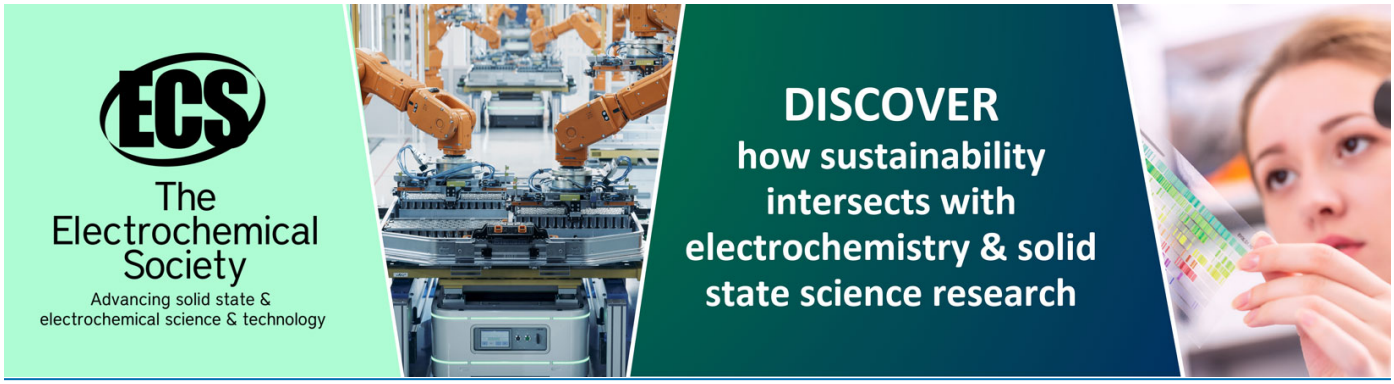
Graphene in chitin based passive Q-switcher



Graphene in chitin based passive Q-switcher

S N F Zuikafly[1], W M F Wan Nawawi[2], L H Ngee[3], H Yahaya[1], W J Yahya[1] and F Ahmad[1]

[1]Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100, Kuala Lumpur, Malaysia
[2] Department of Biotechnology Engineering, International Islamic University Malaysia, P.O. Box 10, 50728 Kuala Lumpur, Malaysia
[3]Department of Chemistry, Faculty of Science, Universiti Putra Malaysia, Serdang, 43400 Seri Kembangan, Selangor, Malaysia

fauzan.kl@utm.my

Abstract. Many materials have been utilized as saturable absorbers in generating pulsed lasers. By incorporating them with host polymers such as polymethylmethacrylate (PMMA), polyvinyl alcohol (PVA) and polyethylene oxide (PEO), the process of saturable absorber integration into the laser cavity is made easier. This work reported the generation of Q-switched pulsed lasers based on graphene embedded in chitin saturable absorber. Graphene: chitin with a concentration of 1:1 and 1.5:1 are integrated into a fiber laser cavity and the laser performance of both SAs are recorded and compared. The graphene chitin SA of 1:1 concentration produces a higher repetition rate and shorter pulse duration of 111.77 kHz and 1.328 μs, respectively. However, the SA with higher graphene content operated at a larger range of input pump power yielding a higher instantaneous peak power and pulse energy of 7.29 mW, and 14.37 nJ, respectively. This work introduces chitin as a potentially excellent natural host polymer as an alternative to conventional ones such as polyvinyl alcohol (PVA) and polyethylene oxide (PEO).

1. Introduction

As instruments of many uses in different fields of science and technology, fiber lasers have become the go-to choice for its flexibility and ease of use. The Q-switched temporal regime of a fiber laser helps provide the laser in pulsed form. The gain modulation of the Q-switched laser is now most commonly controlled by a saturable absorber (SA). This type of approach is called a passive method with the active ones requiring external control elements causing a much-complicated laser system.

With the discovery of real SAs in the early 1990s, many materials have since been investigated as SAs including semiconductor saturable absorber mirrors (SESAMs), carbon nanotubes (CNTs), topological insulator (TI), and black phosphorus (BP) among many others. The Nobel winning uncovering of graphene in 2009 has led to many new and exciting applications of graphene in industrial uses and researches, particularly in optoelectronics. Graphene's wideband operation ranging from the visible to the near-infrared region is mainly due to its gapless band and linear dispersion of Dirac electrons which also allows for a constant 2.3% light absorption [1-2]. Compared to its precursor, CNTs, graphene has the advantages of ultrafast recovery time, low saturation fluence, and broadband saturable absorption [3].

