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Graphene Nanoplatelets (GnP)-PVA Based Passive Saturable Absorber

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Abstract

We demonstrate a passive Q-switched at 1.5 μm region by integrating a graphene nanoplatelets (GnPs) embed in Polyvinyl Alcohol (PVA). The GnPs was dispersed with the aid of surfactant and mixed with PVA by solution casting aroach and then dried at ambient temperature to develop a GnPs-PVA film. The integration of the passive Q-switcher is by attaching a small portion of the developed GnPs-PVA film at the end of fiber ferrule in the laser cavity with ring configuration to generate pulse laser. The experimental works show that the proposed GnPs-PVA film based passive Q–switcher operates at input pump power ranges from 39 mW to 148 mW with central wavelength of 1530.76 nm. We observe the tunable repetition rate from 33 kHz to 91.5 kHz with the shortest pulse width of 2.42 μs. The laser produce maximum instantaneous output peak power and pulse energy of 1.2 mW and 5.9 nJ, with the recorded signal to noise ratio of 28 dB.

Keywords: *graphene nanoplatelets, saturable absorber, Q-switched laser*

1. Introduction

Erbium-doped fiber lasers (EDFLs) which works in Q-switched regime provide a light sources with potential alication in optical communication, laser range finding and material processing [1-3]. There are two common aroach to generate pulse fiber laser, active and passive Q-switching, with the latter provide several advantages such as low-cost, compact and simple circuitry. Basically, the passive saturable absorber (SA) is to reside light dependent intensity material in the laser cavity which enables the high-intensity components of an optical pulse to pass through, while the lower intensity components was blocked depends on the relaxation time of the materials. The compatibility of the material to act as passive saturable absorber is due to their intrinsic properties such as high nonlinearities, ultrafast carrier relaxation and broadband operating wavelength [4,5]. Different types of SA has been proposed and demonstrated for Q-switched fiber laser including carbon nanotubes (CNT), semiconductor saturable absorber mirrors (SESAM) and 2D based materials such as graphene, Topological insulators (Tis), and transition metal sulphides [6-8]. The distinct advantage of graphene based SA over other materials is its extremely broad operation bandwidth.

Graphene is a flat monolayer of carbon atom tightly packed a into two dimensional (2-D) honeycomb lattice. It can be stacked to form 3D graphite, rolled to form 1D nanotube and wraed to form 0D fullerenes [9,10]. Nair et al. [11] has demonstrated that despite being only one atom thick, graphene absorb a significant ($\pi\alpha$=2.3%) fraction of incident white light due to its unique electronic structure. The optical absorption is also found to be frequency independent and proportional to the number of layers [12,13]. Currently, graphene based SA for Q-switched pulse laser was demonstrated using CVD aroach, graphene nanocomposites, graphene oxide and reduce graphene oxide [14-19].

The graphene chemical vapor deposition (CVD) aroach for Q-switched pulse laser has been demonstrated in [14] by sandwiching a thin graphene film produced via CVD between two FC fiber connectors. They reported to produce repetition rate between 34.72 kHz to 53.2 kHz with the shortest pulse with of 3.2 μs, within input pump power from 57.2 mW to 74.23 mW.

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Popa et al [15] demonstrated liquid phase exfoliation route to fabricate graphene-PVA nanocomposites based passive saturable absorber with tunable filter to tune the central wavelength. The tuneable central wavelength is from 1522nm to 1555 nm with threshold of pump power of 74 mW. Meanwhile, Ahmad et al [16] fabricate a graphene based SA by optical deposition of graphene- N-methyl Pyrrolidone (NMP) suspension injected with 11 dBm of 1550 nm laser source. They demonstrated tunable wavelength from 1547.66 nm to 1557.66 nm using fiber Bragg grating as tuning element's with threshold input pump power of 39.8 mW. A wider tunable range of 50 nm was reported in [17] by optical deposition of graphene-Dimethylformamide (DMF) suspension. The SA works within input power from 33 mW to 61 mW and produced maximum repetition rate of 29.05 kHz with shortest pulse width of 4.6 μs. Yap et al, [18] reported a simple aroach to fabricate Graphene oxide (GO) based SA by diing a fiber ferrule end face onto the GO suspension and integrated in Erbium doped fiber laser in ring cavity. The reported threshold input pump power for pulse laser generation is 9.5 mW with range of repetition and shortest pulse width of 16.0 to 57.0 kHz and 3.90 μs, respectively. A higher threshold of 120 mW was reported for reduced graphene oxide (rGO) based SA as reported in [19], in the expense of 1.85 μs temporal pulse width and 125 nJ of pulse energy.

