TUNEABLE FIBER LASER USING SINGLE WALLED CARBON NANOTUBES BASED SATURABLE ABSORBER AND AWG AS SELECTIVE ELEMENT

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Abstract

We report a tunable wavelength fiber laser in Q switched regime using a droplet of single walled carbon nanotubes polymer composite as passive saturable absorber and array waveguide grating as wavelength selective element. The tuneable wavelength is around 18 nm and the repetition rate is fluctuated from 5.4 kHz to 15 kHz. The highest average output power is around 0.007 mW, the maximum pulse energy is 0.7 nJ and the minimum pulse width generated in this proposed set up is around 8 µs.

Keywords: AWG, Single walled carbon nanotubes, Tunable fiber laser

Introduction

Recent advancement in pulse laser has been attracted enormous interest among researchers to work in Q-switched and mode locked regime using passive saturable absorber (SA). Pulse laser with different wavelength, pulse duration and repetition rate have a different potential applications such as optical communications and laser surgery [1-3]. The most widely used passive SA are semiconductor saturable absorber mirror (SESAM) [4], graphene [5,6] and single-walled carbon nanotubes (SWCNT) [7,8] due to ease of integration in fiber cavity and not require any external trigger.

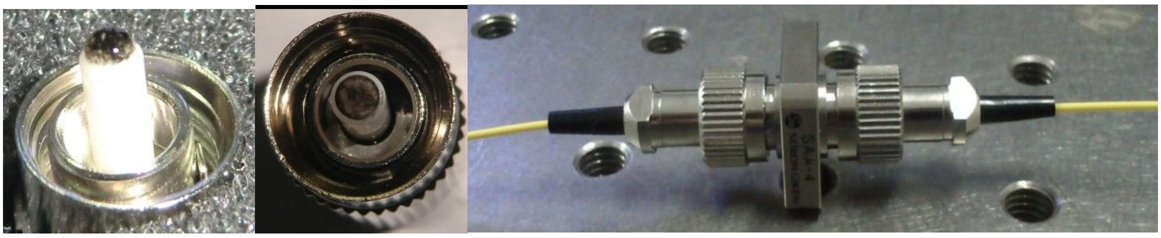
Compared to mode-locking, Q-switching requires less control of cavity parameter and efficient in term of cost, operation and implementation [9]. Recently, tunable fiber laser have been demonstrated using graphene based film [9] and SWCNT [10,11] which enable simultaneously wavelength tuning with pulse laser.

Zhou et al. (2010) using optical deposition method to deposit SWCNT to the fiber end and they used fiber Bragg grating (FBG) as tuning element. To reduced insertion loss of SWCNT, Dong et al. (2010) proposed to deposit SWCNT on the core surface of the SMF end with the aided of optical deposition method and they used variable optical attenuator to tune the gain spectrum. One of the drawbacks of the optical deposition method is to obtain an optimum power and time for deposition for different SWCNT suspension. Most of the reported optical deposition method requires repetition process to control the insertion loss.

This work reported a simple approach of SWCNT deposition to the end of fiber ferrule by using a droplet of the SWCNT-SA based polymer composite suspension. The SWCNT-SA able to work in Q-switched regime and arrayed waveguide grating (AWG) was used as a wavelength selective element for tunable laser with pulse capability.

SWCNT Saturable Absorber Preparation

The SWCNTs used were 99% pure with a diameter of 1-2 nm and length of 3-30 µm and thus it required no purification process. In the experiments, the SWCNTs grains were dispersed in De-ionized (DI) water by means of the surfactant sodium dedocyl sulfate (SDS), which allowed the dispersion of the tubes as individuals in aqueous solution. Nanotubes dispersion was assisted by combining both tip and bath ultrasonication approaches. In the process, 250 mg SWCNTs was added to 400 ml SDS solution in deionized water with 1% concentration and subjected to ultrasonic treatment using a tip sonicator for about 3 hours. A small number of pulses, with a pulse cycle of 0.5s at 90 W/cm^2, were applied to the SWCNTs solution and then undergone ultrasonic bath for 30 minutes at 50 W. Subsequently, the obtained suspension was centrifuged at 1000 rpm to remove large particles of undispersed carbon nanotubes to obtain dispersed suspension that is stable for weeks. SWCNT-PEO composite was fabricated by adding 2.0 ml dispersed SWCNT suspension containing 1.125 mg solid SWCNT into a solution of 1 g Polyethylene oxide (PEO) (average molecular weight of 1 x 10^6 g/mol) in deionized water and thoroughly mixed. The SA is fabricated by dropping a droplet of the suspension to the end of fiber ferrule and let it dry for 24 hours. This will create a thin layer of SWCNT-PEO polymer composite and then mated with another clean fiber ferrule through fiber connecter, which then integrated in the fiber laser ring cavity as shown in Figure 1. The insertion loss was measured as 5 dB.



