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Observation of dark and bright pulses in Q-switched erbium doped fiber laser using graphene nano-platelets as saturable absorber

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ABSTRACT

In this paper, a passively Q-switched Erbium doped fiber laser (EDFL) by residing Graphene nanoplatelets (GnPs) embedded in polyvinyl alcohol (PVA) based saturable absorber (SA) is demonstrated. To aid the dispersion of GNPs, a surfactant is used and then it is mixed with polyvinyl alcohol (PVA) as host polymer to develop GnPs-PVA film based passive SA. The GnPs-PVA based film then integrated in laser cavity in ring cavity configuration for pulse laser generation. The experimental works show that the proposed passive SA operates at input pump power range from 77 mW to 128 mW with a tunable repetition rate from 78.4 kHz to 114.8 kHz and a shortest pulse width of 3.69 µs. The laser produces maximum instantaneous output peak power and pulse energy of 7.3 mW and 30.46 nJ, respectively and accompanied by signal to noise ratio (SNR) of 64 dB.

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1. INTRODUCTION

The first fiber laser was successfully demonstrated in 1960s [1] and it has intensively enhanced the development for both telecommunication [2] and sensor technology [3]. There are two well-known approach to generate pulse fiber laser either active or passive Q-switching. Passive technique become favorable as it offers compactness, low cost, flexibility and simple design compared to active technique. Several methods have been proposed to achieve passive Q-switched fiber laser like nonlinear polarization (NPR) and real saturable absorber (SA) [4]. However, introducing SA into the fiber laser cavity is considered as a decisive way and provide simplicity. Fundamentally, pulsed laser can operate in two different regime which are bright regime and dark regime [5]. Dark pulses are normally referred to a train of intensity dips in a continuous wave background of the laser emission however, most of the pulsed laser operates in bright regime. Graphene based SAs have shown outstanding potential due to its intrinsic characteristic which is ultrafast recovery time and ultra-broadband operation. The intraband relaxation time around 10-150 fs [6] create an opportunity to produce shorter pulse than other materials used as SA. An ultra-broadband operation enable a broad working wavelength which enable us to use different gain media such as Ytterbium, Erbium and Thulium doped fiber.

Graphene nanaplatelets (GnP) is one of the graphene derivatives which GnP is stacks with 3-10 layer of graphene [7], while graphene with number of layer more than 10 is characterize as graphite. The

quality of GnP is alike graphene due to the similarity configuration of pristine basal plane with an enhance of optical, electrical and mechanical properties as compared to graphene oxide (GO) [7]. Basically there are four mainly approaches to synthesize graphene and its derivatives. One is through mechanical exfoliation [8] where scotch tape is used to peel off a layer or layers of graphite from bulk. This method is simple and gives better electronic properties of the samples but have low yield. The number of layers of which the graphite is peeled off is also random and cannot be controlled. There is also a method using insulating surfaces for epitaxial growth [9]. The third was CVD on metals such as Ni [10] and Cu [11] and epitaxial growth on certain facet of metal such as ruthenium (0001) [12]. This method is favourable due to its ability to produce a large area of uniform graphene film [13]. For Q-switched pulsed laser, graphene CVD approach has been demonstrated by placing a graphene based thin film between two fiber connectors [14]. They reported to produces repetition rate of 34.72 kHz to 53.2 kHz with a shortest pulse width of 3.2 µs within input pump power of 57.2 mW to 74.23 mW. Last but not least, there is also a fabrication method using liquid phase exfoliation (LPE) that can produce graphene from graphite and its derivatives and compounds [15]. The LPE method to fabricate graphene polymer composite has been demonstrated by Popa et al [16] where they able to produce a Q-switched pulse laser with a repetition rate of 36 kHz to 103 kHz, a shortest pulse width of 2 µs and signal-to-noise ratio (SNR) of 42 dB. A wider range of repetition rates were also demonstrated [17] ranging from 1.39 kHz to 206.61 kHz using a Graphene based SA fabricated through optical deposition of graphene-N-methyl Pyrrolidone (NMP). Cao et al [18] produced the SA by optical deposition of graphene-Dimethylformamide (DMF) suspension and able to generate Q-switched pulse laser with repetition rate of 8.50 kHz to 29.05 kHz and a shortest pulse width of 4.6 µs.