Graphene nanoplatelets (GnPs) is the derivative of graphene, with 3−10 stacks of graphene [20], while graphene with number of layer higher than 10 is define as graphite. In comparison to Graphene Oxide (GO), the quality of GnPs is same as graphene due to the similarity configuration of pristine basal plane with improve optical, electrical, and mechanical properties [20]. GnPs has been used as filler to improve the thermal and mechanical properties of composites material [21] and low cost fuel cell base material [22], but the alication on optical properties is not intensively reported compared to graphene and graphene oxide. One of the interesting points is that the GnPs film consists of multiple layer of graphene and rather than control the layer numbers by overlaing two to three films produced by CVD as demonstrated by Sun [23].

2. Research Method

Graphene nanoplatelets (GnPs) powder was obtained from Low Dimensional Material Research Center (LDMRC) University of Malaya. The dispersion of GnPs was achieved by adding 40 mg of GnP nano powder in 40 ml of 1% of sodium dodecyl sulfate (SDS) in de-ionized (DI) water, and then sonicated for one hour at 50 W. The solution was then centrifuged at 1000 rpm to remove large particles of undispersed GnPs to obtain dispersed suspension that stable for weeks. The host polymer was prepared by dissolving 1g of polyvinyl alcohol (PVA) (Mw = 89 x 10^3 g/Mol) (Sigma Aldrich) in 120 ml of deionized water. GnP-PVA composite was prepared by adding the dispersed GnPs suspension with PVA solution in one to one ratio. The homogeneous GnPs-PVA composites were obtained by ultrasonic process for one hour. After that, the GnPs-PVA suspension were poured on a petri dish and left to dry at room temperature for about 48 hours to developed GnPs-PVA film with thickness around 50 μm. The morphology of the developed film then was investigated using Field-Emission Scanning Electron Microscope (FESEM) (Hitachi SU8020) as shown in Figure 1. The captured image showed a thoroughly mixed of Gnp in PVA polymer with smooth surface and low aggregation. A small portion of the developed GnPs-PVA film was attached to the end of fiber ferrule and then integrated in the laser cavity assisted by fiber connector. The schematic of the experimental setup of the pulse laser with Erbium doped fiber (EDF) as gain medium as seen in Figure 2. It consists of a 1 m long Erbium doped fiber, a 980/1550 nm wavelength division multiplexer (WDM), an isolator, a GnPs-PVA based SA and 95/5 output coupler in a ring configuration. The EDF characterized by core and cladding diameters of 8 μm and 125 μm, a numerical aperture (NA) of 0.16 and Erbium ion absorptions of 45 dB/m and 80 dB/m at 980 nm and 1530 nm, respectively. It is pumped by a 980 nm laser diode via WDM. An isolator is incorporated in the laser cavity to ensure unidirectional propagation of the oscillating laser. The output of the laser is taed from the cavity through a 95/5 coupler while keeping 95% of the light to oscillate in the ring cavity. The remaining 5% of the oscillating light was taed and connected to 3 dB coupler for simultaneous observation of the optical spectrum analyzer (OSA)/oscilloscope (OSC) and optical power meter (OPM)/Radio frequency spectrum analyzer (RFSA).The optical spectrum analyzer (OSA) is used to record the spectrum of the EDFL with a spectral resolution of 0.05 nm, whereas the oscilloscope is used to observe the output pulse train via a 460 kHz bandwidth photo-detector

(Thor lab, PDA50B-EC). The average output power was measured using an optical power meter (OPM) and signal to noise ratio was recorded using a radio frequency spectrum analyzer (RFSA).

