaining a lot of attention in the field of optical fiber, due to their intrinsic electronic structures and remarkable optical properties [5]. In Q-switching, experimental works on Bi_2Se_3 have been successfully demonstrated, one of which yielding a maximum of 278.8 nJ in pulse energy [8]. Chen et al. [9] establishes a Q-switched laser based on based SA with pulse energy as high as 1.5 μJ . On the other hand, a research work by Wu et al. [10] finds that the saturable absorption property of the Bi_2Te_3 as SA enables wide range of repetition rate, from 12.6 kHz to 177.7 kHz. These results show that TIs, especially Bi_2Te_3 is a promising SA for high energy applications.

Recently Mu et al.,[11] demonstrated combination of 2D-2D materials (Graphene- Bi_2Te_3) as passive saturable absorber to compliment intrinsic drawbacks of each material. Graphene has fast relaxation time around 100 fs, in the expense of low modulation depth. To tune the modulation depth, the Bi_2Te_3 is introduced with slower relaxation time around 500 fs. In application for Q-switching with 85% coverage of Bi_2Te_3 , the reported threshold input pump power is 53.3mW with tunable repetition rate from 9.3 kHz to 35 kHz and the shortest pulse width of 3.247 μs . The maximum pulse energy is 93.18 nJ and the signal to noise ratio around 47.5 dB. They reported a promising result by combining two 2D materials, but their fabrication process is complex which requires two-step chemical vapour deposition (CVD) at high processing temperature.

In this work, we proposed a fabrication of 1D-2D (MWCNTs- Bi_2Te_3) based passive saturable absorber at room temperature and the performance of the generated pulse in Q-switched regime is discussed throughout the manuscript.

EXPERIMENTAL

Materials Preparation

The SA fabrication involves two key material, which is the MWCNTs in acrylonitrilebutadiene-styrene (ABS) 3D printer filament (3DxTech), and Bi₂Te₃ powder (Sigma Aldrich). As per received, the filament diameter and weight is 1.75 mm and 750 g, respectively. Firstly, the MWCNTs-ABS filament is extruded through a 3D printer nozzle of diameter 0.4 mm at 210 °C. This is to reduce the filament diameter to 200 µs for later easy dispersion. The filament is weighed to about 50 mg. Then, the filament is combined with 20 mg of Bi₂Te₃ powder in a small glass container. 2 ml of acetone is added to the mixture before it is thoroughly mixed with the aid of magnetic stirrer at 300 rpm for two hours. After that, the mixture is sonicated for 5 minutes to ensure even dispersion and so that the ABS is fully dissolved. The sonication process produces a MWCNTs- Bi₂Te₃ in acetone suspension. During the experimental work, the suspension is dropped onto one end of a fiber ferrule and left for a few seconds to allow for the acetone to evaporate, leaving only the MWCNTs-Bi₂Te₃ slurry. The ferrule with the newly fabricated SA is then integrated in the laser cavity by mating it with another clean ferrule.

Experimental Setup

The configuration of the Q-switched erbium doped fiber laser (EDFL) based on MultiWalled Carbon Nanotubes – Bismuth Telluride (MWCNTs-Bi₂Te₃) slurry is shown in Figure 1. The components arranged in ring cavity are comprised of a 980 nm laser diode, a 980/1550 nm wavelength division multiplexer (WDM), a one meter long erbium doped fiber (EDF) as the gain medium, the newly fabricated saturable absorber (SA), and an 80/20 output coupler where 80% of the light is returned to the cavity while the another 20% is used for output characterization. The core and cladding diameter of the EDF is 8 µm and 125 µm respectively. The numerical aperture of the EDF is 0.16 and has Erbium ion absorptions of 45 dB/m at 1480 nm and 80 dB/m at 1530 nm. The EDF was pumped by a 980 nm laser diode via the WDM. An isolator is placed to endure uni-directional propagation of the light oscillating in the cavity. An optical spectrum analyser (OSA) with spectral resolution of 0.02 nm, an oscilloscope (OSC), an optical power meter (OPM), and a radio frequency spectrum analyser (RFSA) is used to analyse the output laser.

