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SOLITON MODE-LOCKED GENERATION BASED ON ERBIUM-DOPED FIBER LASER EMBEDDED WITH SINGLE-WALLED CARBON NANOTUBES AS SATURABLE ABSORBER

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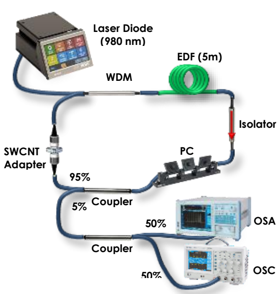
Graphical abstract



Abstract

Soliton mode-locked Erbium-doped fiber laser (EDFL) using single walled carbon nanotubes (SWCNTs) was experimentally demonstrated. In this work, SWCNTs was prepared by embedding into polyvinyl alcohol (PVA) as a saturable absorber. The laser generates a soliton pulse, which operates at 1570 nm region without any additional spectral filter as a 980 nm pump power is increased above the threshold value of 60 mW. The output solitons have a pulse duration of 0.7 ps with a repetition rate of 18.98 MHz. At pump power of 130 mW, the pulse energy and peak power are approximately 0.032 nJ and 43 W.

Keywords: Single-walled carbon nanotubes, mode-locked, passive saturable absorber, soliton, erbium-doped gain media

Abstrak

Penjanaan mod terkunci soliton (Mode-locked) daripada laser gentian berdop Erbium (EDFL) dengan menggunakan tiub nano karbon berdinding tunggal atau SWCNT telah dijalankan secara eksperiment. Dalam kajian ini, penyerap tepu SWCNT dihasilkan dengan melarutkan ia ke dalam polivinil alcohol (PVA). Laser denyutan soliton yang terhasil beroperasi pada kawasan gelombang 1570 nm tanpa penambahan penapis spektrum di mana pam laser pada 980 nm dinaikkan kuasanya melebihi nilai batas minimum pembentukan laser 60 mW. Soliton yang terhasil mempunyai ciri-ciri seperti jangka denyutan sebanyak 0.7 ps dengan kadar pengulangan sebanyak 18.98 MHz. Pada kuasa pam 130 mW. Tenaga denyutan dan puncak kuasa dianggarkan sebanyak 0.032 nJ dan 43 W.

Kata kunci: Tiub nano karbon berdinding tunggal, mod terkunci, penyerap tepu pasif, soliton, gain-media didopkan erbium

1.0 INTRODUCTION

Mode-locked Erbium-doped fiber lasers (EDFLs) are being intensely investigated in recent years due to their many advantages such as compactness, flexibility, and low cost [1, 2]. They have potential scientific applications in many fields such as industry, medicine, remote sensing and optical communication. Till now, mode locked EDFLs are usually achieved by using passive modulation techniques such as nonlinear polarization rotation (NPR) [3-5] and semiconductor saturable absorbers

(SESAMs) [6, 7], but either are costly or requires some finesse to implement, thus rendering the development of a compact ultrafast fiber laser unfeasible.

Recently, the use of carbon nanotubes (CNTs) and graphene material as passive saturable absorbers (SAs) has captured the interest of many researchers working on Q-switched and mode-locked fiber lasers [8-11]. This is due to a number of inherent advantages that they possess, including good compatibility with optical fibers, low saturation intensity, fast recovery time, and wide operating bandwidth. CNT-based SAs are still highly popular more than graphene, as they are easier to fabricate [12, 13]. Furthermore, CNT-based SAs may also have a lower non-saturable to saturable absorption ratio as compared to graphene [14]. A practical CNT absorber construction method suitable for industrial production must be cheap and fast where the output quality is consistent and the physical parameters are controllable. Recently, a simple and cost-effective alternative to fabricate saturable absorber by using composite with embedded SWCNTs in a polymer matrix has been proposed [15]. This method is very promising since the composite exhibits excellent homogeneous dispersion of SWCNTs and it can be used in the form of thin-film. To date, only a few researchers have reported on the fabrication of a high optical quality SWCNT polyvinyl alcohol (PVA) composite film for laser mode-locking applications. For instance.