In photonics, the combination of an SA material and a host polymer to form a polymer composite based SAs is widely used by researchers. The composite form of the SA allows for better handling and mechanical tolerance [1], especially in the laser generation discipline. SAs from many classes of materials have been fabricated by using this technique with no exception to graphene. Polyvinyl alcohol (PVA) and polyethylene oxide (PEO) are the two most commonly used host matrix when fabricating a polymer composite SAs. A graphene-PVA film was reported by Popa *et al.* [4] realizing a tunable Q-switched laser operation from 1522 nm to 1555 nm. Kasim *et al.* [5] generated a Q-switched pulsed laser with the shortest pulse duration of 2.68 μs and a pulse energy of 5.8 nJ. A graphene nanoplatelets (GnPs)-PVA film SA was also demonstrated yielding a maximum repetition rate and pulse width of 91.5 kHz and 2.42 μs, respectively [6]. As an alternative to a man-made polymer, this work is introducing chitin, a biopolymer originally derived from mushrooms [7], in graphene SA fabrication and its performance in a pulsed fiber laser.

2. Graphene Chitin SA Fabrication

The chitin nanofiber was prepared from a cultivated mushroom Agaricus bisporus as reported by Wan Nawawi *et al.* [8]. The process involved the mushrooms being blended for 5 minutes before undergoing hot water extraction and alkali treatment. Graphene Oxide (GO) was synthesized via a modified Hummer's method where graphite flakes were oxidized by Sulfuric acid (H_2SO_4) and Potassium permanganate ($KMnO_4$). The mixture obtained was then washed with a diluted Hydrochloric acid (HCl) solution, using a centrifuge, followed by repeated washing with deionized water until a constant pH of 4–5 was obtained. The graphene oxide powder was mixed thoroughly with the chitin nanofiber for 6 hours aided by a magnetic stirrer before dried at room temperature. After 36 hours, graphene chitin films with different concentrations were formed. 5 mg of graphene oxide powder was added to 5 ml chitin nanofiber to produce a graphene chitin composite of 1:1 ratio and 7.5 mg graphene oxide powder to 5 ml chitin was mixed to produce an SA with 1.5:1 concentration ratio.

3. Experimental Setup

The experimental setup of the Q-switched EDFL with the graphene chitin films as SA is illustrated in figure 1. A 3 m long Erbium-doped fiber (EDF) is used as the gain medium. The EDF is forward-pumped by a 980 nm laser diode via a 980/1550 nm wavelength division multiplexer (WDM). The SA is placed in the cavity by sandwiching it in between two ferrules which are connected with a connector. An optical isolator is also spliced in the cavity to ensure unidirectional propagation of the light. The output of the laser is observed and obtained through an optical spectrum analyser (OSA), an optical power meter (OPM), a radio frequency spectrum analyser (RFSA), and an oscilloscope which are connected through a 3 dB optical coupler.

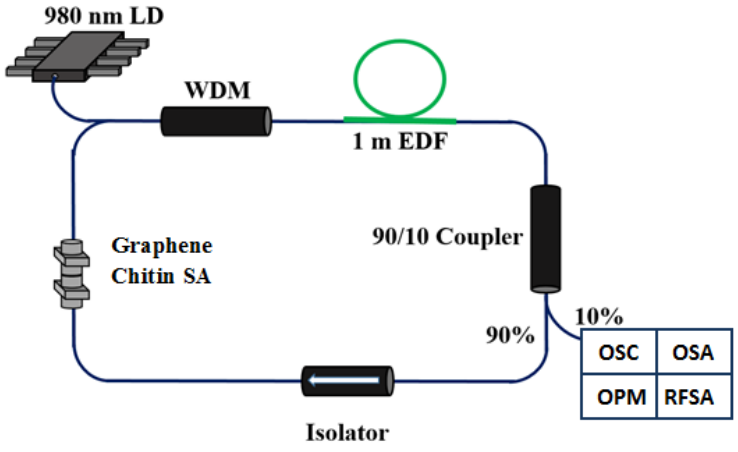


Figure 1. Experimental setup of the Q-switched EDFL based on graphene chitin SA.

