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Research paper

Passively Q-Switched Pulse Erbium Doped Fiber Laser Using Antimony (III) Telluride (Sb_2Te_3) thin Film as Saturable Absorber

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Abstract

This paper demonstrates on an antimony telluride (Sb_2Te_3) thin film sandwiched between two fiber ferrule as saturable absorber for Q-switched pulsed Erbium doped fiber (EDF) laser. The saturable absorber is fabricated by dissolving Antimony (III) Telluride powder into PVA solution and dry in the ambient temperature for 48 hours. Then, 1 mm^2 x 1 mm^2 Sb_2Te_3-PVA film based saturable absorber is sandwiched in between FC/PC ferrule for Q-switched laser generation. The modulation depth of the Sb_2Te_3 is measured as 28.01% with input intensity 0.02 MW/cm^2. The developed passive saturable absorber integrated in EDF laser in ring cavity and the characterised pulse is with repetition rates of 30.21 kHz, shortest pulse width of 3.26 µs and signal-noise-ratio (SNR) of 42 dB. The maximum output pulse energy is achieved at pump power 69.5 mW with 29.5 nJ and the output power 0.89 mW.

Keywords: *Antimony Telluride; Erbium Doped Fiber; Fiber Laser; Q-Switched; Thin Film*

1. Introduction

Antimony telluride is an intermetallic compound crystallizing in a hexagonal lattice belonging to *R-3m* space group. It creates a close packed structure of the *ABCABC* type. These packets consist of single-atom layers of tellurium and antimony, which are arranged in a direction perpendicular to a triple c-axis of the crystal. In contrast to strong covalent-ionic Sb-Te bonds, relatively weak Te-Te bonds exhibit van der Waals interactions [1]. This leads to 2-dimensional (2D) material which receive great interest because of their particular physical properties such as quantum size effect. The band gap of Sb_2Te_3, ΔE~ 0.3 eV [2] allows the large range of light absorption in the possible electromagnetic spectrum, extending from the infrared (IR) to the ultraviolet (UV) [3].

Thus, Sb_2Te_3 can act as a saturable absorber for generating passive mode-locking and Q-switching. In 2013, J.Sotor *et al.* [4] are the first to present Sb_2Te_3 as saturable absorber by using mechanical exfoliation technique and transferred onto fiber connector tip. It is capable in generating optical solitons at central wavelength of 1558.6 nm with 4.75 MHz repetition rate. In 2015, J. Boguslawski *et al.* [5] has successfully proved femtosecond soliton pulse generation in an Erbium doped fiber laser (EDFL) using Sb_2Te_3 which is deposited on the side polished fiber, producing the pulse generation is 298 fs with 33.0 MHz repetition rate. Passive mode-locking generated using Sb_2Te_3 as a SA is based on evanescent field interaction. In 2017, employing the same evanescent field interaction, X. Wang *et al.* [6] are reported the passively Q-switched solid-state laser using Sb_2Te_3 as saturable absorber that was prepared through a facile hydrothermal reaction method producing single pulse energy up to 0.917 µJ at 1045.2 nm central wavelength with corresponding pulse width and repetition rate of 678 ns and 88.34 kHz, respectively.

As the aim of this study, by utilizing absorption field interaction to generate passively Q-switched pulse EDF laser, Sb_2Te_3 thin film as a SA sandwiched in between the two fiber ferrules is employed. This thin film SA sandwiched method offers easy implementation of the SA and easy generation of Q-switched pulse EDF laser, where the SA layer does not depend on its deposition length. Contradict to the evanescent field interaction based SA, the dependence of deposition length on nonlinear properties is crucial. Based on this thin film SA, a stable pulse is obtained with the pulse width of 3.26 µs at repetition rate 30.21 kHz which attracts much attention in applications in laser material processing, remote sensing, medicine, telecommunications, laser spectroscopy and precise optical metrology [7-9].

2. Sb_2Te_3 Saturable Absorber

2.1. Fabrication

The polyvinyl alcohol which is a water soluble synthetic polymer is dissolved in De-Ionized (DI) water with the aid of a magnetic stirrer at room temperature to obtain a polyvinyl alcohol solution. Antimony (III) Telluride-polyvinyl alcohol based saturable absorber are prepared by dissolving 10 mg of Antimony (III) Telluride powder (Sigma-Aldrich, -325 mesh, 99.96% trace metal basis) into 5 ml of polyvinyl alcohol solution by ultra-sonication technique for 90 minutes, followed by centrifugation for 10

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minutes at 2000 rpm to produce a stable Antimony (III) Telluride-polyvinyl alcohol suspension. Then, the Antimony (III) Telluride-polyvinyl alcohol suspension are decanted into a 14.4 cm^3 petri dish and kept in a dry cabinet at ambient temperature for 48 hours.