2. RESEARCH METHOD

The Graphene nano-platelets (GnP) powder obtained from Chengdu Organic Chemicals Co. Ltd., with purity, number of layers, thickness, diameter and density of >99.5wt%, <20, 4-20 nm, 5-10 µm and 0.6g/cm3, respectively, were used without any purification. In order to develop Graphene nano-platelets based passive saturable absorber, two separate suspension was prepared. The first one is to prepare dispersed graphene nano-platelets and the other one is polyvinyl alcohol (PVA) which act as binder, before both were mixed together. Th e GnP nano powder is weighed to about 40 mg and added to 40 ml of sodium dodecyl sulphate (SDS) in 1% deionized (DI) water.The mixture was ultrasonicated using a tip sonicator with pulse cycle of 0.5s at 90 W/cm^2 for 3 hours. After that, the suspension was centrifuge at 1000 rpm for one hour and 70% of the upper suspension was decanted leaving undispersed GNP at the bottom side. Then, the host polymer which is polyvinyl alcohol (PVA) (Mw=89x10^3 g/Mol) (Sigma Aldrich) was prepared by dissolving it into 120 ml of DI water. The GnP-PVA composite was then develop by mixing the dispersed GnP suspension and the PVA solution with one to one ratio. Through a one hour ultrasonic bath process, a homogenous GnP-PVA composite was obtained before it was poured onto a petri dish and let dry at room temperature. After 48 hours, a GnP-PVA film formed and can be peeled off thepetri dish. The film's thickness is approximately 30 µm.The FESEM image and Raman spectroscopy investigation of the SA is shown in Figure 1 and Figure 2, respectively.

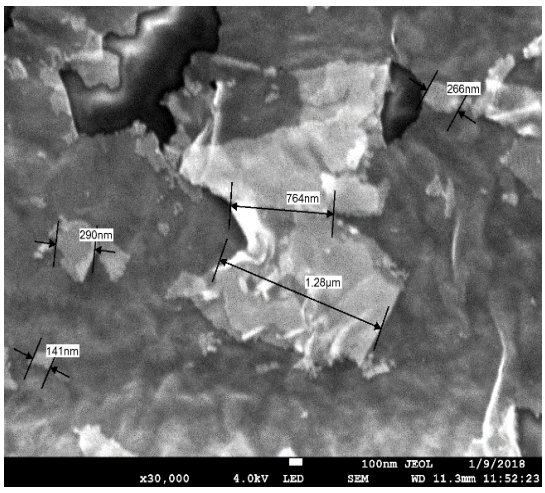

Figure 1. FESEM image of GnP-PVA film

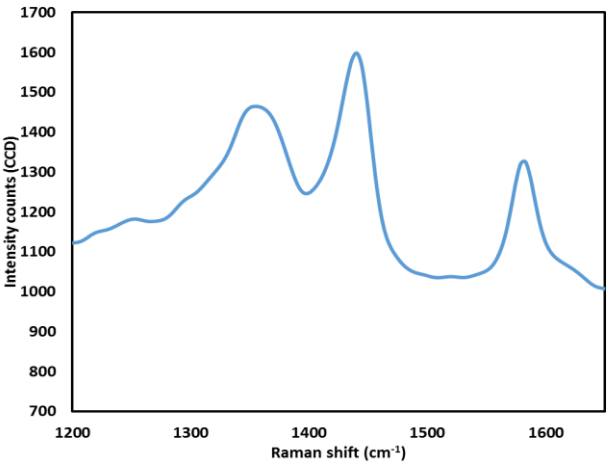

Figure 2. Raman spectroscopy of GnP-PVA film

The experimental setup is as shown in Figure 3. To integrate the GnP-PVA film as the SA into the cavity, the film is cut into a small piece and attached to one end of a fiber ferrule with the aid of index matching gel. A 2m long Erbium doped fiber is used as the gain medium, along with a 980/1550 nm wavelength division multiplexer (WDM), an isolator to ensure uni-directional propagation of the oscillating light, and a 90/10 output coupler to tap out 10% of the light for output characterization. A 3dB coupler is used to allow for simultaneous observation of the pulse produced through an optical spectrum analyser (OSA)/Optical power meter (OPM) and oscilloscope (OSC)/Radio frequency spectrum analyser (RFSA).

