

## Graphene Nanoplatelets (GnP)-PVA Based Passive Saturable Absorber

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### Abstract

A passive Q-switched pulsed laser at 1.5  $\mu\text{m}$  region incorporating graphene nanoplatelets (GnPs) embedded in Polyvinyl Alcohol (PVA) is demonstrated. A surfactant is used to aid the dispersion of the GnPs before it is mixed with PVA to develop a GnPs-PVA film based SA. The SA is integrated into the laser cavity by attaching a cut of the GnPs-PVA film in between two fiber ferrule of the laser ring cavity. The proposed GnPs-PVA film based passive Q-switched laser was able to operate as the input pump power was increased from 39 mW up to a maximum of 148 mW before diminishing. The laser obtained operated with a central wavelength of 1530.76 nm. Repetition rates were obtained at 33 kHz to 91.5 kHz, throughout the tunable input pump power with the shortest pulse width of 2.42  $\mu\text{s}$ . Maximum attainable peak power and pulse energy of 1.2 mW and 5.9 nJ, respectively, was recorded, accompanied by a signal to noise ratio (SNR) of 28 dB.

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

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### 1. Introduction

Erbium-doped fiber lasers (EDFLs) which works in Q-switched regime provide a light sources with potential application in optical communication, laser range finding and material processing [1-3]. There are two common approach 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 material's level of ability when acting as a saturable absorber is highly dependable on their 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 Topological insulators (Tis), graphene, and transition metal disulphides [6-8]. The distinct advantage of graphene based SA over other materials is its extremely broad operation bandwidth.

Graphite is when multiples of hexagon sheets stacked onto each other. Removing one of the hexagon sheets will results in a layer of graphite sheet called graphene [9-10]. The one atom thick material was proven to absorb a high fraction of incident white light [11] which is highly attributed to its unique electronic properties. Since graphene can be stacked to form graphites, the optical properties of it also changes with the changing layers [12-13] which makes it even more versatile and unique. Currently, graphene based SA for Q-switched pulse laser was demonstrated using CVD approach, graphene nanocomposites, graphene oxide and reduce graphene oxide [14-19].

The graphene chemical vapor deposition (CVD) approach for Q-switched pulse laser has been demonstrated in [14] by placing a graphene based thin film which is produced via CVD between two fiber connectors. They reported to produce repetition rate between 34.72 kHz to 53.2 kHz with the shortest pulse with of 3.2  $\mu\text{s}$ , within input pump power from 57.2 mW to

74.23 mW. 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  $\mu$ s. Yap et al, [18] reported a simple approach to fabricate Graphene oxide (GO) based SA by doing 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  $\mu$ s, 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  $\mu$ s 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 application 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 large particles of GnPs in the suspension are taken away by centrifugation at 1000 rpm. The resulted dispersed suspension was added into a PVA solution in one-to-one ratio. The PVA solution was prepared separately at first, by dissolving 1g of polyvinyl alcohol (PVA) ( $M_w = 89 \times 10^3$  g/Mol) (Sigma Aldrich) in 120 ml of DI water. The homogeneous GnPs-PVA composites were obtained by a one hour ultrasonic process. After that, the GnPs-PVA suspension were poured on a petri dish where it is left at room temperature for 48 hours to develop a GnPs-PVA film with a measured thickness of around 50  $\mu$ m. 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 GnPs 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 experimental setup of the pulsed laser with the Erbium doped fiber (EDF) as gain medium is illustrated as seen in Figure 2. The core and cladding diameter of the EDF is 8  $\mu$ m and 125  $\mu$ m, respectively, with a numerical aperture (NA) of 0.16. At 980 nm and 1530 nm, the rate of ion absorptions is at 45 dB/m and 80 dB.m, respectively. As shown in the figure, the laser cavity is pumped by a 980 nm laser diode via a 980/1550 nm wavelength division multiplexer (WDM), an Erbium doped fiber with the length of 1 m, an isolator to prevent any backflow of the light oscillation during laser generation, the newly fabricated GnPs-PVA based thin film, and a 95/5 output coupler. The output coupler is needed to tap out 5% of the output for characterization purposes through a 3dB coupler. The components were arranged in a ring configuration to allow for continuous light oscillations. An optical spectrum analyser (OSA) is used to observe the laser's spectrum with 0.05 nm spectral resolution while an oscilloscope is used to measure the laser's repetition rates and pulse widths. The optical power meter (OPM) and the radio frequency spectrum analyser (RFSA) is used to measure the output power and signal-to-noise ratio (SNR) of the output laser, respectively.