2.2. Measuring the modulation depth of the Sb_2Te_3

Figure 1 shows the twin detector technique to measure non-linear saturable absorption properties of the Sb_2Te_3. The pulsed seed is a mode-locked fiber laser with 16.8 MHz of repetition rate. The mode-locked fiber laser is channelled to a low amplifier before being split up by a 3 dB coupler. One output of the coupler's ports is designated as the reference and the other output port is connected directly to the Sb_2Te_3 thin film SA and both outputs are connected to a second input of the OPM. The collected data is then calculated by using Eq. (1) [10,11]

$$\alpha(I) = \frac{\alpha_s}{1+\frac{I}{I_{sat}}} + \alpha_{ns} \quad (1)$$

where α is absorption, I is the intensity, α_s is saturable absorption, α_{ns} is non-saturable absorption and I_{sat} is the saturation intensity. From Figure 2, the absorption coefficient is measured to be 28.01% with a saturation intensity at 0.02 MW/cm^2, results in an increase in transmission by 72% showing a stronger nonlinear response than graphene which acts as an ultrafast saturable absorber.

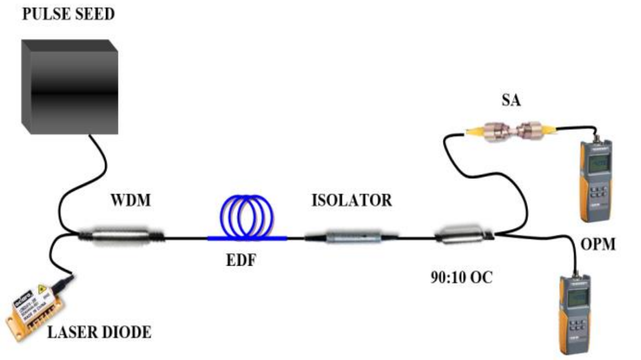

Fig. 1: The schematic diagram of twin detector method for measuring non-linear saturable absorption properties of Sb_2Te_3

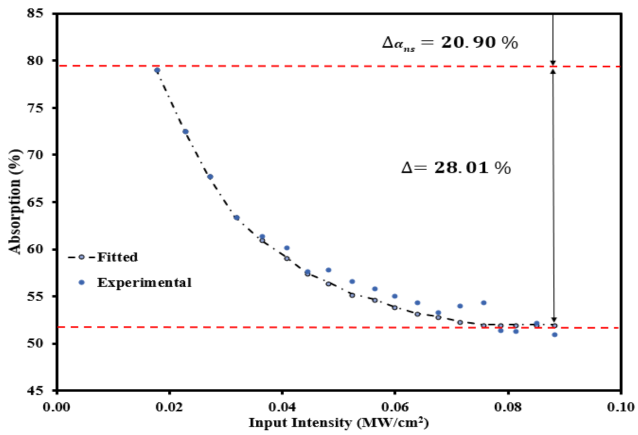

Fig. 2: The absorption spectrum of Sb_2Te_3 showing a depth of about 28.01% with non-saturable absorption is 0.02 MW/cm^2

3. Experimental setup

In this study, Sb_2Te_3 thin film as an SA sandwiched in between the two fiber ferrules utilizing absorption field interaction to generate passive Q-switched pulse EDF laser. This is employed by adapting the experimental setup of the passively Q-switched pulse EDF laser as depicted in Figure 3. The setup in the cavity consists of EDF as a gain medium, a 980/1550 nm wavelength-division multiplexer (WDM), an isolator, Sb_2Te_3 SA, polarization controller (PC), and 90/10 optical coupler. This consists of 5 m long EDF (6.43 dB/m peak absorption at 1530 nm and 5.09 dB/m absorption at 979 nm) pumped via WDM by 980 nm pump diode. The EDF is connected to the input of an isolator to ensure unidirectional oscillations in the clockwise direction within fiber ring cavity. The sandwiched Sb_2Te_3 thin film SA is inserted in between output isolator and input PC is then 10% tapping out from 90/10 optical coupler for signal analysis. The remaining 90 % of the signal is channelled back to 1550 nm WDM to complete the total ring cavity length of 16.08 m. An Anritsu MS9740A optical spectrum analyser with a 0.1 nm resolution is used to measure the output spectrum of the generated Q-switched pulse EDF laser. Analysing the pulse train properties of Q-switched pulse EDF laser make use of the Tektronix MDO3104 oscilloscope together with 5 GHz InGaAs Biased Detector, DET08CFC/M photodetector.