4. Pulsed Laser Generation

Figure 2 shows the OSA trace of both the graphene chitin with 1:1 and 1.5:1 concentration. The graphene chitin of concentration 1:1 operated at 1560.03 nm with a 3 dB spectral bandwidth of 0.79 nm while the graphene chitin of concentration 1.5:1 oscillated at 1530.51 nm with a 3 dB spectral bandwidth of around 1.41 nm. Graphene chitin of concentration ratio of 1.5:1 shifted to an even shorter wavelength at around 1533.53 nm as compared to the one of 1:1 ratio. This is due to the greater amount of graphene in the SA that induced a greater loss in the cavity. The spectrums were obtained at a maximum input pump power of 28.70 mW and 42.29 mW, for 1:1 and 1.5:1 concentration ratio, respectively.

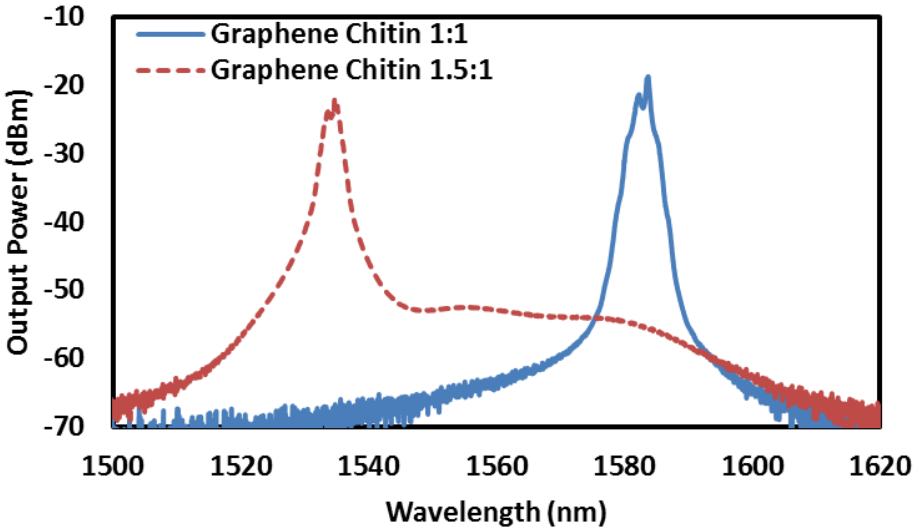


Figure 2. The optical spectrum of Q-switched EDFL based on graphene chitin SAs.

The graphene chitin SA with a concentration ratio of 1:1 was first employed in the cavity. The proposed ring laser cavity generated a Q-switched lasing as the pump power was tuned over 10.58 mW. The lasing was maintained up to the pump power of 28.70 mW before it started to lose stability. By reversing the pump tuning, the lasing can be re-achieved with the pump power range kept within the 10.58 mW to 28.70 mW span. No such lasing can be observed without the SA integration even when the pump power was tuned over a wide range indicating that the SA was responsible for the acquired Q-switched lasing. The same goes for the SA of ratio 1.5:1 with a different input pump power range from 15.11 mW to 42.49 mW. The slightly larger range of tunable input pump power may be attributed to the higher amount of graphene present in the SA, allowing for a higher degree of light saturation and absorption during the laser generation process.

The pulse train repetition rates of the Q-switching operations are shown in figure 3. In the case of the SA with a 1:1 concentration ratio, the highest repetition rate of 111.77 kHz was obtained with a corresponding shortest pulse width of 1.33 μs. 95.24 kHz of repetition rate and 1.95 μs of pulse width were subsequently obtained for the SA ratio of 1.5:1. Both of the pulse trains showed a stable Q-switching operation with little to no amplitude modulation. The insets show the single pulse envelope of the pulse train repetition rate with the corresponding shortest pulse widths.