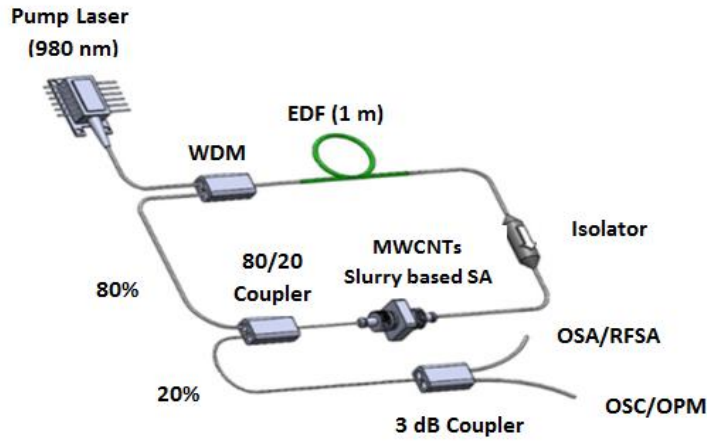


Figure 1: Experimental setup of the proposed passively Q-switched EDFL with MWCNTs-Bi₂Te₃ slurry based SA

RESULTS AND DISCUSSION

Before integrating the MWCNTs- Bi₂Te₃ based SA in the laser cavity, the central wavelength is investigated beforehand, and it is found that the laser threshold is at the pump power of 12.76 mW. After SA integration, a self-starting Q-switched pulsed is obtained by just increasing the pump power to 18.31 mW which is much lower than the 2D-2D work by Mu et al. [11]. Beyond 73.79 mW, the generated pulse is observed to be unstable and slowly dissipated. The output spectrum of the Q-switched laser is shown in Figure 2 for both before and after the SA integration at maximum pump power. The laser operated at central wavelength of 1558.42 nm compared to 1560 nm before the SA is placed in the cavity. Figure 3 shows the pulse train repetition rates of the EDFL at pump power of 73.79 mW. No distinct amplitude modulation is observed in the spectrum. The separation of the adjacent pulse is around 16.7 μ s which correspond to repetition rate of 59.88 kHz. Figure 4 shows the shortest pulse width with single pulse envelop with full width at half maximum (FWHM) of 7.66 μ s.

