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HIGH SIGNAL-TO-NOISE RATIO Q-SWITCHING ERBIUM DOPED FIBER LASER PULSE EMISSION UTILIZING SINGLE LAYER TRIVIAL TRANSFER GRAPHENE FILM SATURABLE ABSORBER

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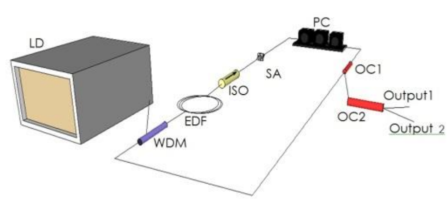
Graphical abstract



Abstract

This paper presents the high signal-to-noise ratio (SNR) Q-switched erbium-doped fiber laser pulse emission using a commercial single layer graphene (SLG) film as a saturable absorber (SA). A sandwiched-type structure with transferred single layer SLG film between two fiber ferrules is formed to function as the SA. Q-switched pulse emission with repetition rate from 47.25 kHz to 67.39 kHz and round-trip time per oscillation from 7.42 μs to 10.36 μs are obtained from the laser cavity set-up. The SNR of 62.64 dB shows a good quality of pulse generation using the SLG film as SA. The effortless production of SLG is enabling factor to produce fast fabrication and low cost SA for application in Q-switched pulsed fiber lasers.

Keywords: Signal to noise ratio, Q-Switched pulsed laser, single layer graphene film, saturable absorber, erbium-doped fiber laser

Abstrak

Kertas kerja ini membentangkan nisbah isyarat-kepada-hingar yang tinggi (SNR) Q-suis gentian laser dop erbium pancaran denyut menggunakan filem grafin lapisan tunggal (SLG) komersial sebagai penyerap boleh-tepu (SA). Satu struktur jenis-diapit dengan filem lapisan tunggal SLG dipindahkan di antara dua ferrules serat dibentuk untuk berfungsi sebagai SA. Q-suiz pancaran denyut dengan kadar ulangan dalam julat 47.25 kHz hingga 67,39 kHz dan lebar denyut daripada 7.42 μs kepada 10.36 μs diperolehi daripada rongga laser disusun-atur. Penjanaan denyut dengan SNR 62,64 dB menunjukkan kualiti yang baik apabila menggunakan filem SLG sebagai SA. Pengeluaran SLG tanpa berusah-payah adalah faktor yang membolehkan SA difabrikasi dengan cepat dan murah untuk pengunaan dalam laser gentian denyut Q-suis.

Kata kunci: Isyarat kepada nisbah bunyi, Q-Suiz laser denyut, filem lapisan tunggal grafin, penyerap boleh-tepu, erbium dop laser gentian

1.0 INTRODUCTION

Ultrafast fiber laser has been a hot topic investigated since decades ago. Passive pulsed fiber laser based on saturable absorber (SA) benefits the applications such as biomedical diagnoses, optical fiber communication and material processing [1-5]. Passively Q-switched technique utilizing SA is preferable compared to active mode-locking approach due to its simplicity and the cost of implementing the system is generally less [6]. The Q-switched mechanism is performed when there is a sudden spike of high peak power pulse. Initially, the cavity loss is high and the gain in the cavity is stored. After that, when the stored gain accumulated, the net cavity loss becomes substantially zero. In this case, the stored gain which exceeds the cavity loss builds up a short pulse with extreme high peak power.

Signal–to-noise ratio (SNR) is used as a ratio to compare the level of desired signal to the level of background noise, or signal power to the noise power. A higher SNR indicates more signal than noise, more suitable to transfer useful information than irrelevant data in communication. In erbium-doped fiber laser (EDFL) cavity, SNR depicts how well the energy is being transferred to the signal rather than redundant noise.

Graphene SA was firstly reported in year 2011 by two groups of researchers, Sun et. al. [5] and Bao et. al. [6]. Referring to [6], pure graphene is a material that shows ultrafast non-linear saturable absorption and competancy to previous reported SA material such as semiconductor saturable absorber mirror (SESAM), singled-wall carbon nanotube (CNT), graphene family members such as reduced-graphene oxide and graphene oxide (GO). Pure graphene has lower saturable absorption threshold for mode locking ranges fom 8 mW to 40 mW, ultrafast recovery time of approximate to 200 fs, and pulse width of 756 fs. In addition, graphene shows wide-band operating spectral range due to its gapless energy band gap. Figure 1 shows the absorption of photon and saturation of absorption for graphene.