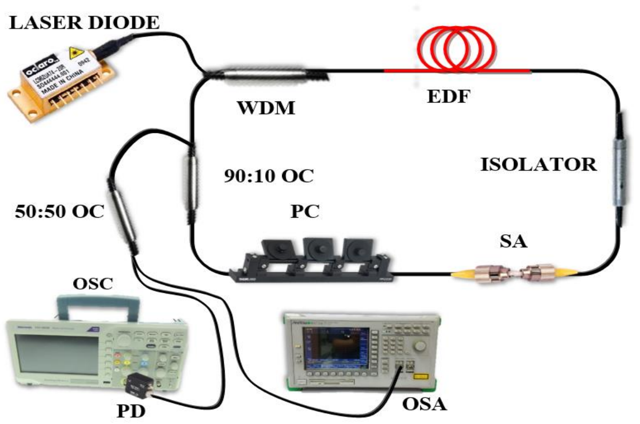

Fig. 3: Schematic diagram of Q-switched pulse EDF laser using Sb_2Te_3 thin film as SA. (LD- 980nm laser diodes, WDM-wavelength division multiplexing, EDF-erbium doped fiber, SA-saturable absorber, PC-polarization controller, 90:10 / 50:50 OC- 90:10/ 50:50 optical coupler, PD-photodetector, OSA-optical spectrum analyser, OSC-oscilloscope)

4. Results and Discussions

In this experiment, EDF laser begins the continuous wave (CW) at the pump power of 7 mW. A transition of CW to pulse regime is obtained at pump power of 18.4 mW giving the repetition rate of 13.96 kHz with pulse width of 6.86 µs. The system remains observable until the pump power reaches 69.5 mW with the operating wavelength approximately at 1560 nm and peak power 17.3 dBm, as illustrated in Figure 4. The Q-switched pulse EDF laser performance is examined at a fixed wavelength and by changing the pump power.

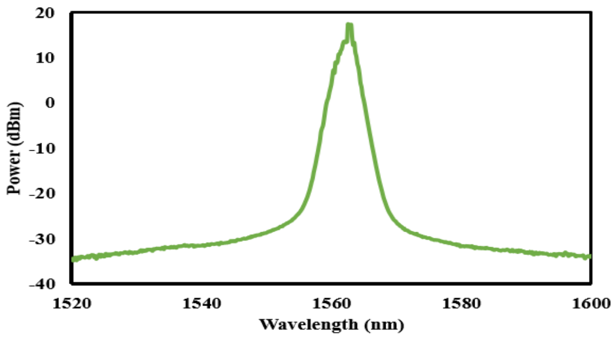

Fig. 4: The laser emission spectrum of the EDF-doped fiber approximately at 1560 nm.

Figure 5 shows the measurement of laser output in time domain by using a photodetector and an oscilloscope at pump power of 69.5 mW which gives a repetition rate of 30.21 kHz. This corresponds to a time interval of 33.10 μs between the two pulses where each pulse measures a pulse width of 3.26 μs. The intensity of the peaks is almost constant at around 0.5 V, indicating that the output is adequately stable. In Figure 6, the RF spectrum of Q-switched pulse EDF laser obtained from the oscilloscope shows the value of a fundamental frequency of 30.21 kHz at a signal to noise ratio (SNR) of 42 dB.

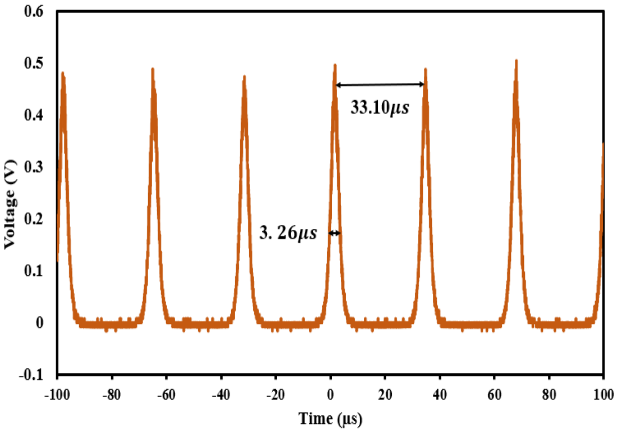

Fig. 5: Typical pulse train at 69.5mW input pumping power.

