IOP Conf. Series: Materials Science and Engineering **210** (2017) 012046 doi:10.1088/1757-899X/210/1/012046

Mode-locked Erbium-doped fiber laser generation using hybrid ZnO/GO saturable absorber

H. Hassan*, M. M. Ariannejad, R. Safaei, I. S. Amiri, H. Ahmad
Photonics Research Centre, University of Malaya, 50603 Kuala Lumpur, Malaysia

Email: *hazirah2711@siswa.um.edu.my

Abstract. Mode-locked generation of erbium-doped fiber laser (EDFL) with hybrid zinc oxide/graphene oxide (ZnO/GO) thin film as saturable absorber (SA) is proposed and practically demonstrated. The SA shows the modulation depth of 18.69% and it has been sandwiched between the fiber ferrules. Mode-locked pulse occurred at pump power of 14.8 mW and by varying the pump power to maximum threshold 27.43 mW, the repetition rate of the pulse fixed at 19.98 MHz at 1563 nm of central wavelength. The pulse width is estimated as 0.90 ps, whereas the pulse energy is calculated as 27.0 nJ.

1. Introduction

Nowadays, ultrafast fiber laser are of great interest among scientists and researchers due to their multifaceted applications for example in optical telecommucation, medicine and material processing. Although there are many types of ultrafast laser, passively mode-locked pulse laser is point out for the low cost, accuracy and compactness [1]. In order to generate passively mode-locked fiber laser, saturable absorber (SA) is governing the startup characteristics of the mode-locking process [2].

Many SAs had been used to produce mode-locked such as nonlinear polarization rotation (NPR), carbon nanotubes (CNTs), graphene oxide and many other 2D materials [3-6]. Compare to artificial saturable absorber approaches, film based SAs give a better performance in enviromental stability and independent to the polarization in the cavity. What is more interesting, when comparing between single material and hybrid material, hybrid material shows compelling technique to upgrade the graphene application by exhibiting the variety characteristics with high performance compare to single material [7]. Oxygen is reactive functional group that contain in the graphene oxide to enhance the chemical functionalization of the material. Besides that, various inorganic nanoparticle used to hybridize with GO or graphene for example Ag, Au, TiO_2 and ZnO.

In this article, mode-locked EDFL using hybrid ZnO/GO is proposed and demonstrated. Hybridization of the ZnO/GO is a new material use as SA to generate mode-locked fiber laser. ZnO/GO film is sandwiched between the fiber ferrules and the spectrum is observed. Addition to that, there is no mode-locked pulse construct using hybrid ZnO/GO SA.

2. Nonlinear Optical Absorption Characteristics of Hybrid ZnO/GO SA

Twin detector technique was used to characterize the nonlinear absorption characteristic [8] of hybrid ZnO/GO SA. A passively mode-locked fiber laser source is employed with pulse width of 0.60 ps, repetition rate of 28.01 MHz and central wavelength (λ_c) of 1563 nm. The output power from both detectors were recorded as the value of attenuation is gradually decreased. Low-dispersion amplifier and variable optical attenuator are used to control the signal power, then splitted into two equal part via 50/50 optical coupler. First output is connect directly to optical power meter (OPM), whereas the other output port is layered with ZnO/GO thin film before connected to another similar OPM.

From the result, the nonlinear optical absorption is calculated and fitted using the saturation model formula [9]:

$$\alpha(I) = \frac{\alpha_s}{1+\frac{I}{I_{sat}}} + \alpha_{ns} \quad (1)$$

where α is optical absorption, I is intensity, α_s is saturable absorption, α_{ns} is non-saturable absorption and I_{sat} is saturation intensity. Figure 1 depicts the absorption against power density graph of the SA.

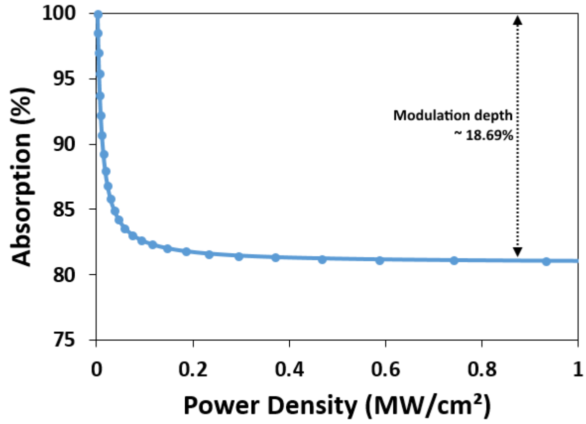

Figure 1. Measured saturable absorption of hybrid ZnO/GO SA.