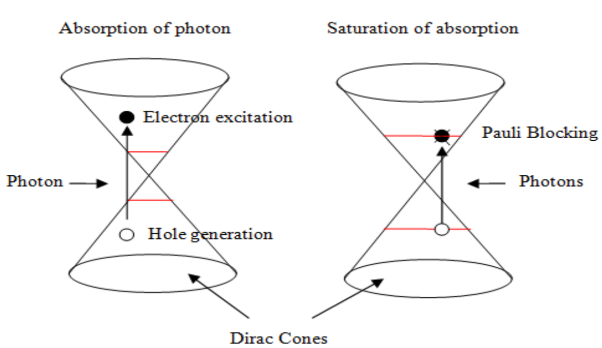


Figure 1 Absorption saturation of graphene

The operating wavelength for graphene as SA does not depend on the bandgap. For low electron excitation intensity, absorption of photons happened and electrons are excited from lower Dirac cone to upper Dirac cone. After the photo-excitation process, these excited electrons thermalize and recombine with the hole in the valence band to form a hot Fermi-Dirac distribution [7]. The resultant electron-hole pairs prevent further proton absorption by limiting the number of energy band level that the excited electrons can fill in. Nevertheless, when more photons react with graphene, the photogenerated carriers increase in concentration and fill the states near the edge of valence band and conduction band. Hence, saturation absorption is achieved due to the phenomenon so-called as Pauli Blocking [7].

In this paper, a Q-switched fiber laser by using a single layer trivial transfer graphene (TTG) SA is reported for the first time by using an easy fabrication process where only a few seconds was needed. The SA was produced in a sandwiched-type structure with a transferred single layer TTG film placed between two fiber ferrules. In this report, Q-switched result utilizing single layer TTG film was compared with our result is, high SNR of 62.64 dB was obtained using this low cost SA.

2.0 EXPERIMENTAL

In the experiment, the SA was fabricated by cutting a single layer TTG film into a small piece, where then it was immersed in a petri dish filled with deionized (DI) water. This process is necessary to detach the single layer TTG from the filter paper attached to it. A single mode fiber (SMF) ferrule was applied with silica matching gel for better attachment of single layer TTG film to the fiber ferrule facet. After a few seconds, the floated single layer TTG film was taken with a tweezer and was attached to the fiber ferrule. Using a fiber connector, the pigtail with the single layer TTG film was connected to the other pigtail, to make it as a sandwich-type SA as shown in Figure 2.

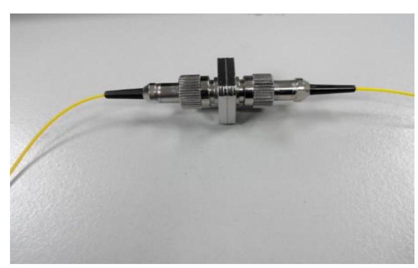


Figure 2 Sandwiched-type SA between two fiber ferrules

The Q-switched EDFL was constructed with a few optical fiber components, polarization controller (PC), wavelength division multiplexer (WDM), erbium-doped fiber (EDF), optical coupler (OC) and optical isolator (ISO) as shown in Figure 3.

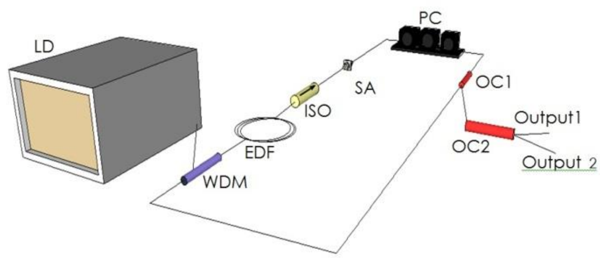


Figure 3 Laser ring cavity for Q-switched EDFL pulse emission

Based on Figure 3, the cavity was constructed in a ring configuration with 5 m length of a commercial EDF (HP980) as gain medium. The EDF has a dispersion coefficient of -60 ps/nm/km and was forward pumped by a 975 nm laser diode (LD) with maximum pump power of 340 mW. This was achieved by using a 980/1550 nm wavelength division multiplexer (WDM) as a combiner between the LD and EDF. An isolator was placed between the WDM and SA to ensure unidirectional clockwise direction of oscillation within the ring cavity. The PC was utilized in the cavity to reduce cavity birefringence effect. Coupler (OC1) of 70/30 was used to guide 70% of light signal back to the laser cavity and 30% of light signal was connected to another coupler (OC2) with coupling ratio of 50% per output port.

To balance the dispersion effect in the cavity, 17.6 m SMF with dispersion coefficient of 17 ps/nm/km was spliced in the laser cavity. Under this condition the group velocity dispersion (GVD) of the cavity is close to 0 ps^2. This is important so that the laser cavity was optimized to have a net anomalous dispersion. The normal dispersion from SMF was offset with anomalous dispersion from EDF. Soliton operation relies on the balance between net anomalous dispersion and self phase modulation (SPM). The output of the 50/50 coupler was then connected to measuring equipments such as optical spectrum analyzer (OSA), optical power meter (OPM), digital oscilloscope and radio frequency (RF) spectrum for output monitoring.

