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Investigation of output power in ring CW fiber laser using graphene saturable absorber

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ABSTRACT

This paper reported the effect of different coupling ratio in continuous wave fiber laser in a ring cavity configuration. Different coupling ratios of 10/90 and 50/50 were tested. Where the output power may vary depending on the ratio and it can be applied to specific area that requires either high or low output power. In addition, generation of passive Q-switched erbium doped fiber laser (EDFL) using graphene based saturable absorber in ring cavity using different coupling ratio was experimentally investigated. As a result, wavelength centered at 1566.62nm is obtain from EDFL cavity. Moreover, the cavity using coupler of 50/50 is capable to achieve Q-switched pulses as compared to the cavity using coupler of 10/90. Where the maximum output power recorded is 336mW with pulse repetition rate of 23.74 kHz. In addition, the pulse width is 3.84μs, and pulse energy is 14.15nJ.

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1. INTRODUCTION

The erbium-doped fiber (EDF) first was invented the late 1980s. It was proven that EDF to be a versatile material system with a wide range of applications, including broadband optical sources, wide-band optical amplifiers, and tunable lasers. Amplified spontaneous emission (ASE) in erbium-doped fiber has been used to construct light sources with the advantages of high output power and broad optical bandwidth [1]. Passive Q-switching technique based on saturable absorbers (SAs) requires no additional electronic switching components. Compared with actively Q-switched fiber lasers, passively Q-switched fiber lasers have significant advantages of compactness, simplicity, and flexibility in design. To date, semiconductor saturable absorber mirrors (SESAMs) [2] and single-wall carbon nanotubes (SWCNTs) [3-4] have been widely used for passive Q-switching. However, SESAMs have a narrow tuning range and require complex fabrication and packaging. With SWNTs, it often needs to control the diameter or chirality of nanotubes for obtaining saturable absorption in the desired wavelength range. Nanotubes not in resonance may introduce undesired large non-saturable loss in tunable lasers [5].

Graphene has emerged as a new innovative nanomaterial and a good SA for mode-locked and Q-switched fiber lasers due to its outstanding linear and nonlinear optical properties [6-8]. Compared with SESAMs or SWCNTs, graphene as a SA exhibits many advantages, including ultrafast saturation recovery time, low saturation threshold, large saturable-absorption modulation depth, and an ultra-broad wavelength-independent saturable-absorption range [9, 10]. Very recently, Mansoor et al., obtained stable 2.3μs pulses from an erbium doped fiber laser (EDFL) passively Q-switched by a graphene-based SA [11]. As it has been explained by Ismail et al, the usage of thicker GSA will take a longer time and higher pump power to make the graphene bleached, thus increase the absorption time [12].

Coupling ratio in a ring cavity plays a crucial role because it determines the power will be supply and power will be tap out from the cavity. The coupling ratio can be changed in order to achieve higher output power or low threshold pump power using 5/95, 10/90, 20/80, 30/70, 40/60 or 50/50 [13]. In this paper, we experimentally demonstrate and investigate the output power of the generation of Q-switched EDFL by using Graphene as the saturable absorber using two different coupling ratio.

2. RESEARCH METHOD

The design of our cavity follows according to the experiment demonstrated by Ahmed et al. [14] as illustrated in Figure 1. The 980/1550nm laser diode is used to pump power into wavelength division multiplexer (WDM) and straight goes into 3-meter Erbium Doped Fiber. The EDF is being used as a gain medium because it is cheaper compared to others such as zirconia-erbium doped fiber. The Erbium ion absoption is 23dBm at 980nm has a numerical aperture of 0.16. The core and cladding diameter are 4 and 125µm respectively. An isolator is placed after the EDF in order to prevent the light being reflected backwards and cause a serious damage to the laser diode. Different coupling ratios were used to demonstrate the tunable output power.

Saturable absorber is used specifically to generate Q-switched pulse laser. The generation of the pulsed laser is considered as passive because only SA is used to generate the pulses. The purpose of choosing graphene as our saturable absorber because it is easy to fabricate and cheap. The graphene is placed on top of the fiber ferrule at connector is used to connect the isolator with coupler. A coupler with a ratio of 10/90 is used to tap 10% of the original power out of the cavity for measurement purpose. The rest 90% of the power is being injected back into the cavity. This 10% output power will be divide equally in 50/50 coupler which the first 50% goes to oscilloscope (OSC) and the other 50% goes into optical spectrum analyzer (OSA).