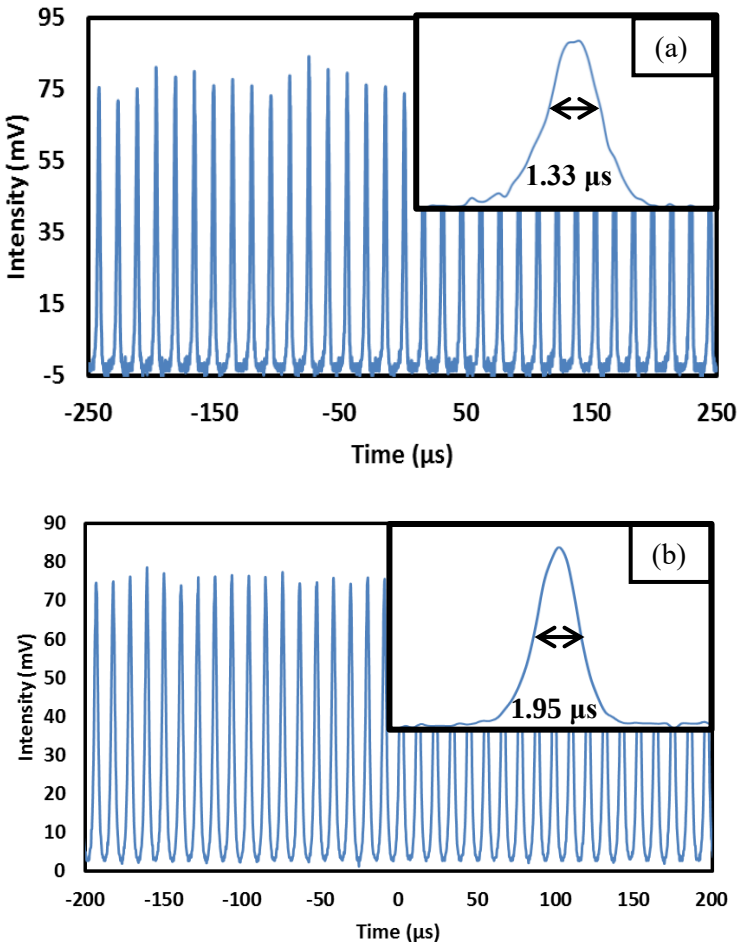


Figure 3. Pulse train repetition rate of the Q-switched EDFL based on graphene chitin SAs on concentration ratio (a)1:1 and (b) 1.5:1 and corresponding pulse envelope

When tuning the input pump power from 10.58 mW to 28.70 mW, the repetition rate increased almost linearly as also seen from past reported works on Q-switching operation [9-11], from 20.76 kHz to 111.77 kHz. The same trend was also observed in the pulse laser using the graphene chitin of concentration 1.5:1 where the repetition rate increased from 33.33 kHz to 95.24 kHz. This can be seen in figure 4. The increase in the repetition rate also contributed to the increase in the pulse energy as the pulse energy was calculated by dividing the average power with the repetition rate. The maximum pulse energy of 7.45 nJ and 15.60 nJ was obtained for SA concentration of 1:1 and 1.5:1, respectively. In the rather small range of the tunable pump power, the highest repetition rate and pulse energy obtained is higher than most of the reported works based on graphene polymer composite SAs [5-6][12].