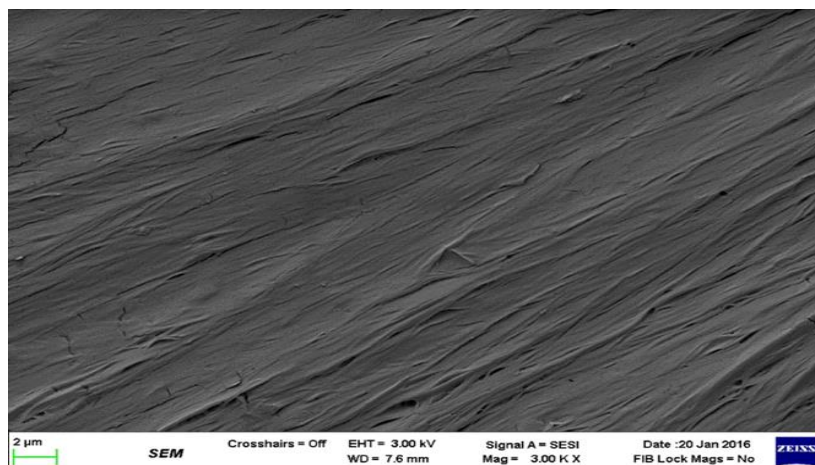


Figure 1. Graphene Nanoplatelets (GnP)-PVA

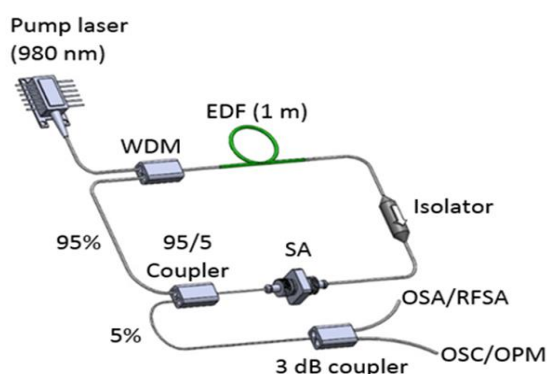


Figure 2. Integration of GnP-PVA film based SA in fiber laser in ring cavity

### 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 evolution 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.

