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Q-Switched dual-wavelength erbium-doped fiber laser using graphene as a saturable absorber

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Q-Switched dual-wavelength erbium-doped fiber laser using graphene as a saturable absorber

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Abstract. We proposed stable Q-switched dual-wavelength initiated by graphene as saturable absorber inside erbium-doped fiber laser cavity. Continuous-wave and pulse spectrum of erbium-doped fiber laser (EDFL) was successfully demonstrated and analysed where the lasing starts at a pump power of 50.4 mW. Threshold pump power generates continuous-wave at 1560 nm which is then shifted to 1558.7 nm as the SA is inserted. Q-switched EDFL generates a maximum repetition rate of 115.9 kHz which corresponds to a pulse width of 41 μs. The generation of dual-wavelength at two different wavelengths are also demonstrated in these works.

1. Introduction

Last year, distinguished scientists in the field of laser physics celebrated their discovery of chirped optical pulses and optical tweezers which make ultrashort pulses as an important scientific tool in the world. Since then, many researchers start to pay more attention to producing efficient ultrafast laser. Recently, most works in laser physics start to focus more on all-fiber laser system as it provides more advantages than solid-state laser. Its reliability, flexibility, compactness and maintenance-free operation make it more useful than other laser systems. There are two techniques to generate pulses in all-fiber laser system, which are active and passive means. The latter offers more flexibility and feasibility as it did not require additional mirror or lenses inside the system [1]. Therefore, the passive technique is frequently used with the implementation of material inside the laser cavity. Among materials, 2-dimensional material attracts more research attention as it demonstrates excellent confinement of electron and holes inside the atom [2].

In 2003, Geim and Novoselov had discovered a promising carbon allotrope, graphene [3]. This Nobel prizes winning material had drawn vast research attention due to its excellent condensed matter properties as well as its dynamics charge carriers density (massless Dirac Fermion) [4]. Mobility of graphene seems unique as no scattering occurs even after thousands of interatomic distances. In fact, an atomically thin carbon precursor possessed strong interatomic bonds which prevent lattice dislocations and crystal defects even at high temperature [5]. Thus, Bao *et al.* demonstrated a functional picosecond laser using graphene by manipulating its saturable absorption properties in erbium-doped fiber laser (EDFL). This ability is attributed to low saturation intensity and high photocarrier density

[6]. This zero-gap semimetal exhibit ultrafast recovery time (~200 fs) which are able to operate at broad operation regimes (1-2 µm). In this work, we demonstrate a Q-switched dual-wavelength operates at 1.55 µm region by utilizing the erbium-doped fiber (EDF) cavity implemented with graphene as saturable absorber.

2. Experimental setup

In this experiment, the fiber laser consists of a 980 nm laser pump. The EDFL is utilized as a lasing medium since it produces laser in a wavelength of 1550 nm. The ring configuration gives an advantage to loop the beam into the system. The laser diode is connected to a wavelength-division multiplexer (WDM). The input of WDM is linked to the patch cable via 980 nm port with a standard type of connector. After that, the output of WDM is connected into the fiber with doping material, erbium. Then the optical coupler is connected to the end side of the EDF and divided into two sections which are 10% and 90% output power. 90% output is used to loop back the signal into WDM while 10% output of optical coupler is connected to measuring instruments for analysis purposes. Measuring tools used are optical power meter and optical spectrum analyser to observe the laser spectrum. Next, 10% output is connected to fiber Bragg grating (FBG) to operates at 1550 nm to observe the dual wavelength result. Figure 1 shows the overview schematic diagram for analysing the laser erbium doped setup.