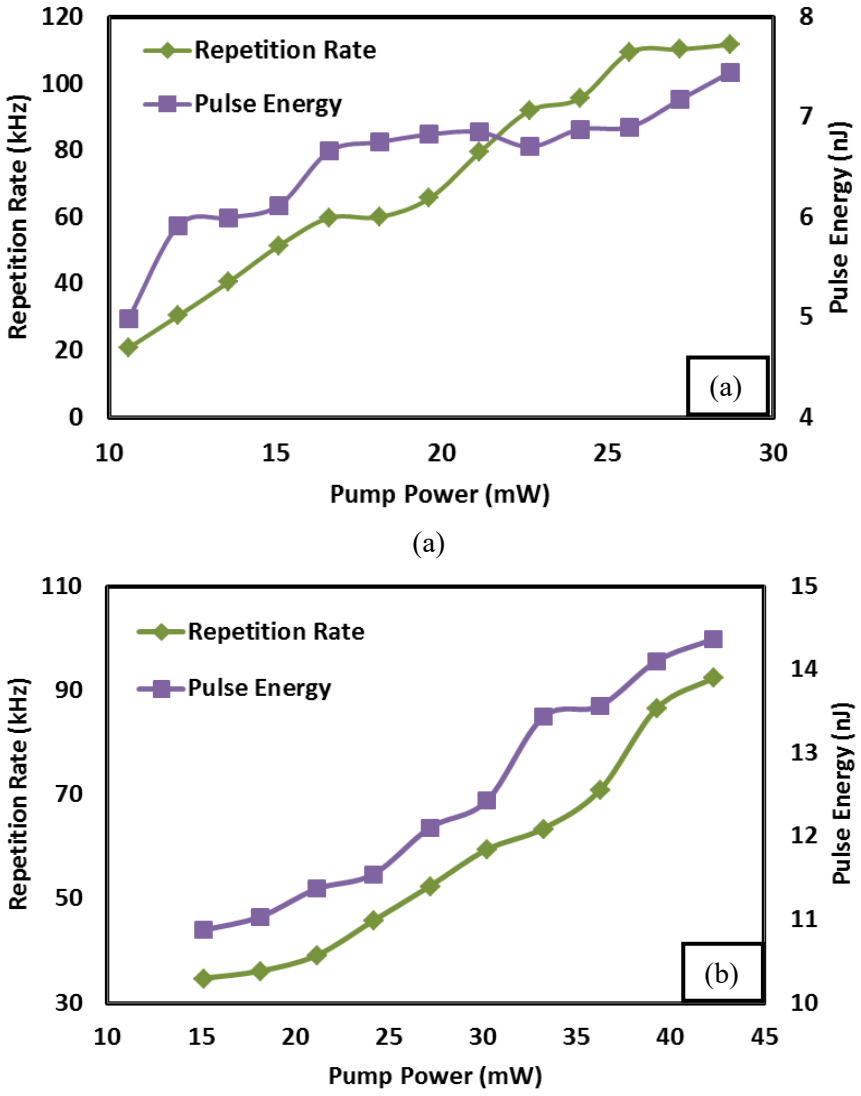


Figure 4. Repetition rate and pulse energy against input pump power of the Q-switched EDFL based on graphene chitin SAs of concentration ratio (a) 1:1 and (b) 1.5:1.

As a contrast to the repetition rate, the pulse width does not share the same relationship with the increasing input pump power. Demonstrating a typical trend of Q-switched lasers [9-11], the pulse width was reduced from 4.21 μs to 1.33 μs when using the graphene chitin SA with a concentration ratio of 1:1. Thereafter the SA with a 1.5:1 ratio demonstrated the same trend with decreasing pulse duration from 3.43 μs to 1.97 μs, as shown in figure 5. The shortest pulse width obtained was lower than other reported works using graphene-based SAs with other host polymers [5-6][12]. Both pulse widths obtained are lower if not comparable to many SAs based on other materials including black phosphorus, copper, and nickel oxide [13-16]. The peak power increases with the increasing pump power to a maximum of 5.61 mW and 7.29 mW, for each concentration ratios, respectively.