3. Experimental Arrangement

The schematic drawing of the fiber laser is presented in Figure 2. The laser resonator is consist of 3-m EDF, wavelength division multiplexer (WDM), isolator, 3-dB output coupler and hybrid ZnO/GO SA. The EDF have absorption coefficient of 11.3 dB/m at 979 nm wavelength, mode field diameter of 6.6 µm and numerical aperture (NA) of 0.21. The EDF having backward-pumped by 1480 nm Fitel laser diode (LD) through WDM. The EDF is connected to the common port of the WDM and again to another similar WDM on its other end. The purpose of the second WDM is to remove any excess pump power from the laser cavity in order to optimize the performance of the system. When the EDF is pumped by the LD, amplified spontaneous emission (ASE) spectrum is generated. The ZnO/GO SA is insert between a pair of pigtails surface and integrated into the laser resonator. The cavity has total length around 9.5 m with the rest of the cavity is constructed with single mode-fiber SMF-28. Twenty percent of the light is removed from the ring resonator while another 80% is continues to pass through the resonator, via an optical isolator which ensure that the light propagate in one direction only. The spectrum of the laser is captured by the. An oscilloscope is used with a 1.2 GHz bandwidth photodetector to capture the mode-locked emission.

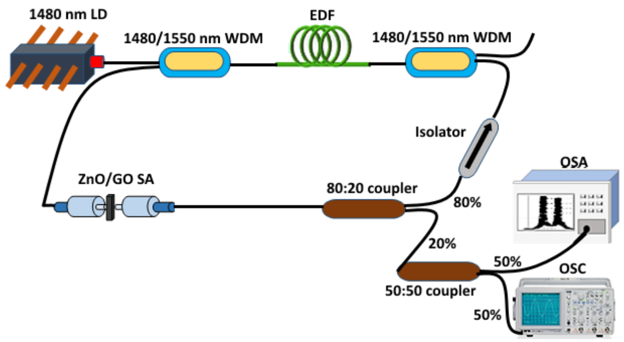

Figure 2. Experimental setup of the purposed mode-locked EDFL.

4. Results and Discussion

An Anritsu MS9740A optical spevtrum analyzer (OSA) with span 200 nm and resolution 0.03 nm is used to observe the output lasing spectrum of the EDFL via 50% of the cavity output. The initial threshold pump of the mode-locked operation started at 14.8 mW. But, when the pump power increases to until 27.43 mA, the mode-locked pulse starts to alter and diminish due to strong non-linear phase shift. A reliable mode-locked pulse train is observed at 14.8 mW pump power as shown in Figure 3 (a). During the operation of the mode-locking, the pulse repetition rate fixed at 19.98 MHz frequency which proved that the mode-locked formed at fundamental frequency. Figure 3 (b) depicts the mode-locked spectrum at central wavelength of 1563 nm and FWHM spectral bandwidth of 5.6 nm.

