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Passively Mode-Locked Fiber Laser by Utilizing TTG film on a D-Shaped Fiber as a Saturable Absorber

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Abstract: In this paper, we propose a mode-locked fiber laser by utilizing single layer Trivial Transfer Graphene film (TTGF) as a saturable absorber (SA). The SA was deposited on the top of a side-polished D-shaped fiber. The SA was then integrated in the ring cavity configuration, with a clockwise light propagation. Three distinctive 2 m erbium doped fibers (EDFs) those are Metro-Gain15 EDF, Iso-Gain6 EDF and Iso-Gain12 EDF were used as gain media, interchangeable in the experiment. From the results, the Metro-Gain15 EDF gives the most proficient gain medium on generating a passively mode-locked fiber laser. The Metro-Gain15 Erbium doped mode-locked Laser was successfully producing ultrashort pulse with 8 nm spectral band-width, 13 MHz of repetition rate and 915 fs pulse duration. These outcomes demonstrated that TTGF deposited on the D-shaped fiber is a suitable component as an SA to produce a stable output passively mode-locked fiber laser for many optical fiber applications.

Keyword: Mode-Locked fiber laser, Single Layer Graphene, Erbium Doped Fiber and Ultrashort pulse.

1. Introduction

Ultrafast lasers can be useful especially in the field of optical fiber communications [1], ultrafast probing [2], nonlinear microscopy [3] optical tomography [4], optical metrology [5, 6], frequency chain generation [7], optical atomic clocks [8] and high precision spectroscopy [9]. Ultrafast laser through the generation of optical mode-locking system has become an interesting topic in on-going research due to its ability to generate ultrashort pulses in a very small focusing waveguide named as a single mode optical fiber [10]. Few techniques in generating the ultrafast laser are by using semiconductor saturable absorber mirror (SESAM) [11], nonlinear polarization rotation technique (NPR) [12], figure of wight design [13] and recently by using saturable absorber materials [14].

A passively mode-locked Erbium-doped fiber laser is capable of generating pulses of light with extremely short duration in the order of picosecond to femtosecond pulse duration. The pulse producing mechanism is initiated from noise filtering process by incorporating saturable absorber (SA) within the laser cavity [15]. Recently, graphene, a single layer atom of carbon, has been a great candidate to be applied as the saturable absorber due to its desirable optical characteristic such as ultrafast recovery time [16]. Graphene have a low band gap energy which leads to a higher possibility of the emission to be absorbed at low power and transmitted at higher energy level [17]. This is the advantage of using the saturable absorber material which can function as a device that absorbs certain frequency range and allows other frequency having a higher energy level to pass through.

To date, many designs of erbium-doped fiber amplifiers (EDFAs) have been proposed using different methods of fabricating the saturable absorber. A few of the methods are by sandwiching the saturable absorber materials in between the fiber ferrules [18], however this technique has few disadvantages such as the graphene SA is easy to burn and creating high loss point in the cavity. Other technique is by using a tapered fiber coated with saturable absorber materials such as graphene, carbon

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nanotubes and molybdenum disulphide (MSO2) to generate the mode-locking operation in the cavity [19-22]. In this paper, we have reported and demonstrated a mode-locked fiber laser design by using a single layer graphene coated on a D-shaped fiber to function as the saturable absorber. Comparison of mode-locked fiber laser performances was then observed by using a different types of fiber gain medium such as Metro-Gain15 Erbium doped fiber (M15-EDF), Iso-Gain12 EDF (I12-EDF) and Iso-Gain6 EDF (I6-EDF).

2. Experimental setup

Fig. 1 shows the experimental configuration for the proposed passively mode-locked fiber laser design by using the D-shaped fiber as the saturable absorber. The gain medium used was a 2 m Metrogain-15 erbium doped fiber (EDF) with an absorption coefficient of 20 dB per meter at 1530 nm wavelength. The emission of light starts from the amplified spontaneous emission (ASE) once the EDF being pumped by a 100 mW, 980 nm laser source. The connection of the EDF and the 980 nm laser source was made through a 980/1550 nm wavelength division multiplexer (WDM).