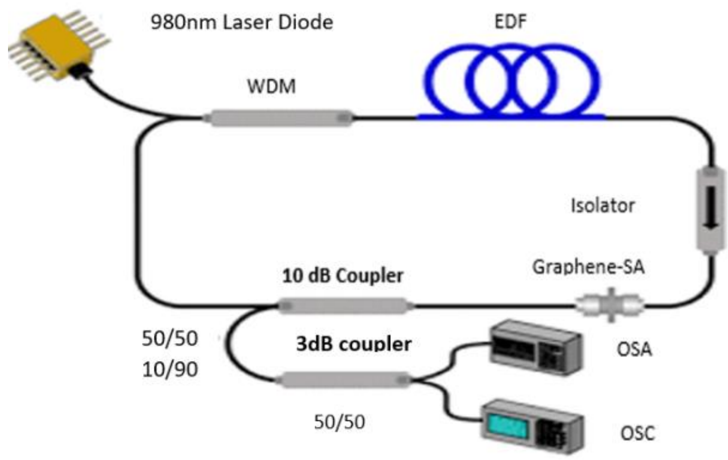

Figure 1. Schematic diagram to generate Q-switch cavity

3. RESULTS AND ANALYSIS

In this work, the pump power from the laser diode at 980nm varied from 42.6mW to 187.0mW. Two different coupling ratio were used in this investigation, 10/90 and 50/50. Using a coupler of 10/90, the optical spectrum of Q-switched pulses is presented in Figure 2 is centered at 1566.62nm.

Figure 3 shows the performance of the Q-switching in ring cavity. This includes the comparison of repetition rate of the pulse train at different input pump power level which is 50mW, and 75mW. At the initial pump power threshold level which is 50mW, the Q-switched pulse train appears with the repetition rate of 6.4kHz. Then the input power increased gradually to 75mW, the pulse train is still appearing in a stable condition. The repetition rate at 75mW power level is 16.31kHz. The input power increased up to 96mw, and it was found that the pulse trains with repetition rate 21.23kHz still appear and in a stable condition. As for comparison with Dong et al. [10], we managed to get repetition rate much higher compared to their maximum repetition rate which is 12.5kHz.

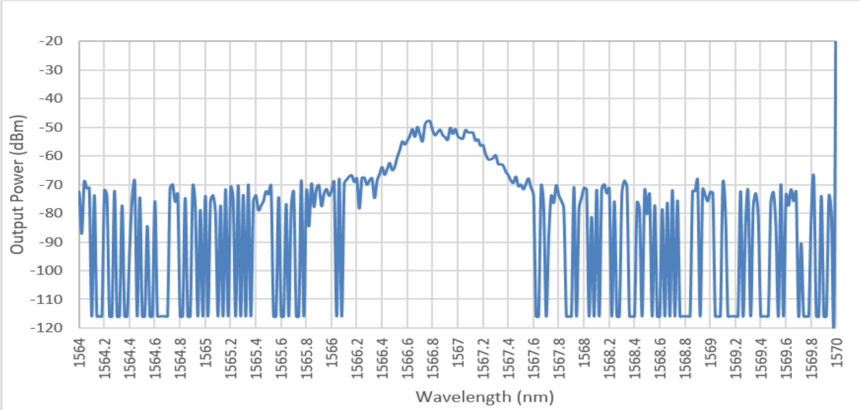

Figure 2. Output spectrum of Q-switched generated from EDF laser at threshold pump power