This paper describes a proposed soliton mode locked Erbium-doped fiber laser (EDFL) in the L-band region using a simple, compact and cheap SWCNTs based SA. The SWCNTs were of larger diameter specifically chosen to operate optimally at a larger wavelength region of 1.5 μm and prepared using Polyvinyl alcohol (PVA) composite. The SA is constructed by sandwiching the composite film between two fiber connectors to generate mode-locked pulses with a pulse width of 0.7 ps as well as a repetition rate, average output power, pulse energy and peak power of 18.98 MHz, 0.42 mW, 0.032 nJ and 43 W, respectively. The proposed mode locked operates at L-band wavelength region which is desirable for many L-band applications, such as optical communications by using all-fiber configuration.

2.0 EXPERIMENTAL

Figure 1 shows the experimental setup of the proposed mode-locked EDFL using the fabricated SWCNTs-PVA film as a SA. A 5 m long Erbium-doped fiber (EDF) was manufactured by Fibercore Limited Company and was the I-25 product, which is employed as a gain medium. It is pumped by a 980 nm laser diode via a 980/1550 nm wavelength division multiplexer (WDM). The EDF has an absorption coefficient of 24 dB/m and 42 dB/m at 980nm and 1531nm, respectively. The EDF with numerical aperture of 0.24 has a cut-off wavelength of 900 nm and a mode field diameter of 5.8 μm. An isolator is used in the laser setup to avoid the backward reflection and ensure unidirectional propagation of the oscillating laser. A polarization controller (PC) is used to adjust the polarization state of the oscillating light propagating in the laser cavity. The output laser is tapped via a 95/5 coupler which keeps 95% of the light oscillating in the ring cavity. The SA is used to obtain the mode locked pulse, which was fabricated by sandwiching a small cutting of the film between two FC/PC fiber connectors. Index-matching gel was applied onto the fiber ferrule before attaching the film to minimize the insertion loss. The insertion loss of the SA was approximately 1.5 dB at 1550 nm. The cavity length is measured to be approximately 15 m. The optical spectrum analyzer (OSA) with a spectral resolution of 0.07 nm was used for the spectral analysis of the mode-locked laser and an oscilloscope (OSC) was used to analyze the output pulse train of the mode-locking operation via a photo-detector. Optical autocorrelators was used to measure the pulse width of the output pulse train.

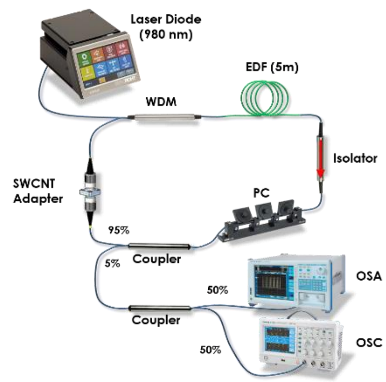


Figure 1 Experimental setup for the mode-locked EDFL

3.0 RESULTS AND DISCUSSION

The performance of the proposed mode-locked EDFL is investigated by varying the 980 nm pump power from 0 to 130 mW. It is observed that the stable soliton mode locking pulse generation begins when pump power reaches 60 mW. The mode-locking pulse generation is due to the SWCNTs-PVA film, which functions as SA. The SA preferentially transmits higher power and promotes the formation of a pulse from noise. Figure 2 shows the output spectra of the proposed EDFL at pump power of 130 mW. From the figure it can be seen that the output pulse is operating in soliton pulse regime with multi-wavelength sidebands. The obtained spectrum is broad from approximately 1561 nm to about 1576 nm at a reference level of -45 dBm with a peak power of about -36 dBm at center wavelength of 1570 nm. The 3-dB bandwidth of the spectrum is 9.8 nm.

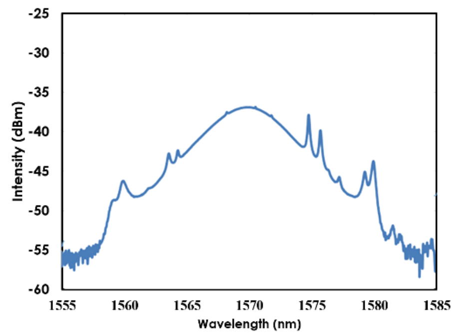


Figure 2 Optical spectrum of the proposed EDFL mode-locked at pump power of 130mw

Figure 3 shows the oscilloscope pulse train obtained from the EDFL mode locked at pump power of 130 mW. It can be seen from the figure that the pulse train is quite uniform with pulse separation of 52.68 ns. The measured repetition rate of the pulses is approximately 18.98 MHz, which is about the same as the calculated value, taking into account the length and the refractive indices of the different fibers that make up the laser cavity. Figure 4 shows the autocorrelation trace of the soliton takes on a sech^2 field with pulse duration of 0.7 ps is measured at the full width half maximum (FWHM).