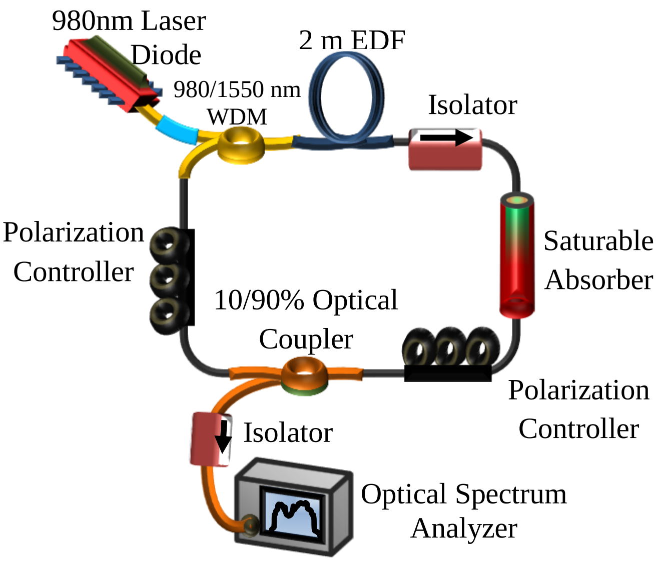

Fig. 1 Experimental setup of passively mode-locked fiber laser by using D-shaped fiber.

The ASE created in the EDF was then propagating in forward direction following the direction of the isolator, inserted after the EDF, before being connected to the D-shaped optical fiber (DSOF). The DSOF used in the experiment is a ready to use waveguide which has been polished on the side of the fiber which has been purchased from The Phoenix Photonics Company. The saturable absorber was fabricated by affixing the single layer graphene on the top of the DSOF. The first step to transfer the single layer graphene was by dipping it to the deionized water. After the single layer graphene was floating, the transferring process was carefully done by placing the substrate on the surface of the DSOF by using small tweezers for better handling. The insertion loss of the D-shaped fiber and the TTG was about 5 dB. The output from the SA was then connected to a 90/10 optical coupler via a polarization controller (PC). The 90 % output of the coupler was connected back to the 1550 nm of the WDM port, as the input. In addition, 10 % port was being used as the output source to be analyzed temporally and spatially by the optical devices.

The spectral measurement was done by using an optical spectrum analyzer (OSA) with a 0.02 nm resolution. Meanwhile, the temporal measurement was done by using a 10 GHz of oscilloscope with 3.5 GHz bandwidth of photodetector (PD).

The oscillating light was propagating in a unidirectional way, towards the clock wise direction, assisted by the isolator incorporated inside the cavity. This is crucial to exclude the back reflection from disturbing the stability of the mode-locked fiber laser. The 10 % output was then connected to another isolator, before connected to the analyzer, for spectra and pulse analyses. For comparison purposes the 2 m M15-EDF was then replaced with the 2 m I12-EDF (with absorption coefficient of 17 dB per meter) and I6-EDF (with absorption coefficient of 7.2 dB per meter) interchangeable for the output performance observations.

3. Results and discussion

Fig. 2 shows the optical output power spectra of the ASE for three different fibers, which are M15-EDF, I12-EDF and I6-EDF, observed by using the optical spectrum analyzer. It can be seen from the output spectrum, the highest output power of the spectra comes from the M15-EDF with the maximum optical output power at -31 dBm, followed by I12-EDF and I6-EDF at -45 dBm and -63 dBm, respectively. The maximum emission is coming from the M15-EDF due to the highest Erbium dopant concentration that the M15-EDF has, compared with the other two fibers. This leads to the highest emission of ASE coming from the M15-EDF with the output difference of about 14 dB compared to I12-EDF, and about 32 dB compared with the I6-EDF.