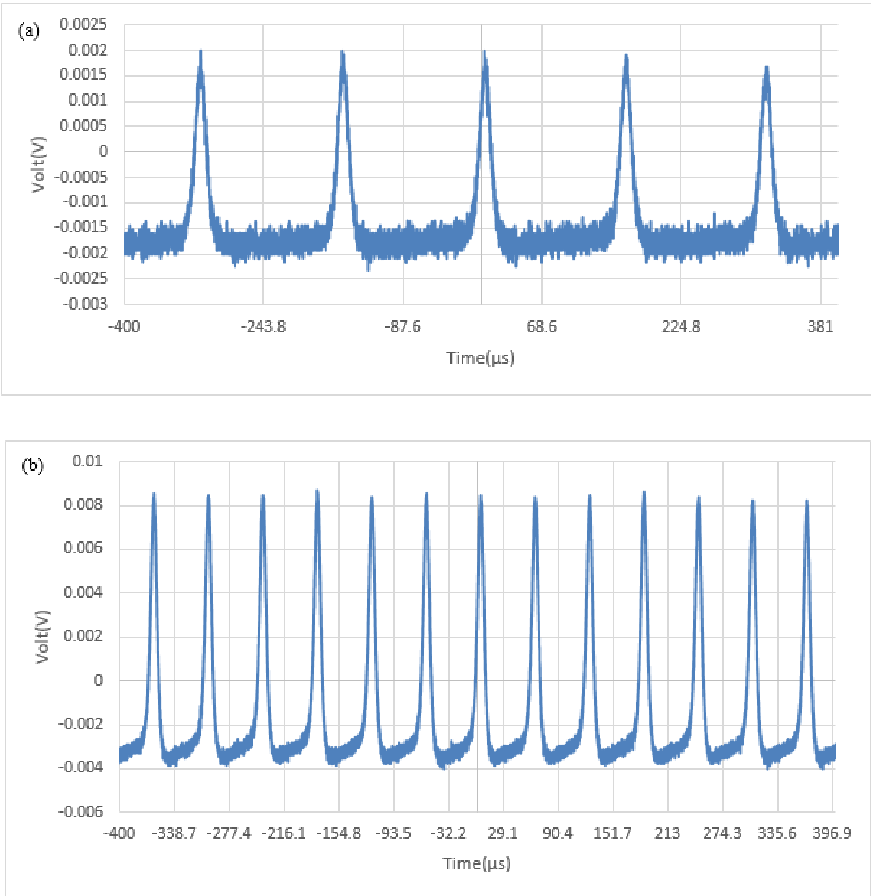

Figure 3. Q-switched pulse train under different pump powers, (a) 50mW, (b) 75mW

Based on our previous work [13] and according to the basic passive Q-switching theory which states that as the pump power increases, the cavity output power increases as depicted in Figure 4. Clearly the output power using coupler of 10/90 is less than the output power using coupler of 50/50. It's worth mentioning that the minimum pump power using coupler of 50/50 is 220mW and for coupler of 10/90 is 170mW. This is because in case of 10/90, 90% of the input power generated at 170mA return back to the cavity and generates an output signal at 1566.62nm. But when the return power reduces using the other coupler, 50/50, then more input power is needed in order of the system to generate signals at 1566.62nm, which can't be happened at 170mA, and it can be achieved only at 220mA.

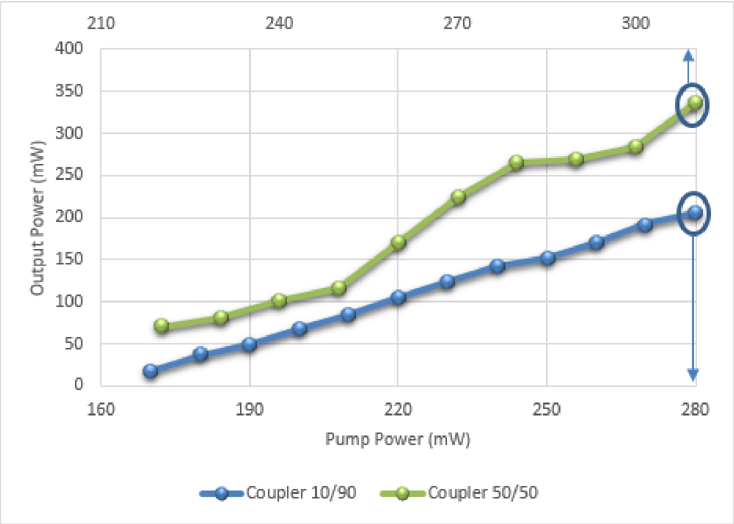

Figure 4. Output power versus pump power

In addition, to Q-switching theory as the pump power increases the repetition rate increases and the pulse width decreases. Same results could be achieved with low input power. As a comparison between two different kind of coupling ratios, 10/90 and 50/50, at pump power 280mW, the pulse energy of Q-switching pulses recorded 9.7nJ and 12.34nJ for 10/90 and 50/50 respectively as shown in Figure 5. Clearly good results can be achieved when coupler of 50/50 is used.