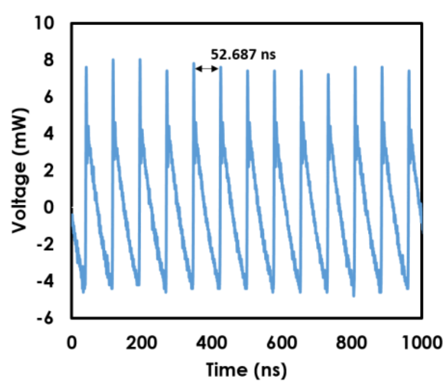


Figure 3 Pulse train from the proposed mode locked EDFL at pump power of 130mW

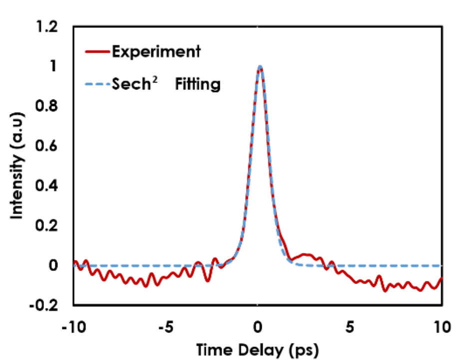


Figure 4 Autocorrelator trace with sech^2 fitting at pump power of 130 mW

Figure 5 shows the RF spectrum which is result of the frequency beating between every two modes in mode locked laser. From the figure, the first harmonic is obtained at 18.98 MHz, with subsequent harmonics occurring at nth intervals, thus validating the pulse train obtained in Figure 5. The RF spectrum confirms that the signal to noise ratio of the mode locked is 42 dB at frequency of 18.98 MHz, thus indicating that the output pulse is stable with low amplitude fluctuations. Figure 6 shows the average output power and pulse energy as function of 980 nm pump power. From the figure it is observed that both output power and pulse energy increase linearly with the increment of the pump power. At pump power of 130 mW, the average output power of the soliton mode locked is 0.42 mW and thus the pulse energy and peak power are estimated at 0.032 nJ and 43 W, respectively.

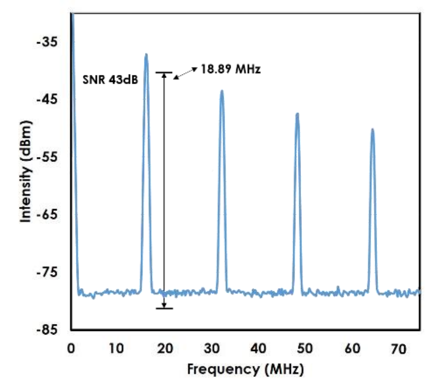


Figure 5 RF spectrum measured over the range scale of 70 MHz

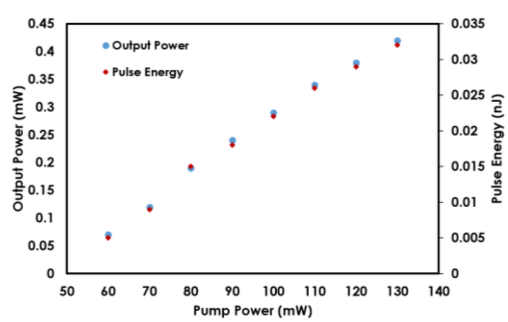


Figure 6 Average output power and pulse energy as function of 980 nm pump power for the proposed mode locked EDFL

4.0 CONCLUSION

In this work, a passively mode-locked EDFL using SWCNTs-PVA based SA is proposed and demonstrated. The SWCNTs-PVA thin film is sandwiched between two ferrules and incorporated in the EDFL ring cavity to generate a soliton mode-locked pulse train operating in 1569.3 nm region. The mode locked have a repetition rate, average output power and pulse energy of 18.98 MHz, 0.42 mW and 0.032 nJ, respectively. The peak power of the output pulses is 43 W, with a pulse width of 0.7 ps. This proposed EDFL mode-locked has narrow pulse width in the L-band region, making it suitable as a very short pulse generator for optical communications and sensing applications.

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