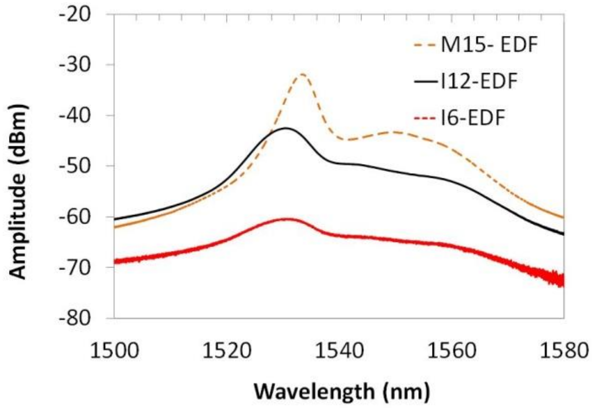

Fig. 2 Optical output spectra of the amplified spontaneous smission (ASE) for three different fibers.

Fig. 3 shows the mode-locked spectra for three different fibers, which are M15-EDF, I12-EDF and I6-EDF, measured by the optical spectrum analyzer. As can be depicted from the spectral configuration, the I6-EDF only gave an output lasing without producing the mode-locked output, centered at 1530 nm due to its short length of fiber, which having a low concentration of Erbium ion. This subsequently leads to failure of passing the threshold state of mode-locked lasing.The other two fibers, I12 and M15-EDF were successfully producing a mode-locked spectra with a slightly different pattern from one to another with center wavelengths of about 1560 nm each. The widest mode-locked 3dB bandwidth is from the M15-EDF due to the highest Erbium dopant concentration to compare of the other two fibers. The higher concentration of Erbium dopant leads to the higher amount of light emission in this region. The mode-locked 3 dB bandwidth is about 8 nm for M15-EDF and about 6 nm for I12-EDF.

Fig.4 shows the repetition rate for the mode-locked outputs of M15-EDF and I12-EDF, measured by the oscilloscope. Both gain media give about 13 MHz repetition rate. The 13 MHz repetition rate of the mode-locked output is perfectly matched with the total amount of cavity length which is about 15.6 m for two different types of EDF.

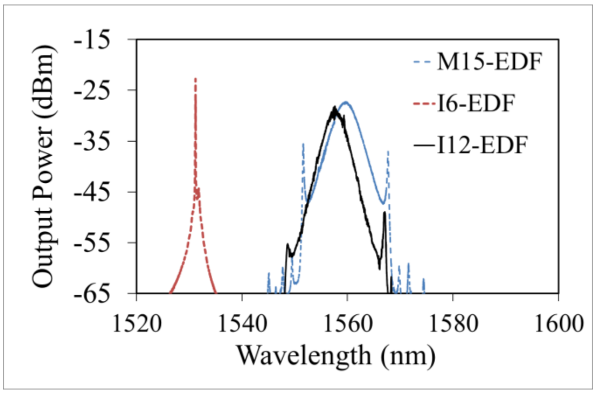

Fig. 3 The Output spectra for Passively Mode-Locked fiber laser by using M15, I6 and I12-EDF.

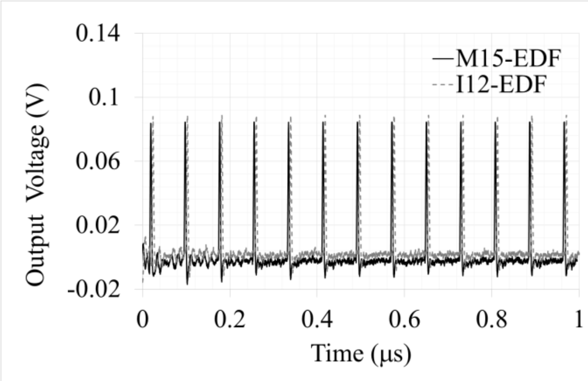

Fig. 4 The repetition rate of the Mode-Locked fiber laser by using M15, and I12-EDF.