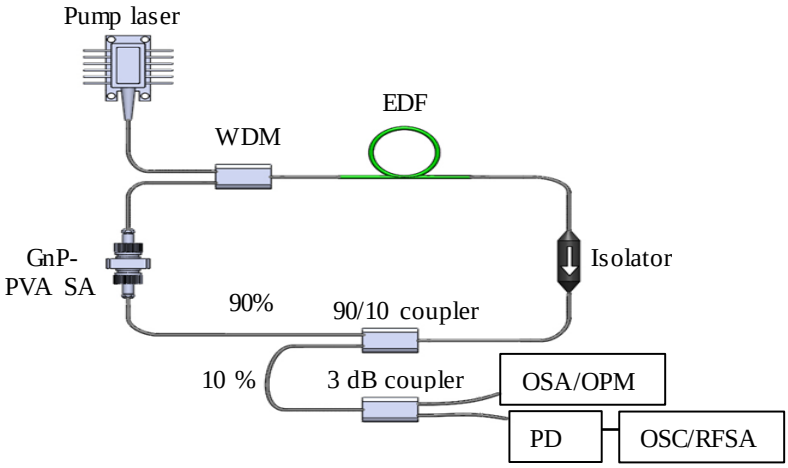

Figure 3. Experimental set-up of fiber laser in ring cavity

3. RESULTS AND ANALYSIS

A 3dB spectral broadening of around 1 nm occurred as the wavelength shifted from 1571.67 nm during CW lasing to 1562.30 nm due to the insertion of the GnP-PVA film SA, as shown in Figure 4. The self-started dark pulsed Q-switched fiber laser occurs at input pump power of 77 mW and continue to input pump power of 90 mW as in Figure 5. Above 90 mW, the Q-switched pulse oscillate at bright pulse or ordinary Q-switched pulse until the maximum pump power of 128 mW.