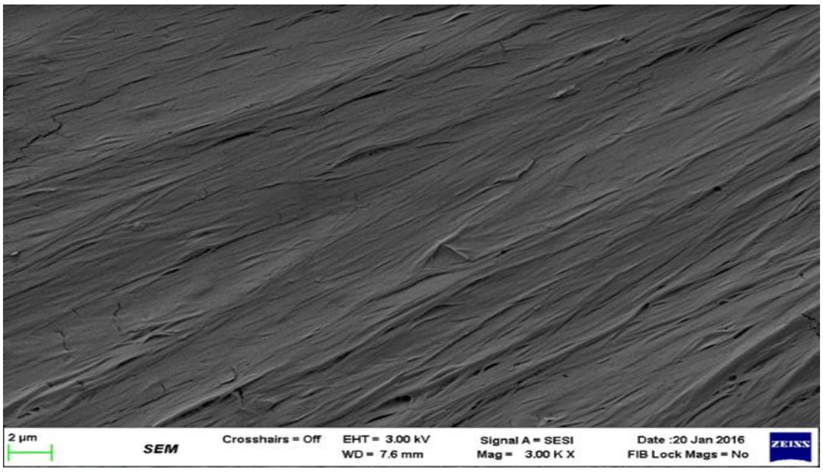

Figure 1. Graphene Nanoplatelets (GnP)-PVA

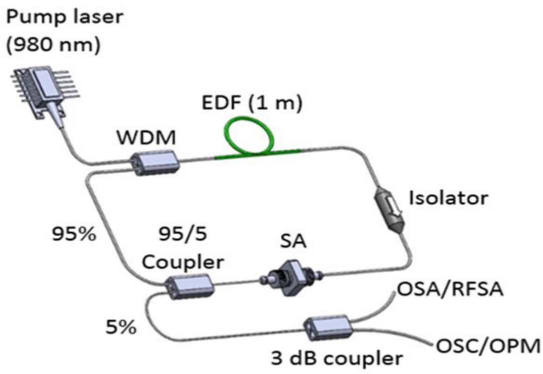

Figure 2. Integration of GnP-PVA film based SA in fiber laser in ring cavity

3. Results and Analysis

The experimental results revealed the central operating wavelength for continuous wave lasing is at 1559.19 nm. The integration of GnPs-PVA film based saturable absorber (SA) in the laser cavity produced Q-switched pulsed laser with threshold input pump power of 39 mW. The generated Q-switched pulse laser shifted the central wavelength to 1530.76 nm with 3-dB spectral broadening around 1 nm due to loss induced by the passive saturable absorber as shown in Figure 3. The eution of the time domain within input pump range from 39 mW to 148 mW. Beyond 148 mW, there is no pulse generated due to the GnP-PVA SA is fully saturated or dislocated due to induced heat and pressure at high input pump power. There is no pulse laser observed when the GnPs-PVA film based SA was removed from laser cavity, confirming the sole effect of GnP-PVA SA for pulse laser generation. Furthermore, the pulse train of the generated pulse was recorded using the oscilloscope for the range of input pump power from 39 mW to 148 mW. Figure 4 (a) and (b) shows the recorded pulse train at threshold and the maximum input pump power, with respective pulse width. The generated pulse train shows a stable pulse train with no peak fluctuation at threshold input pump power and at maximum input pump power.

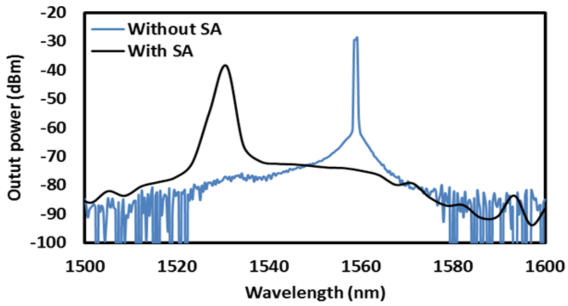

Figure 3. OSA trace without SA and with SA

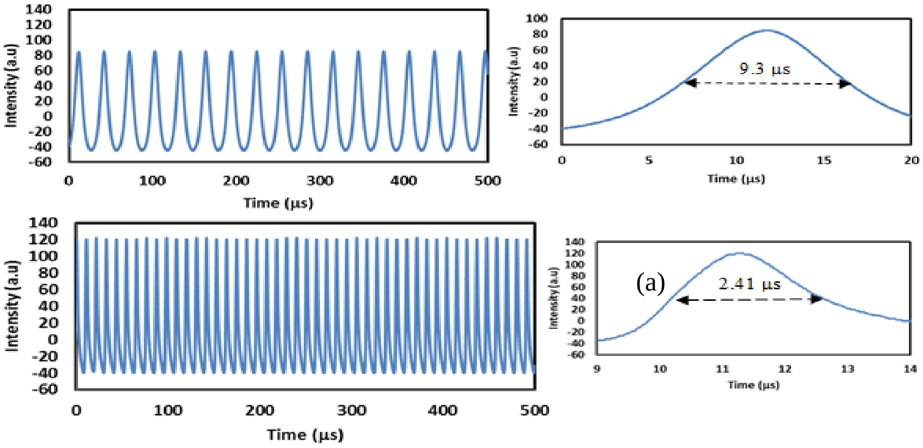

Figure 4. (a) At threshold pump power of 39.1 mW with pulse train of 32.2 kHz and single pulse envelope with pulse width of 9.3 µs (b) At maximum pump power of 148.7 mW with pulse train of 91 kHz and single pulse envelope with pulse width of 2.41µs