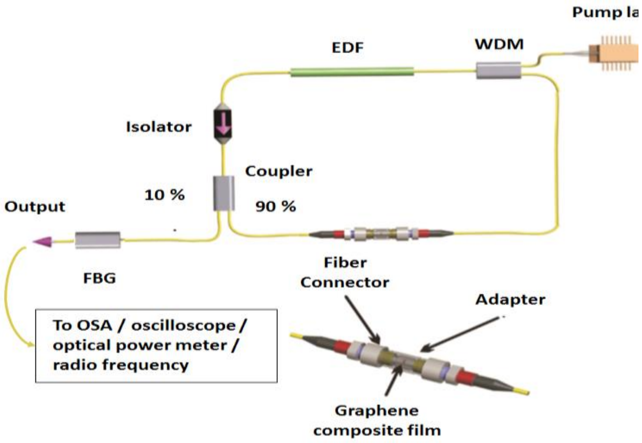

Figure 1. Erbium-doped fiber laser setup.

3. Results and Discussion

Figure 2 compares the output spectrum for the EDF with and without the graphene as saturable absorber when the pump power is fixed at a current of 400 mA. We can observe the operating wavelength of the laser shifts from 1560 nm to 1558.7 nm with the incorporation of the SA. This is attributed to the cavity loss of the resonator. To compensate for the loss, the laser is operated at a shorter wavelength near the peak absorption wavelength of the EDF to acquire more gain. Without the SA, the EDF operates in continuous mode.

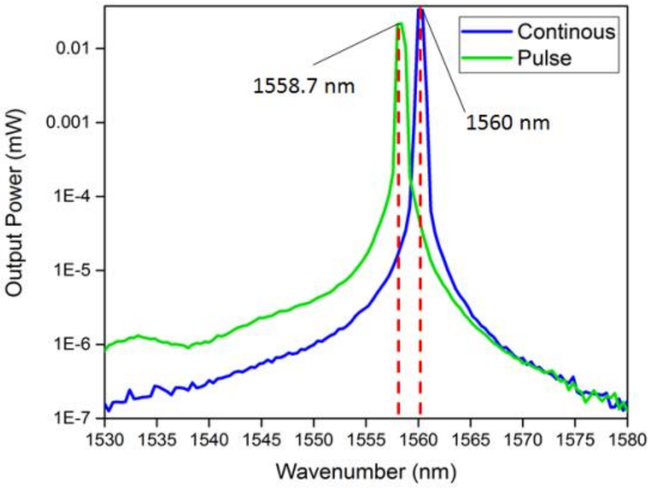

Figure 2. Output spectra from both EDFLs configured with and without the SA at a pump power of 400 mW.

The 10% of the light was coupled to the oscilloscope and the 90% port was coupled to the saturable absorber. The current supply to the laser diode pump starts from 260 mA until 490 mA. Those values correspond to the pump power of 115.83 mW with a maximum pump power of 231.61 mW. The production power growth as the input power increased. The repetition rate and pulse width of the Q-switched pulses generated from this fiber laser taken against the laser diode pump power are shown in figure 3. It can be seen from the figure that the repetition rate increases almost linearly against the pump power from 68.12 kHz at a pump power of 75.9 mW, which is the Q-switching threshold, to a maximum value of 115.9 kHz at a pump power of 136.6 mW. It must be noted that the repetition rate of the EDFL is not limited to this value, and higher repetition rates can be obtained if a pump laser diode with a higher output power is used. By adjusting the pump power from 115.83 mW to 231.61 mW, pulse width displayed reading of 41 µs to 20 µs. However, this work is limited by a maximum available pump power of 137 mW. Figure 4 depicts the output pulse train of 300 cm EDF Q-switched fiber laser, taken from the oscilloscope that was connected to the photodiode. It operates at the same pump power of 115.8 mW, with the repetition rate value of 24.39 kHz. This corresponds to a time interval of 41 µs between the pulses in the pulse train. Δt in the figure denotes the pulse width value obtained at 115.8 mW pump power. The intensity of the peaks is almost constant at 7.8 mV, indicating that the output of the laser is adequately stable.