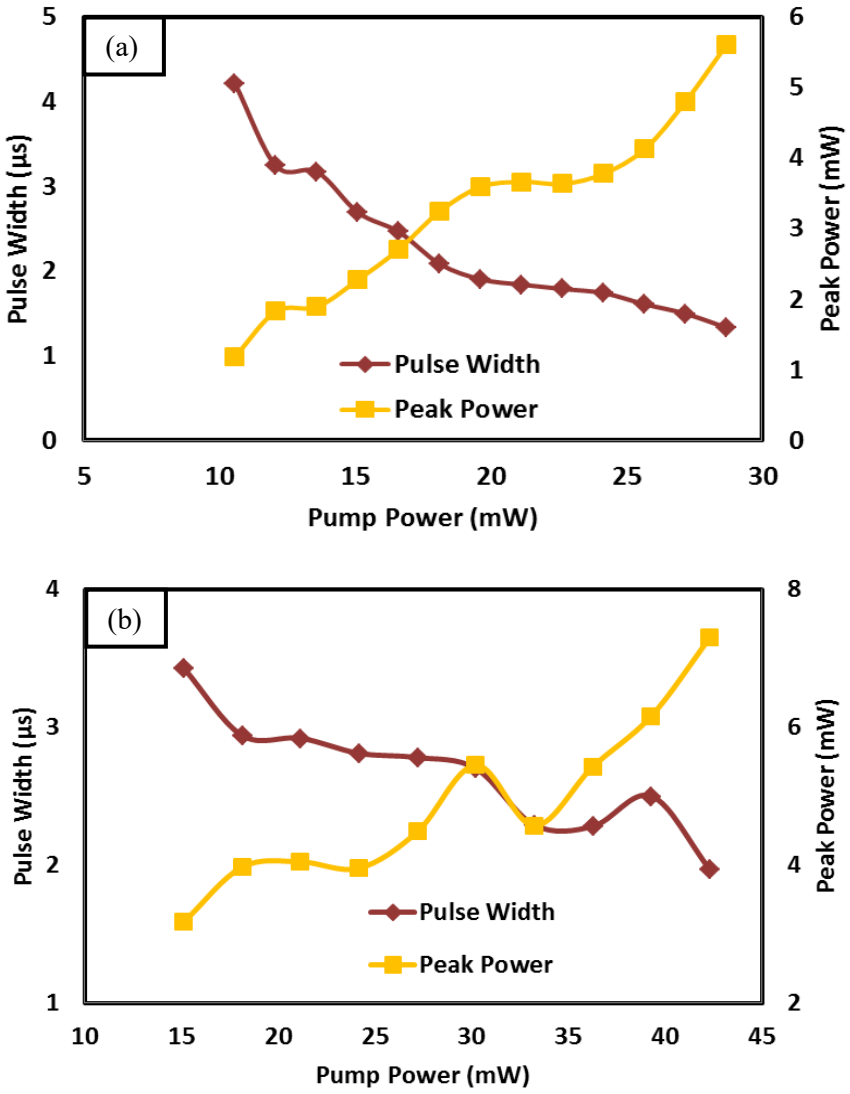


Figure 5. Pulse width and peak power against input pump power of the Q-switched EDFL based on graphene chitin SAs of concentration ratio (a) 1:1 and (b) 1.5:1.

Both of the SA concentrations yield a very high signal-to-noise ratio (SNR) of above 50 dB indicating both lasers generation was operated stably. The RFSA spectrums with a 1000 kHz span are depicted in figure 6. At maximum input pump power, the first beat node at 111.77 kHz was 51.71 dB for the graphene chitin SA of 1:1 concentration ratio. The SA with 1.5:1 concentration ratio yielded a marginally higher SNR of around 56.21 dB.