Fig. 5 shows the pulsewidth measurements for the mode-locked output taken by using the autocorrelator (Alnair: HAC-200 series) for M15-EDF and I12-EDF. The pulsewidth measurements were taken from the 13 MHz of repetition rate mode-locked output by using M15-EDF for (a) and I12-EDF for (b) as the gain medium. The pulsewidths measured are 915 fs and 934 fs for M15-EDF and I12-EDF, respectively. The data was taken from an auto correlator with sech2 pulse shape approximation. The ultra-short pulse widths indicate stable pulses operation. By considering the output performance of the three fibers used, the mode-locked by using M15-EDF shows the best results to compare of with I12-EDF and I6-EDF, especially on giving the narrowest pulse width of 915 fs duration.

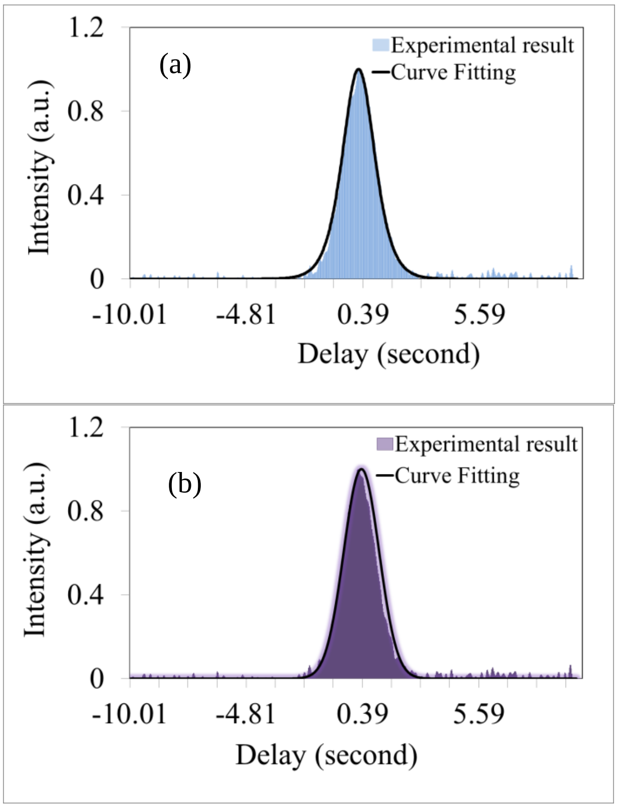

Fig. 5 The pulsewidth of the mode-locked fiber laser by using (a) M15-EDF and (b) I12-EDF.

Fig. 6 shows the stability performance by observing the spectral evolution of the output power for the mode-locked fiber laser by using M15-EDF, The output changes was observed every 5 minutes and the data was recorded as depicted in Fig. 6. The slight amount of changes of the output showing a stable pulses operation for the case with a 100 mW of pump power used.

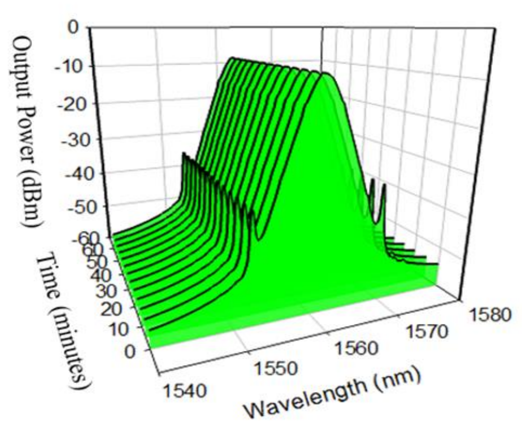

Fig. 6 Stability performance for the proposed mode-locked fiber laser output.

4. Conclusion

We have successfully proposed and demonstrated a passively mode-locked fiber laser by using D-shaped fiber together with a TTG to work as the saturable absorber. The proposed design capable of producing a stable pulse duration with 13 MHz of output repetition rate. The maximum value of average output power obtained was 4 mW at 100 mW of pump power, with the pulse durations of 915 fs and 934 fs by using M15-EDF and I12-EDF respectively. The mode-locked 3 dB bandwidth is about 8 nm for M15-EDF and about 6 nm for I12-EDF. The proposed setup was really simple, stable, reliable and useful for various kinds of applications.

Acknowledgements

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