(a) (b) (c)

Figure 1. (a) Droplet of SWCNT-PEO (b) Thin layer after left in room temperature for 24 hours (c) Integration in fiber laser

Raman spectroscopy was then used to confirm the presence of SWCNTs within the composites and their diameter distribution. Figure 2 shows Raman spectrum of SWCNT-PEO composite deposited on the fiber ferrule, taken at 532 nm excitation. The spectrum obviously shows the distinct feature of the SWCNT where the so-called G peak originated from tangential vibrations of the carbon atoms [12], was observed to be prominent at 1586 cm^{-1}. The sharp Lorentzian G peak indicates that the semiconducting SWCNT is properly attached to the end of fiber ferrule. In the low frequency region, the radial breathing modes are observed, which their energy is inversely related to SWCNT diameter. The diameters of the SWCNT, d, can be estimated from the peak position, ω_{rbm} using the relationship d(nm) = $248/\omega_{rbm}(cm^{-1})$[13]. Since, the two distinct peaks are observed at 161 and 241 cm^{-1}, the SWCNT diameter is estimated to be within 1.0 to 1.5 nm. The carbon and G' are also observed at 1393 cm^{-1} and 2686 cm^{-1}, respectively.

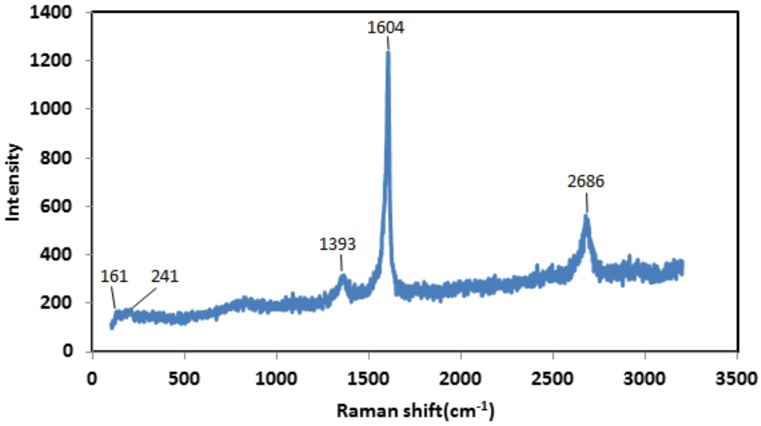


Figure 2. Raman spectrum of the SWCNT polymer composite deposited on the fiber ferrule

Experimental Setup

Figure 3 shows the proposed setup for the tuneable fiber laser operated in Q-switched region. The proposed setup employed a 1 m highly doped large mode area EDF (LIEKKI Er80-8/125) and used as the gain medium. This fibre was employed as the high erbium concentration decreases considerably the length of the required fibre for lasing whilst simultaneously reducing the possibility of nonlinear effects to occur in the fibre. The length of the fibre has been optimised to ensure optimum gain in the proposed configuration.

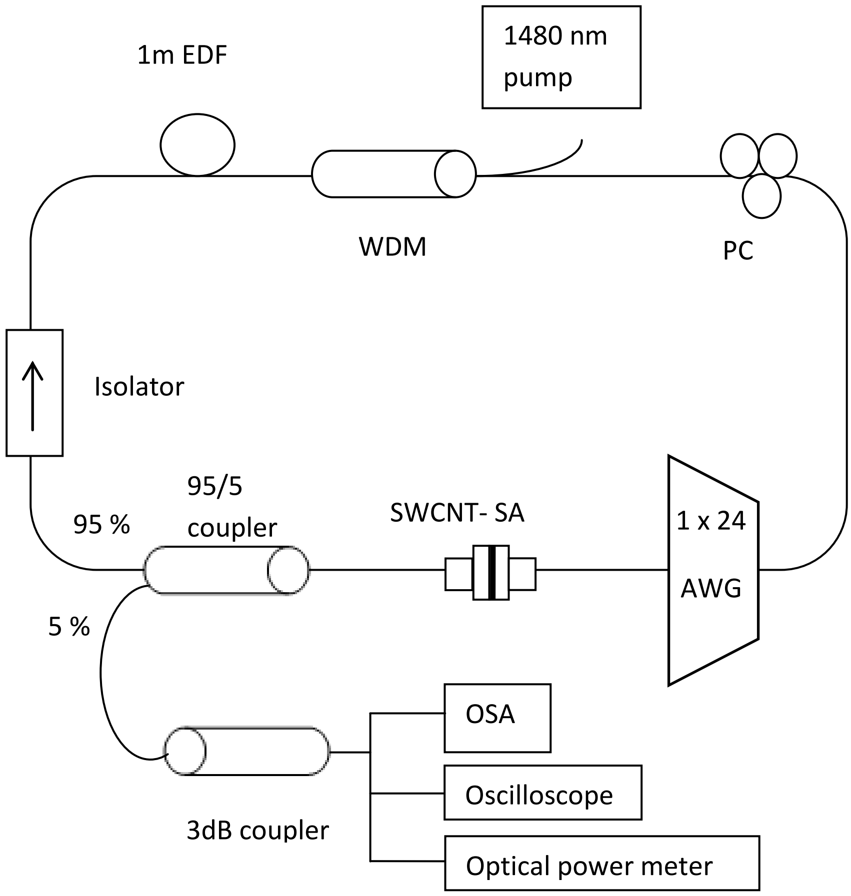


Figure 3. Experimental setup of the proposed tunable fiber laser. (PC: polarisation controller; AWG: arrayed waveguide grating; SWCNT-SA : single walled carbon nanotubes saturable Absorber; OSA: optical spectrum analyser; WDM: 1490/1550 nm wavelength division multiplexer; EDF: erbium-doped fibre)