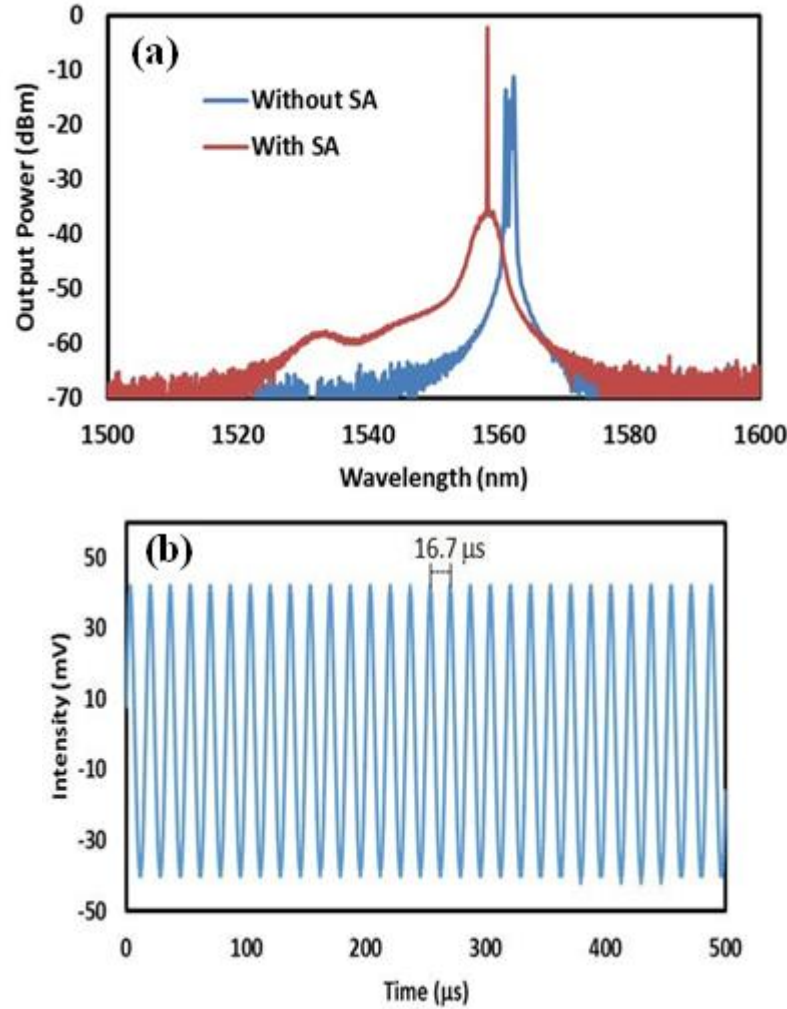


Figure 2: (a) OSA trace with and without SA, (b) Pulse train of 59.88 kHz at maximum input power

The relationship between the repetition rate and the pulse width with respect to the pump power is illustrated in Figure 5. The monotonous increase of the repetition rate as well as the almost linear decrease of the pulse width as the pump power is increased gradually, agrees with the Q-switching theory using saturable absorber [12]. By increasing the pump power from 18.31 mW to 73.79 mW, the repetition rate also increases from 19.59 kHz to 59.88 kHz. However, the pulse width is reduced from 18.26 μs to 7.66 μs. A shorter pulse width can be obtained by optimizing the laser cavity. The maximum repetition rate of 59.88 kHz obtained is higher than other separate reported works based on MWCNTs and TIs based on Bismuth Telluride and Bismuth Selenide [6-7][13-14].

The calculated peak power and pulse energy of the Q-switched EDFL is shown in Figure 6 with respect to the pump power. As the pump power is tuned to the maximum,

a peak power and pulse energy of 13.71 mW and 111.85 nJ is obtained, respectively. The obtained pulse energy is higher than some other reported works on MWCNTs and TIs-based passive SA [6][10][15]. The pulse energy is also very high as compared to the work in [11] where the pulse energy is at 93.18.