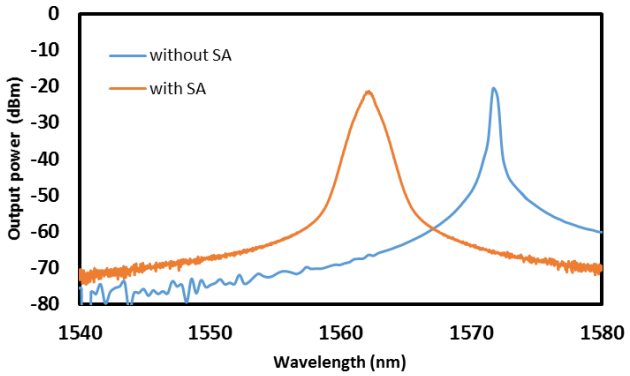

Figure 4. OSA trace without SA and with SA

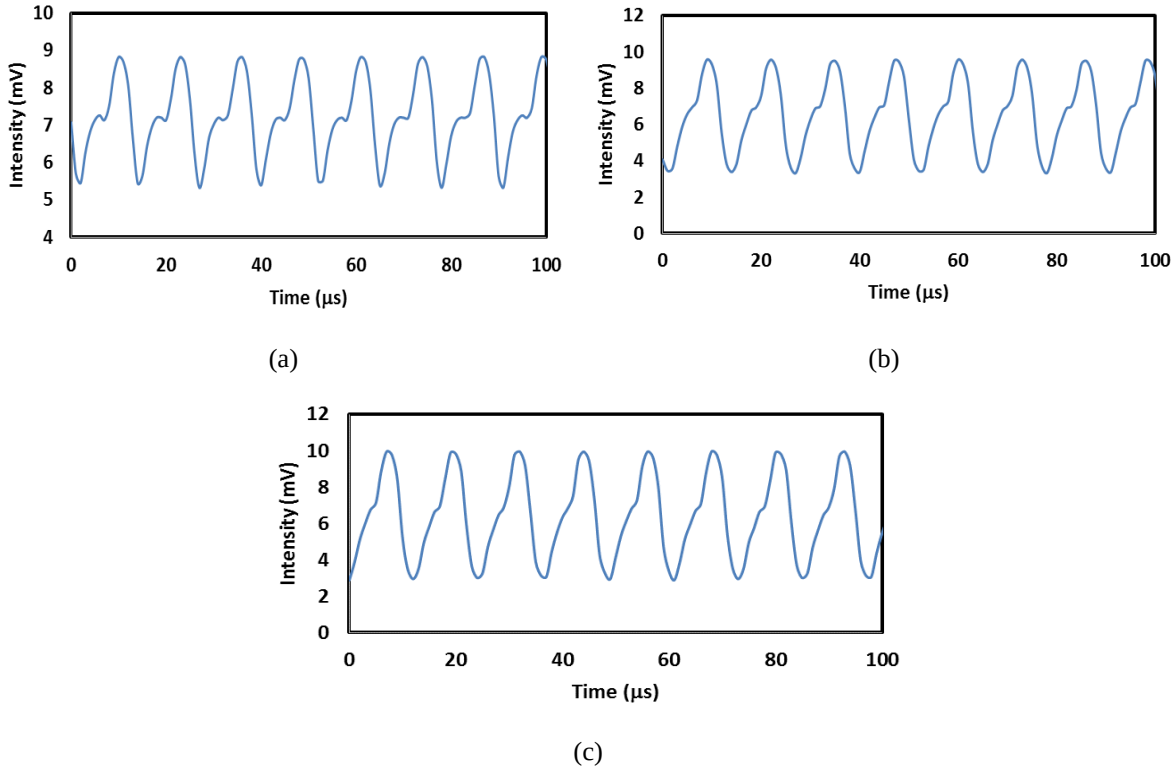

Figure 5. Dark pulse emission of the proposed EDFL at different pump power, (a) 77 mW, (b) 84 mW, (c) 90 mW

The oscilloscope trace at maximum input pump power of 128 mW is shown in Figure 6 with the inset showing the shortest pulse width of 3.69 μs. The repetition rate were tunable from 78.4 kHz to 114.8 kHz with increasing pump power. These value provide a highest value if compared to previous works [16, 18-24]. The relationship between the pump power and the repetition rate as well as the pulse width is portrayed in Figure 7. As the pump power is increased gradually, the repetition rate increases as well from 78.4 kHz to 114.8 kHz while the pulse width is reduced from 8.12 μs to 3.69 μs. This observation corresponds to the trending of pulse width and repetition rate that commonly observed in passively Q-switched lasers [25]. The shortest pulse width generated in this experiment is slightly better than previous work in [18-20, 25]. From the measured pulse repetition rate, pulse width and average output power, the pulse energy and peak power are calculated and being tabulated in Figure 8. As shown, both peak power and pulse energy increased as the input pump power increased. The maximum pulse energy and instantaneous peak power produced by the generated pulse is 30.46 nJ and 7.3 mW, respectively. Beyond 115 mW input pump power, the pulse energy is toward decreasing trends due to the slight difference in average output power as pulse energy, $E=P_{av}/f$. The generated instantaneous peak power is better than in [22] and the pulse energy higher than in [19, 22, 24]. The measured signal to noise ratio is around 64 dB as shown in Figure 9, at maximum input pump power, shows the high stability of the generated pulse and higher than previous works in [18, 26].

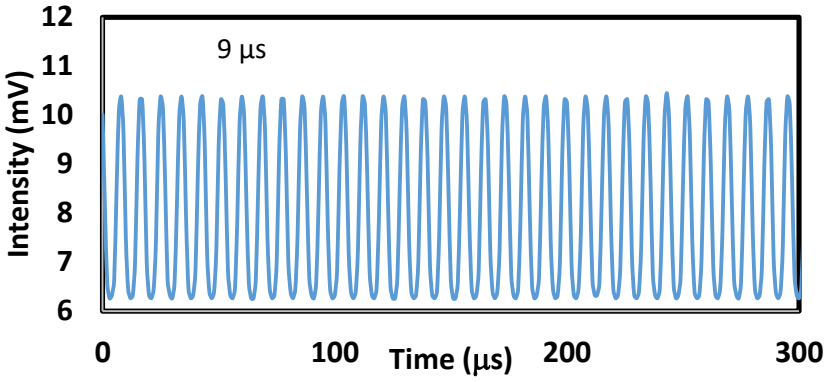

Figure 6. Pulse train of bright regime at 128 mW; inset: Shortest pulse width of 3.69 µs