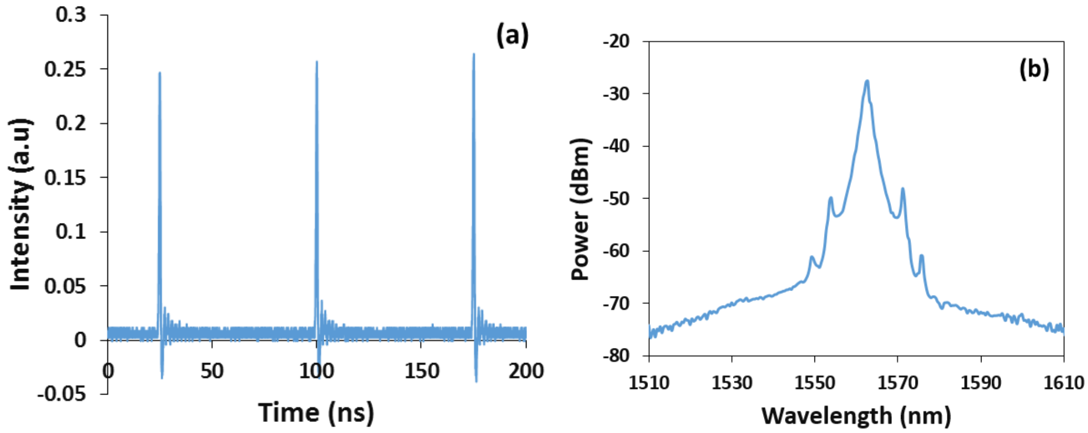

Figure 3. (a) mode-locked pulse train at 14.8 mW. (b) output spectrum from OSA

Besides that, RF spectrum analyzer is employed to check the stability of the mode-locked spectrum as shown in Figure 4 (a). The pulse width is analyze using autocorrelator. Figure 4 (b) depicts single pulse measured at 0.90 ps and resolution of 50 fs.

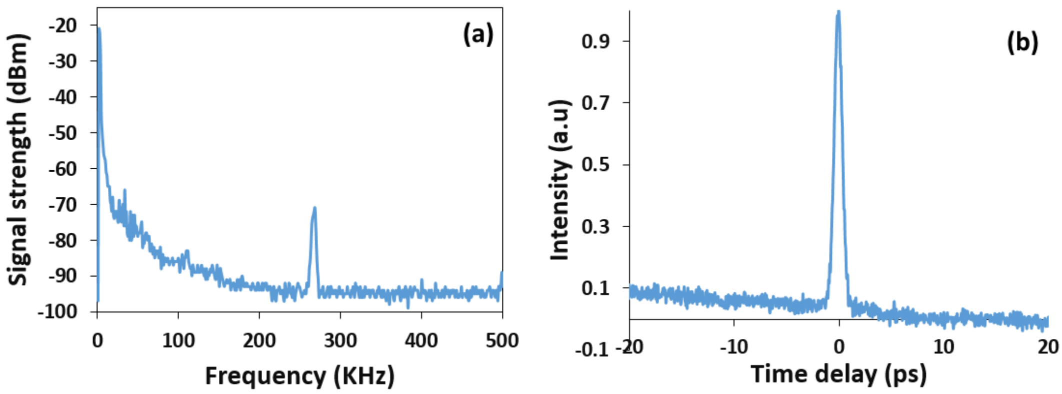

Figure 4. (a) Radio-frequency optical spectrum of the mode-locked EDFL. (b) pulse width captured by autocorrelator

Throughout the mode-locked operation, pulse energy increase when the pump power increase. The highest pulse energy is 37.5 nJ achieved when the pump power is 27.43 mW as shown in Figure 5.

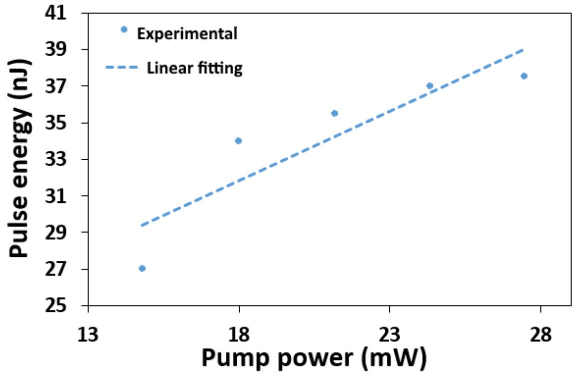

Figure 5. Pulse energy trend when increasing pump power

5. Conclusion

Passively mode-locked EDF laser have been proposed and practically demonstrated operating at 1563 nm with incorporation of hybrid ZnO/GO saturable absorber. The EDFL generates mode-locking pulse at pump power of 14.8 mW. By varying the pump power until 27.43 mW, the pulse repetition rate remain constant at 19.98 MHz with pulse width of 0.90 ps and having pulse energy of 27.0 nJ.

Acknowledgement

Funding for this research was made possible by the University of Malaya through the UMRG (RP029A-15AFR)

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