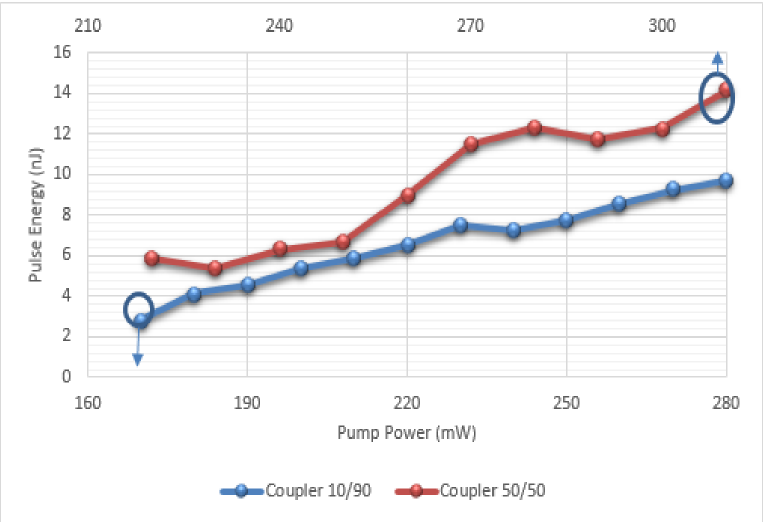

Figure 5. Pulse energy against the pump power

Clealry from Figures 6 and 7, as the pump power set at 280mW, the achievable repetition rates are 21.23kHz and 21.48kHz using coupler with ratios of 10/90 and 50/50 respectiviely. Thus pluse width 5.215µs and 4.9686µs for couplers with ratios of 10/90 and 50/50 respectiviely.

Since input power to OSA is limited, we stopped at 350mW as a pump power in case of coupling ratio 50/50, to avoid damaging the OSA. Hence, at the maximum state of input pump power, the repetition rate is 25.91kHz and the pulse width is 3.293µs. The pulse width obtained in this experiment is narrower compared to pulse width demonstrated by [15, 16], which is 9.84µs where the authors used black phosphorus to generate Q-switched laser pulse.

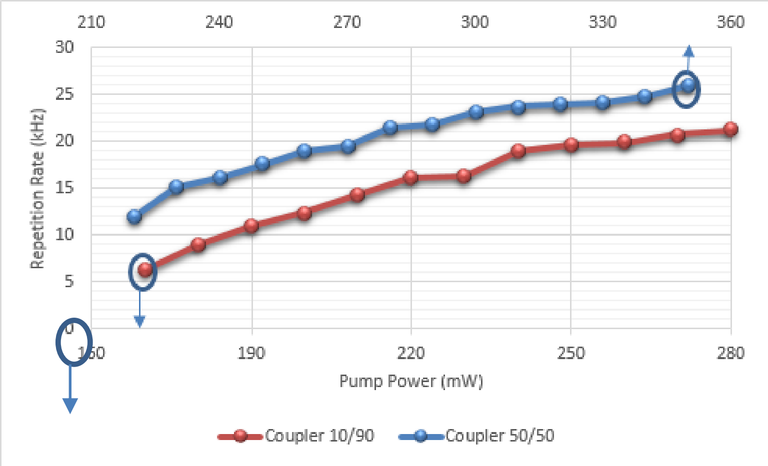

Figure 6. Repetition rate against the pump power

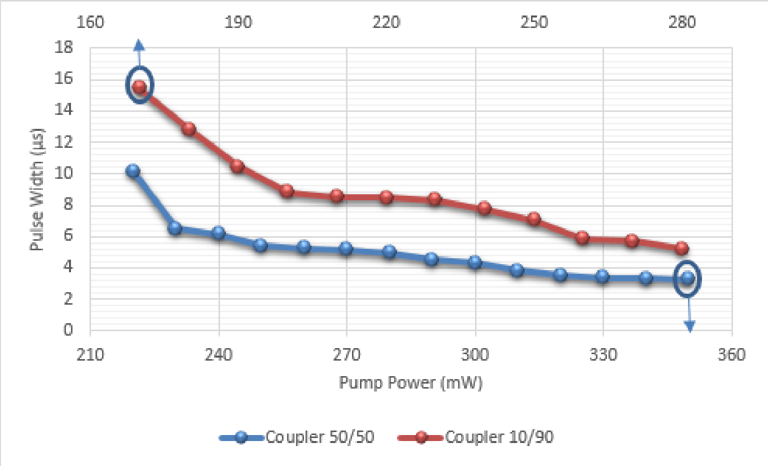

Figure 7. Pulse width against the pump power

4. CONCLUSIONS

In conclusion, the paper is experimentally investigated the effect of the different coupling ratio in CW fiber laser ring cavity. The output power of the ring cavity is tunable using different coupling ratio. Clearly 50/50 coupling ratio can be used to generate Q-switched pulses with good properties and high repetition rates. This achievement proves that a little feedback power to cavity is enough to generate Q-switched pulses, and it will also be useful to have an output pulses with high power.

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