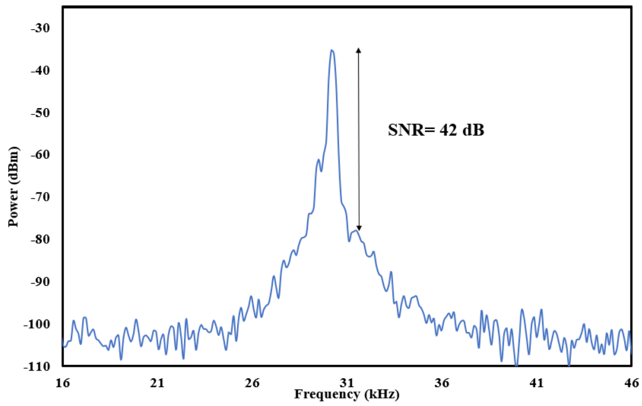

Fig. 6: RF spectrum at 69.5 mW input pumping power.

Figure 7 shows the relationship between the pulse width and repetition rate of Q-switched pulse EDF with respect to incident pump power. An increase in pump power from 18.4 mW to 69.5 mW, the pulse repetition rate increases monotonically from 13.96 kHz to 30.21 kHz while the pulse width decreases from 6.86 μs to 3.26 μs, which are the typically characteristics of Q-switching operation.

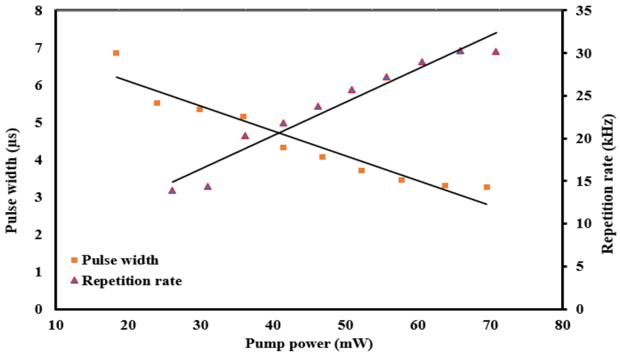

Fig. 7: Pulse width and pulse repetition rate versus pump power.

Figure 8 show the relationship of output power and pulse energy as function of pump power for Q-switched pulse EDF. The maximum output pulse energy is achieved at pump power 69.5 mW with 29.5 nJ and the output power 0.89 mW. If the pump power is increased further, the Q-switched pulse EDF state disappears. A stable Q-switched pulse EDF state can be obtained by decreasing the pump power.

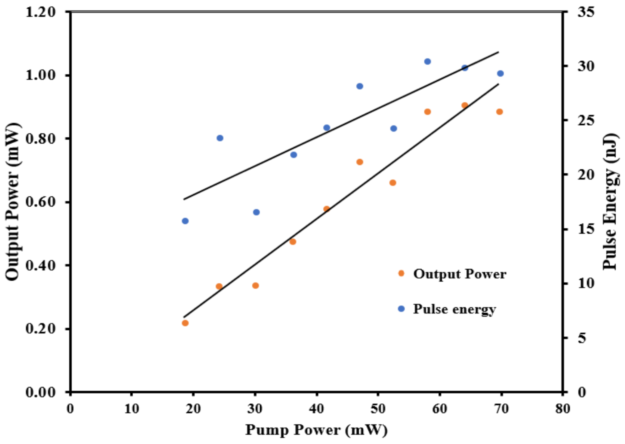

Fig. 8: Output power and pulse energy versus pump power.

In Table 1, we summarize all reported EDFL performances using thin film Sb_2Te_3 SA in comparison to our work. This thin film SA sandwiched method offers easy implementation of the SA and easy generation of Q-switched pulse EDF laser, where the SA layer does not depend on its deposition length. Contradict to the evanescent field interaction based SA, the dependence of deposition length on nonlinear properties is crucial.

Table 1: Performance comparison of EDFL between various methods of Sb_2Te_3 as SA in laser cavity

Method	Deposition method	Repetition rate	Wavelength(nm)	Pulse duration	Ref
Deposited onto fiber ferrule	Micromechanical exfoliation	4.75 MHz	1558	1.8 ps	[4]
Deposited onto fiber ferrule	Mechanical exfoliation	304.00 MHz	1558	2.2ps	[12]
Deposited on side-polished fiber	Mechanical exfoliation	22.32 MHz	1565	128 fs	[13]
Deposited on side-polished fiber	Mechanical exfoliation	34.58 MHz	1560	417 fs	[14]
Deposited on side-polished fiber	Liquid phase exfoliated	22.13 MHz	1556	449 fs	[15]
Deposited on side-polished fiber	Direct fusion technique	33.00 MHz	1564	298 fs	[5]
Deposited in microfiber	Fused tapering	94.00 MHz	1530	-	[16]
Deposited side-polished fiber	Sputtering	19.50 MHz	1065	5.9 ps	[1]