3.0 RESULTS AND DISCUSSION

The single layer TTG film used in this work was provided by Advanced Chemical Supplier (ACS) company, Figure 4 shows the Raman Spectrum for the single layer TTG film that was used to fabricate SA. The Raman Spectrum shows two prominent peaks, which located at 1573 cm^{-1} and 2682 cm^{-1} contributed from G band and 2-D band, respectively. The 2-D peak reflects its high quality single layer graphene whilst the G peaks indicates the intralayer vibrations of the sp^2 hybridized carbon atom. The weak signal coming from D-band proved the high crystallinity due to low disorder-induced first order scattering of the graphene film [8, 9]. The intensity ratio of the peak G and 2-D is equal to approximately 0.3. The low D peak indicates low defect density and high crystallinity of the single layer TTG film.

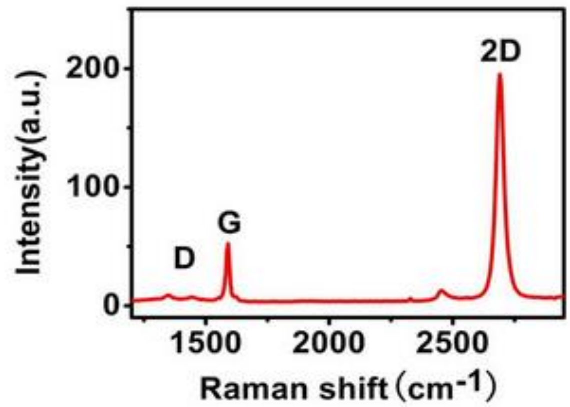


Figure 4 Raman Spectrum for Graphene-SiO_2 from ACS material

Figure 5 shows an optical spectrum of the Q-switched fiber laser observed from the OSA. The laser was generated typically at the wavelength between 1530.0 nm to 1536.5 nm with the output power of 33.89 mW when the graphene SA was incorporated inside the laser cavity.

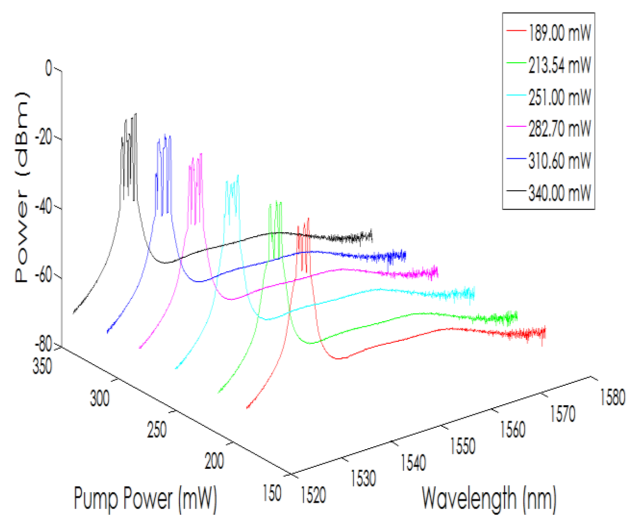


Figure 5 Optical Spectrum at LD pump power of 340mW

Figure 6 depicts the oscilloscope trace of the Q-switched pulse train for LD pump power of 340 mW. The laser is oscillating with a cavity roundtrip of 10.36 microseconds corresponds to a Q-switched repetition rate of 47.25 KHz. The length of the cavity is 10.71 m. The pulse train shows almost similar amplitude modulation in each envelope of Q-switch. In other word, there is weak consequence of self mode-locking.

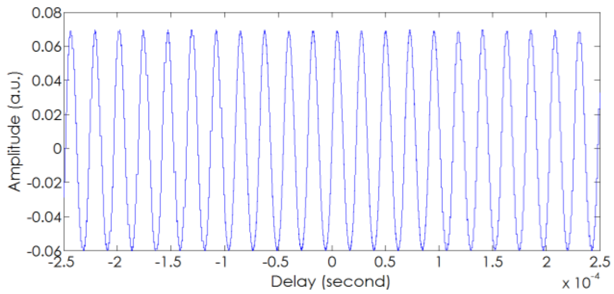


Figure 6 Oscilloscope result for EDFL at LD pump power of 340 mW

Figure 7 shows the relationship between repetition rate (kHz) and round-trip time per oscillation (μs) versus LD pump power (mW). From Figure 7, the primary axis shows that the repetition rate increases when the LD pump power increases. This is the general trend for Q-switching mechanism. When LD pump power was increased from 189 mW to 340 mW, the frequency increases almost linearly from 47.25 kHz to 63.4 kHz. On the contrary, for the secondary axis the round-trip time per oscillation decreases from 10.36 μs to 7.42 μs when LD pump power decreases. The trend for repetition rate is expected to be increased, and decrement for round-trip time per oscillation is predicted if the pump laser current is further increased in both condition.