(b)

Figure 5 shows the measured generated pulse train with the respective pulse width in the function of input pump power. The repetition rate increase from 33 kHz to 91.5 kHz when the input pump power tuned from 39 mW to 148 mW. The pulse width shows the decreasing trend from 9.3 µs to 2.41 µs with the increasing input pump power. This observation corresponds to the decreasing pulse width with the increasing repetition rates which commonly observed in passively Q-switched lasers [24]. The output average power (P_{av}) was measured with an optical power meter. The pulse width (Δt_p) and the pulse repetition rate (*f*) were observed using digital oscilloscope via photo-detector. From the recorded data, pulse energy and instantaneous peak power is calculated using formula of E= P_{av}/f and $_{eak}$=E/Δt_p. Figure 6 shows the calculated peak power and pulse energy as function of pump power. The calculated peak power and pulse energy shows an increasing trend for input pump power varied from 39 mW to 104 mW. The maximum peak power and pulse energy is 1.2 mW and 5.9 nJ, respectively at input pump power of 104 mW. Beyond 104 mW input pump power, the peak power and pulse energy is toward decreasing trends due to decreasing of the recorded average output power. Figure 7 shows the stability of the generated pulse using Radio frequency spectrum analyzer (RFSA) with the span of 500 kHz. The first beat note is around 28 dB and the generated pulse laser propagates with high stability as shown with the stable peak of the recorded RFSA.

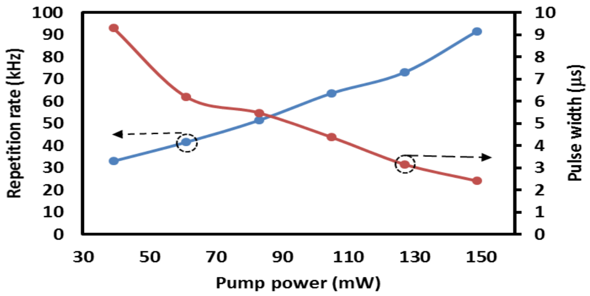

Figure 5. Repetition rate and pulse width as function of pump power

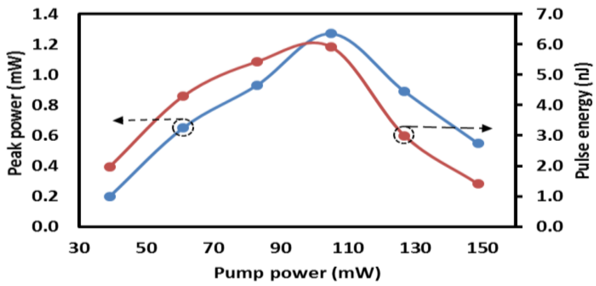

Figure 6. Peak power and pulse energy as function of pump power

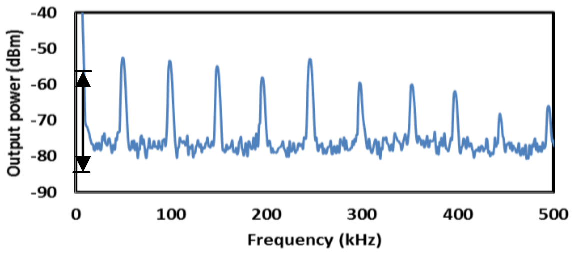

Figure 7. RFSA measurement for repetition rate of 50 kHz with 500 kHz span, the first beat note of 28 dB

4. Conclusion

Graphene nanoplatelets-PVA (GnP-PVA) film based passive Q-switcher was successfully demonstrated at 1.5 µm region. The solution casting aroach at room temperature in fabricating GnPs-PVA based saturable absorber is simple, low cost and offer a scalable production of the SA. Experimental works shows the capability of the developed GnPs-PVA film to act as passive Q-switcher when resides in Erbium doped fiber laser (EDFL). The film able to operates to the maximum input pump power of 148 mW, maximum repetition rates of 91.5 kHz and shortest pulse width of 2.42 µs. The calculated output peak power and pulse energy of 1.2 mW and 5.9 nJ, can be use in meteorology and material processing.

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