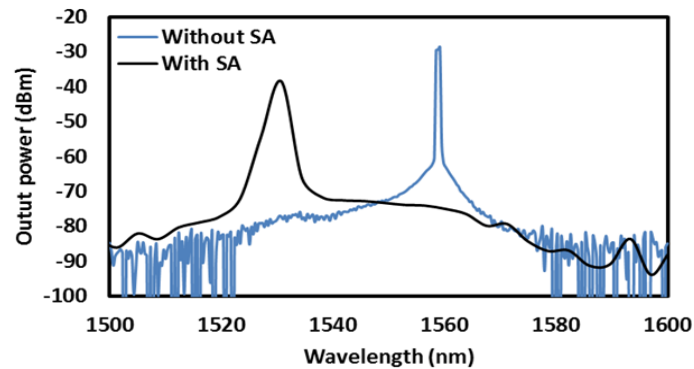


Figure 3. OSA trace without SA and with SA

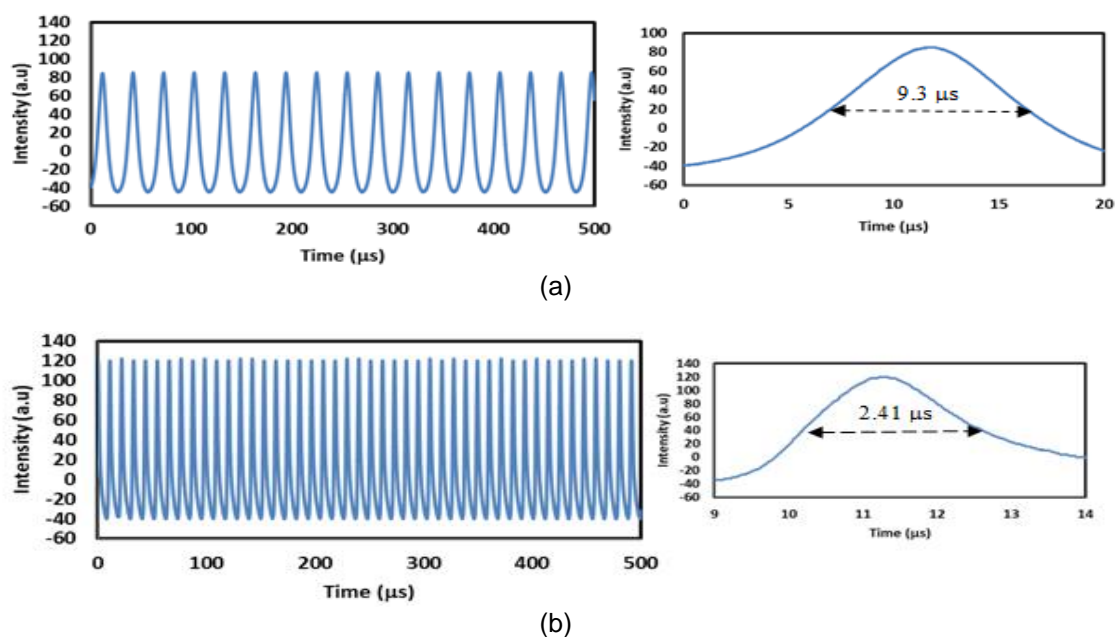


Figure 4. (a) At threshold pump power of 39.1 mW with pulse train of 32.2 kHz and single pulse envelope with pulse width of 9.3  $\mu\text{s}$  (b) At maximum pump power of 148.7 mW with pulse train of 91 kHz and single pulse envelope with pulse width of 2.41  $\mu\text{s}$

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  $\mu\text{s}$  to 2.41  $\mu\text{s}$  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 ( $\Delta t_p$ ) 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  $e_{ak} = E/\Delta t_p$ . 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.

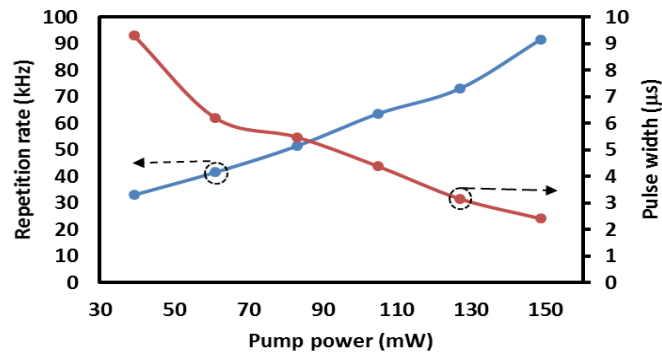


Figure 5. Repetition rate and pulse width as function of pump power

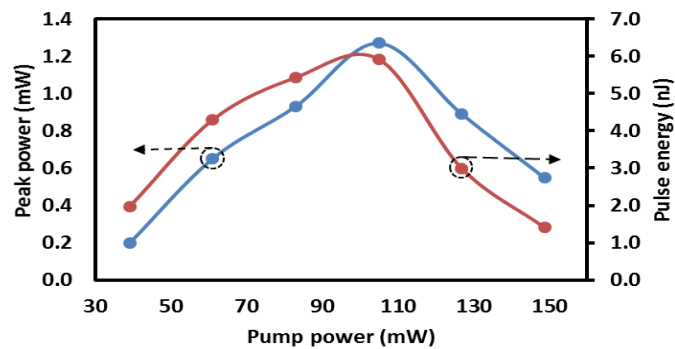


Figure 6. Peak power and pulse energy as function of pump power

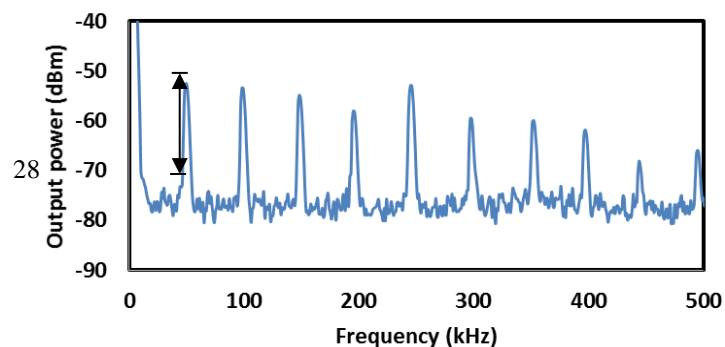


Figure 7. RFSA measurement for repetition rate of 50 kHz with 500 kHz span, the first beat note of 28 dB

#### 4. Conclusion

Graphene nanoplatelets-PVA (GnP-PVA) film based passive Q-switcher was successfully demonstrated at 1.5  $\mu\text{m}$  region. The solution casting approach at room temperature in fabricating GnPs-PVA based saturable absorber is simple, low cost and offers 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  $\mu\text{s}$ . 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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