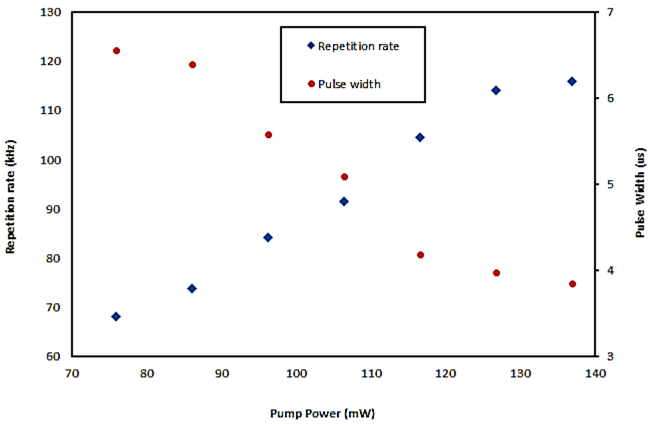

Figure 3. Pulse repetition rate and pulse width against pump power.

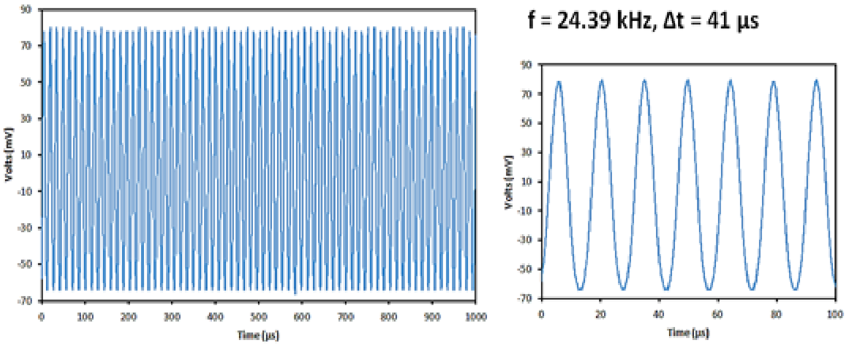

Figure 4. An output pulse train of the graphene-based Q-switched EDFL

The experimental setup for the dual-wavelength lasing spectrum of graphene EDFL is shown in Figure 1. The system was constructed using Fiber Bragg grating as a wavelength selective mirror. FBG used 95.78% reflection of the laser back to the cavity. The peak of the reflectivity is about 1550 nm. By considering only 4% of the transmission FBG as the output laser, wide-band wavelength spectrum is visible confirming the existence of FBG in the system. Figure 5 shows the dual wavelength spectra that oscillate at two wavelengths which are 1547.3 nm and 1554.6 nm. However, the result gained is not strong as there is no obvious result for dual wavelength to appear.

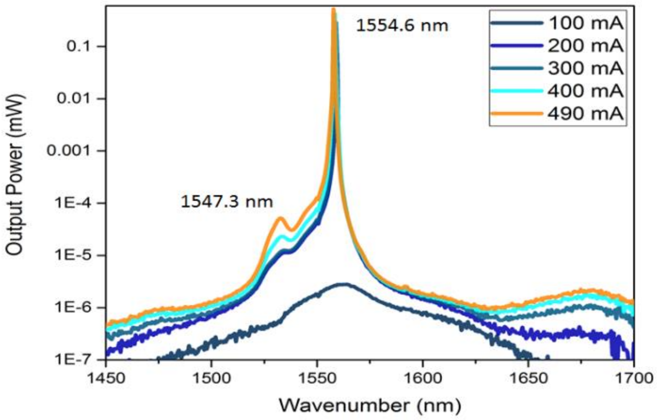

Figure 5. A typical dual-wavelength lasing spectrum of graphene Q-switched EDFL

4. Conclusions

The experiment was successfully conducted for the passively Q-switching, dual wavelength EDFL. Up to this point, the objective of exploring and investigating graphene as saturable absorber has been fulfilled. However, there are many other avenues in which this research could be continued and expanded. One of them is to explore and investigate the superiority of graphene oxide in place of graphene as the saturable absorber. Tunable Q-switched fiber lasers can also find many potential applications in various fields. Thus, in this work, three types of wavelength selective elements are suggested to improve the data from the previous result in generating tunable Q-switched fiber lasers.

Acknowledgements

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