Solid state laser based Sb_2Te_3	Facile hydrothermal reaction	88.34 kHz	1045	678 ns	[6]
Sandwiched between two fiber ferrule	Thin film	30.21 kHz	1560	3.26 μs	Our work

4. Conclusions

We have successfully demonstrated passively Q-switched pulse EDF laser using thin film Sb_2Te_3 as saturable absorber sandwiched between two fiber ferrules. A stable 3.26 μs pulse operates at 1560 nm wavelength with fundamental repetition rate of 30.21 kHz is obtained. The Q-switched emission is obtained at low pump power of 18.4 mW. This result indicates that thin film Sb_2Te_3 SA indeed could be used as simple, low cost, and low insertion loss for mode-locked fiber laser or ultrafast fiber laser applications.

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References

[1] Kowalczyk M, Bogusławski J, Zybała R, Mars K, Mikuła A, Sob oń G, & Sotor J (2016), Sb_2Te_3-deposited d-shaped fiber as a saturable absorber for mode-locked yb-doped fiber lasers. *Optical Materials Express* 6, 2273-2282.
[2] Ando Y (2013), Topological insulator materials. *Journal of the Physics Society of Japan* 82, 102001.
[3] Reina A, *et al (*2008), Large area, few-layer graphene films on arbitrary substrates by chemical vapor deposition. *Nano letters* 9, 30-35.
[4] Sotor J, Sobon G, Macherzynski W, Paletko P, Grodecki K & Abramski KM (2014), Mode-locking in er-doped fiber laser based on mechanically exfoliated Sb_2Te_3 saturable absorber. *Optical Materials Express* 4, 1-6.
[5] Boguslawski J, *et al* (2014), Mode-locked er-doped fiber laser based on liquid phase exfoliated Sb_2Te_3 topological insulator. *Laser Physics*, 24 105111.
[6] Wang X, Xu J, Sun Y, Zhu Z, You Z & Tu C (2017), Near infrared passively q-switched solid-state laser based on Sb_2Te_3 topological insulator saturable absorber. *Journal of Luminescence* 192, 1-5.
[7] Sotor J, Sobon G, Macherzynski W & Abramski KM (2014), Harmonically mode-locked er-doped fiber laser based on a Sb_2Te_3 topological insulator saturable absorber. *Laser Physics Letters* 11, 055102.
[8] Steinmeyer G, Sutter DH, Gallmann L, Matuschek N & Keller U (1999), Frontiers in ultrashort pulse generation: pushing the limits in linear and nonlinear optics. *Science* 286, 1507-1512.
[9] Keller U (2003), Recent developments in compact ultrafast lasers. N*ature* 424, 831-838.
[10] Garmire E (2000), Resonant optical nonlinearities in semiconductors. *IEEE Journal of Selected Topics in Quantum Electronics* 6, 1094-1110.
[11] Ahmad H, Ruslan NE, Ismail MA, Ali ZA, Reduan SA, Lee CSJ & Harun SW (2016), Silver nanoparticle-film based saturable absorber for passively q-switched erbium-doped fiber laser (EDFL) in ring cavity configuration. *Laser Physics* 26, 095103.
[12] Sotor J, Sobon G, Macherzynski W & Abramski KM (2014), Harmonically mode-locked er-doped fiber laser based on a Sb_2Te_3 topological insulator saturable absorber. *Laser Physics Letter* 11, 055102.
[13] Sotor J, Sobon G & Abramski KM (2014), Sub-130 fs mode-locked er-doped fiber laser based on topological insulator. *Optics Express* 22, 13244-13249.
[14] Sotor J, Sobon G, Grodecki K & Abramski KM (2014), Mode-locked erbium-doped fiber laser based on evanescent field interaction with Sb_2Te_3 topological insulator. *Applied Physics Letters* 104, 251112.
[15] Boguslawski J, *et al* (2014), Mode-locked er-doped fiber laser based on liquid phase exfoliated Sb_2Te_3 topological insulator. *Laser Physics* 24, 105111.
[16] Liu W, *et al* (2015), Generation of dark solitons in erbium-doped fiber lasers based Sb_2Te_3 saturable absorbers. *Optics Express* 23, 26023-26031.