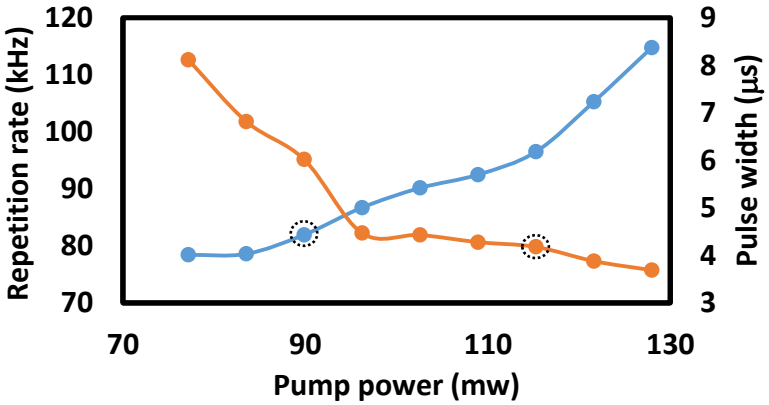

Figure 7. Repetiton rate and pulse width as a function of pump power

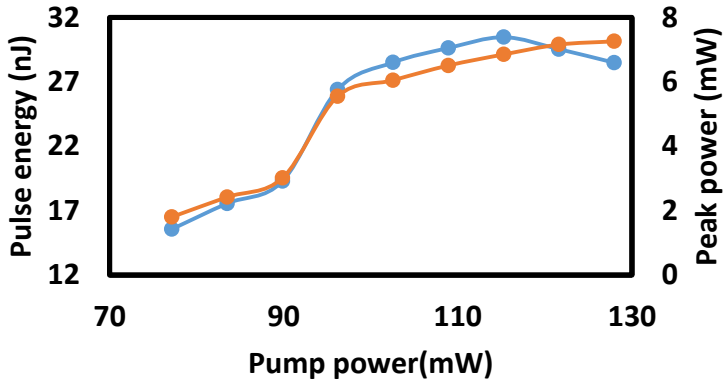

Figure 8. Peak power and pulse energy as a function of pump power

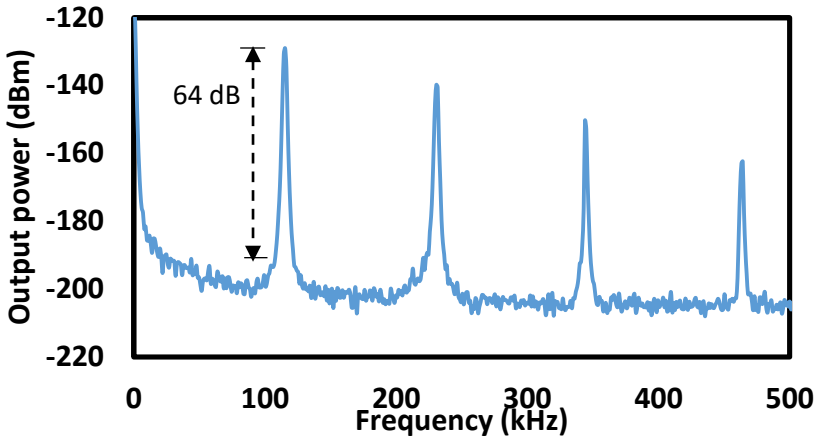

Figure 9. RFSA measurement of first beat note at a repetition rate of 114.8 kHz

4. CONCLUSION

Graphene nanoplatelets-PVA film based passive Q-switched EDFL was successfully demonstrated. This approach to fabricate GnP-PVA is both scalable, affording the possibility of high-volume production, and versatile in terms of being well suited to chemical functionalization. These advantages mean that graphene and its derivatives produced by the colloidal suspension method are good nanofillers to incorporate into the polymer to form functional composites.

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