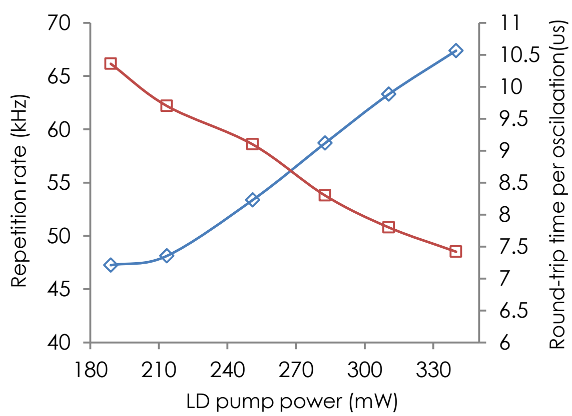


Figure 7 Trend for repetition rate and round-trip time per oscillation on different LD pump power

Figure 8 shows the result obtained from RF spectrum analyzer. Based on the findings, the span is set up to 500 kHz starting from 0 kHz. The frequency separation between two peaks is 62.0 kHz at LD pump power of 340 mW. Since the separation between each peaks are constant, the laser cavity is stable.

The SNR is obtained with the aid of RF spectrum. From Figure 8, the SNR is measured by taking subtraction of the highest intensity with the lowest intensity for the first peak. As a result, the SNR of 62.64 dB is obtained which is higher in comparison to the previous published work on Q-switching mechanism in Table 1.

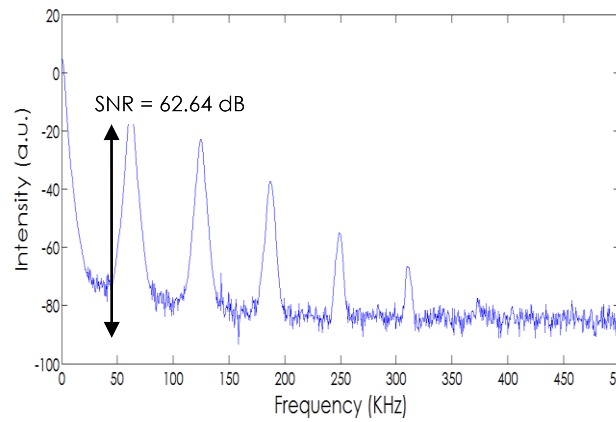


Figure 8 RF Spectrum for Q-switched EDFL at LD pump power of 340mW

4.0 CONCLUSION

In conclusion, a high SNR pulse from Q-switched EDFL using single layer graphene film TTG as SA was demonstrated. The Q-switching mechanism can be easily achieved by transferring the TTG film to the SMF ferrule and connected as "sandwiched-type" to another SMF ferrule via a optical connector. The repetition rate and pulse duration is similar to previous reported work in the unit of kHz and μs respectively. The main contribution in this work is that the quality of pulse with SNR higher than 60 dB was achieved. Hence, by using TTG film trasferring method, a better quality pulse can be obtained for potential applications in related areas such as optical communication system.

Acknowledgement

We would like to express our appreciation to ACS company for providing the Raman Spectroscopy Spectrum for SLG film to fabricate the SA.

Table 1 Comparison of present work with previous published journals

References	Methods	Materials	Laser Wavelength (nm)	Pump Power mW	Repetition Rate kHz	Pulse Duration µs	SNR dB
[1]	Tapered Fiber Optical Deposition	Graphene-polymer Composite	1539.4 - 1539.8	30.70	20.00	3.89	30.00
[10]	SMF Ferrule Optical Deposition	Topological Insulator (TI) Suspension	1510.9 - 1589.1	240.00	13.00	53.00	36.40
[11]	SMF Ferrule Optical Deposition	TI (Bi_2Se_3) Suspension	1980.0	2600.00	26.80	18.00	43.00
[12]	SMF Ferrule Optical Deposition	TI (WS_2 polymer composite)	1568 - 1572	350.00	110.00	-	-
[13]	Material Film Transfer	Few layer MoS_2 film	1521.71 - 1567.67	46.10	16.78	5.70	~50.00
[14]	Material Film Transfer	Multi-walled CNT	1060.2	65.72	24.27	16.20	-
[15]	Material Powder Attachment to SMF ferrule	GO nano powder	2000	165.00	20.00	6.00	54.00
[16]	SESAM	InAs	2970	3005.00	37.64	1.68	50.00
This paper	Material Film Transfer	Single layer grapheme film	1530 – 1536	340.00	67.39	10.36	62.64

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