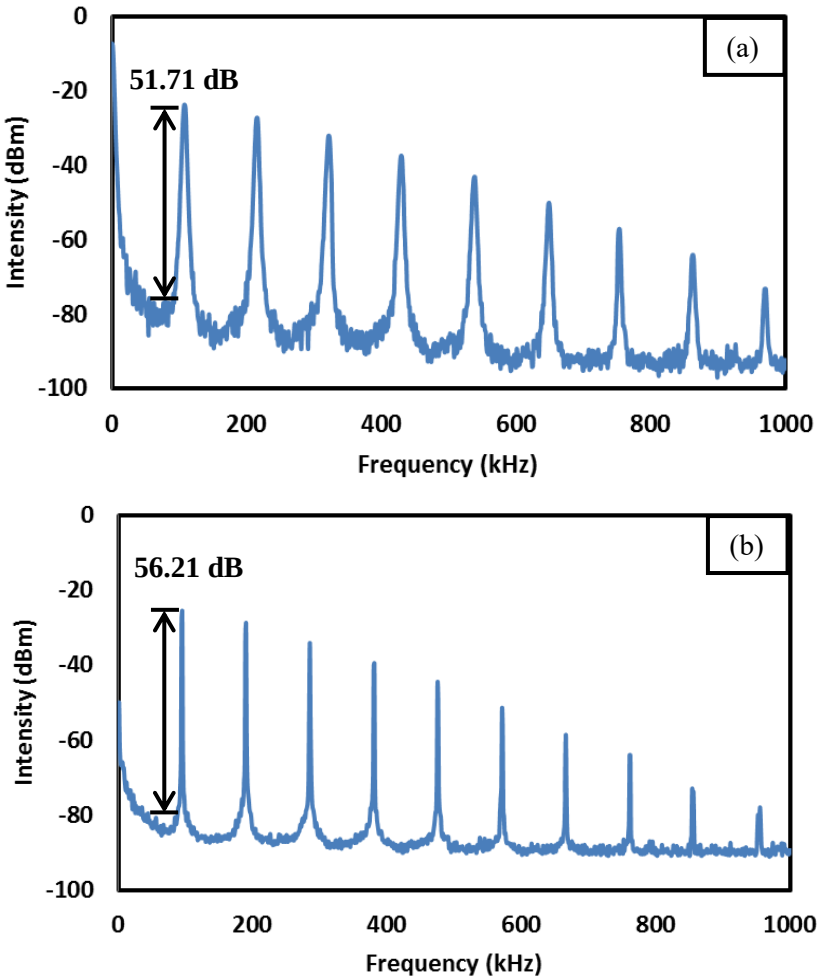


Figure 6. RFSA measurement of the Q-switched EDFL based on graphene chitin SAs of concentration ratio (a) 1:1 and (b) 1.5:1.

5. Conclusion

A Q-switched EDF laser was successfully demonstrated by using graphene composited with a chitin biopolymer in two different concentration ratios. The combination of the SA material with a biopolymer is the first ever to be reported in pulsed laser generation. A high repetition rate and shortest pulse width of 111.77 kHz and 1.33 μs, respectively, were obtained. The high laser stability was also proven by high SNR value for both concentrations of the SAs.

References

[1] Feng Y, Dong N, Wang G, Li Y, Zhang S, Wang K, Zhang L, Blau W J and Wang J 2015 *Optic Express* **23** 559-569
[2] Hasan T, Scardacl V, Tan P H, Bonaccorso F, Rozhin A G, Sun Z and Ferrari A C 2011 *Nanotube and Graphene Polymer Composites for Photonics and Optoelectronics* (Boston: Springer) p 279-354
[3] Bianchi V *et al.* 2017 *Nature Communications* **8** 15763
[4] Popa D, Sun Z, Hasan T, Torrisi F, Wang F and Ferrari A C 2011 *Appl Phys Lett* **98** 0731066
[5] Kassim N, Anyi C L, Haris H, Ahmad F, Ali N M, Ahmad H, Munajat Y and Harun S W 2014 *Journal of Nonlinear Optical Physics & Materials* **23** 1450009
[6] Hussin N, Ibrahim M H, Ahmad F, Yahaya H, Harun S W 2017 *Telkomnika* **15** 814-819

[7] Park B K and Kim M M 2010 *Int. J. Mol. Sci* **11** 5152-5164
[8] Wan Nawawi W M F, Lee K Y, Kontturi E, Murphy R J and Bismarck A 2019 *ACS Sustainable Chemistry & Engineering* **7** 6492-6496
[9] Fan M, Li T, Li G, Zhao S, Yang K, Zhang S, Zhang B, Xu J and Krankel C 2017 *Optic Express* **25** 12796-12803
[10] Kang Z, Liu M, Li Z, Li S, Jia Z, Liu C, Qin W and Qin G 2018 *Photonics Research* **6** 549-553
[11] Liu H H, Chow K K, Yamashita S and Set S Y 2013 *Opt. Laser Technol*. **45** 713
[12] Ahmad H, Samion M Z, Sharbirin A S, Norizan S F, Aidit S N and Ismail M F 2018 *Laser Physics* **28** 055105
[13] Fauziah C M, Rosol A H A, Latiff A A and Harun S W 2017 *IOP Conference Series: Materials Science and Engineering* **210**
[14] Sadeq S A, Al-Hayali S K, Harun S W and Al-Janabi A 2018 *Results in Physics* **10** 264-269
[15] Muhammad A R, Ahmad M T, Zakaria R, Rahim H R A, Yusoff S F A Z, Hamdan K S, Yusof H H M, Arof H and Harun S W 2017 *Chinese Physics Letters* **34** 034205
[16] Rizman Z I, Arof H, Latiff A A, Retna A and Harun S W 2018 *Nonlinear Optics, Quantum Optics* **49** 311-319