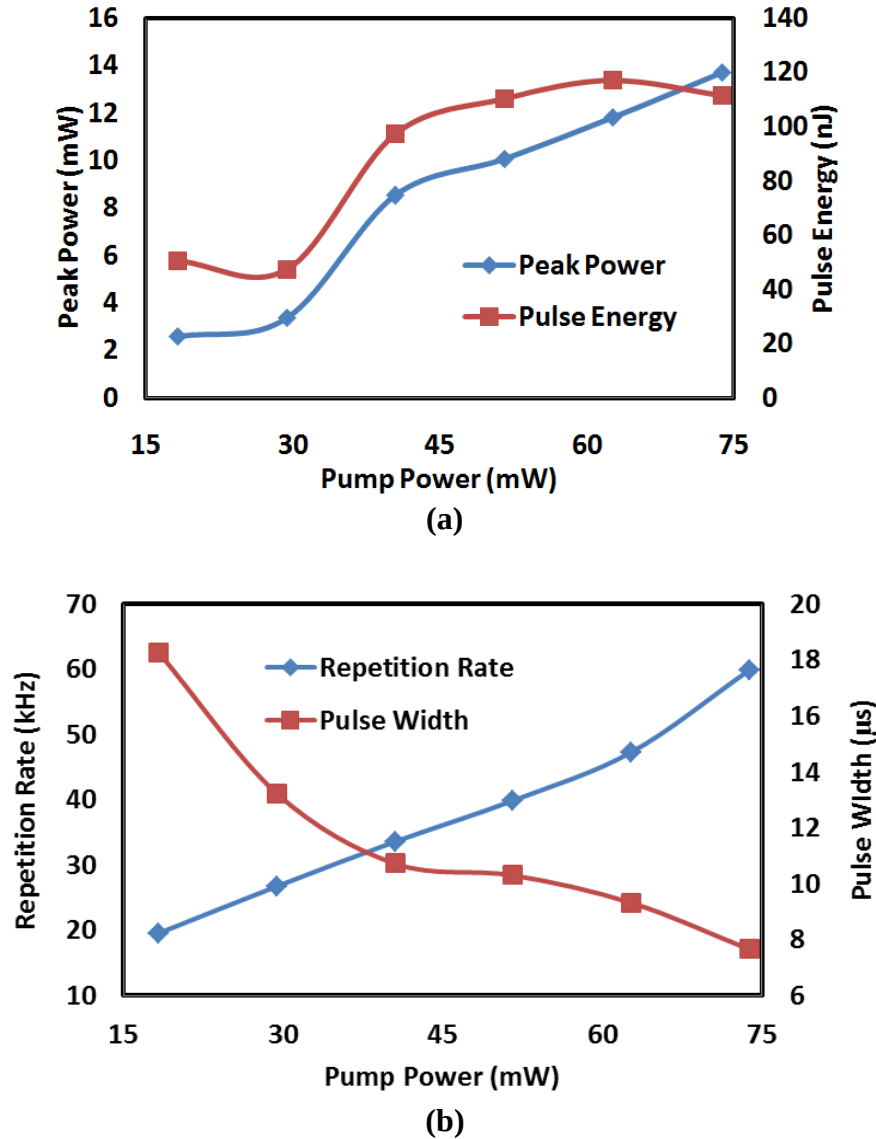


Figure 3: Input pump power versus (a) repetition rate and pulse width (b) peak power and pulse energy

The RFSA is used to measure the stability of the pulse generated. As shown in Figure 4, the peak to pedestal extinction of 60 dB is measured at 59.88 kHz, at maximum pump power, indicating high generated pulse stability. When comparing the SNR value of 47.5 dB at [11], this work produces a more stable pulsed laser generation.

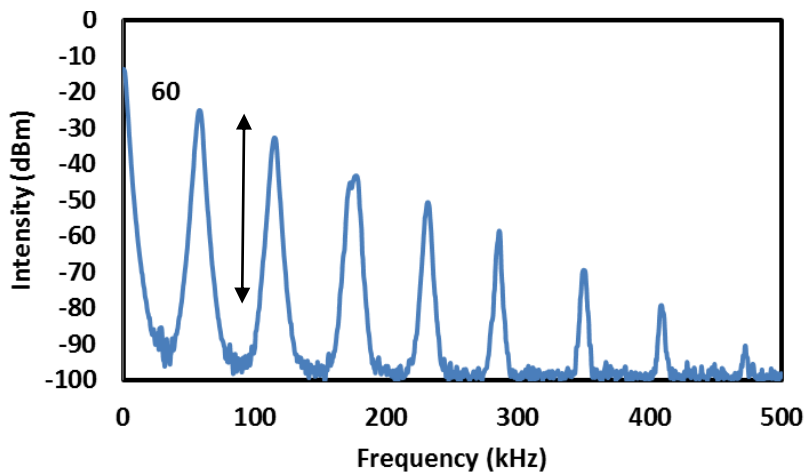


Figure 4: RFSA measurement of SNR at 73.79 mW

CONCLUSION

In summary, the proposed passively Q-switched EDFL with MWCNTs- Bi₂Te₃ slurry as a saturable absorber was successfully demonstrated. A high pulse energy of 111.85 nJ is obtained through the experiment, which is considerably higher than most of the reported work based on the same materials. This shows that the MWCNTs and TI based SA may have a potential superior saturable absorption when worked together, rather than separately.

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