The EDF is pumped by a 1480 nm laser diode pump, which is connected via a 1480/1550 nm wavelength division multiplexer (WDM). The WDM is then connected to a Polarisation controller (PC) and a 1x24 channel arrayed waveguide grating (AWG) as a wavelength selective element. Output of the AWG is connected to SWCNT-SA which act as a passive saturable absorber that only allow high intensity light pass through to create pulse laser. The output of the saturable absorber are connected to 95/5 coupler with 5% of the output going to 3 dB coupler which is connected to optical spectrum analyser (OSA), an oscilloscope and optical power meter for data collection. The remaining 95% is connected to isolator to ensure unidirectional operation and the ring cavity is employed by connecting EDF gain medium in between WDM and the isolator.

Results and Discussion

By employing AWG as wavelength selective element, the wavelength can be tuned from channel 1 to channel 24 with 0.8 nm inter channel spacing. The output spectra for different wavelengths are illustrated in Figure 4 with pump power of 112 mW. The tuneable wavelength is from 1530.4 nm to 1548.5 nm which is around 18 nm, higher than reported by Zhou (2010) which is about 5 nm. The peak output power is stable for wavelength below 1540 nm and fluctuated at wavelength 1541.4 and 1544.6.

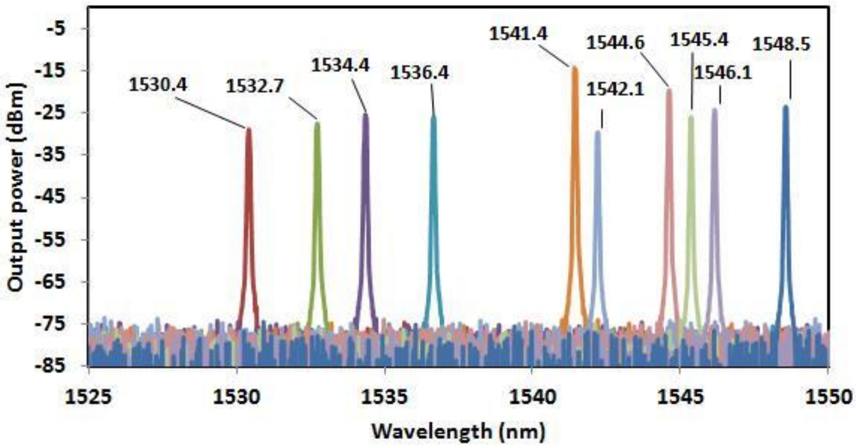


Figure 4. Tuneable wavelength fiber laser

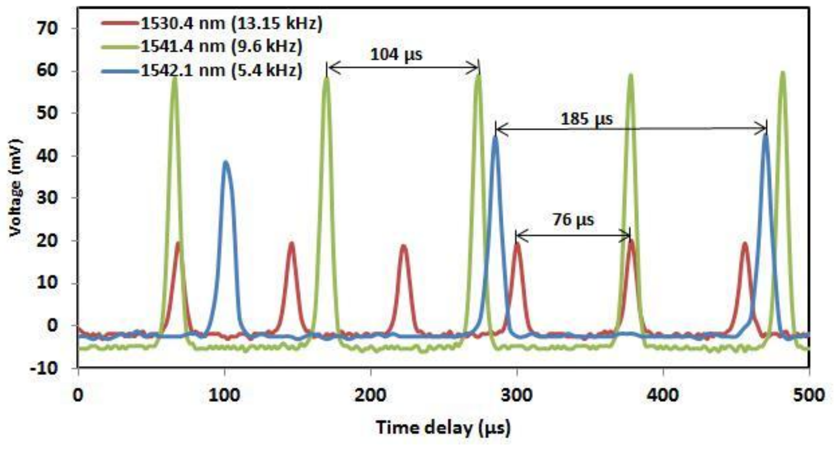


Figure 5. Train of pulses for tuneable wavelength at 1530.4 nm 1541.4 nm and 1542.1 nm

Figure 5 shows the train of pulses for three different wavelengths which carry different repetition rate. For wavelength at 1530.36 nm, 1541.40 nm and 1542.17 nm, the respective repetition rate is 13.15 kHz, 9.6 kHz and 5.4 kHz. The train of pulses shows stable pulses with a constant time delay. The resonance wavelength is depending on diameter of SWCNT with inversely proportional relationship given by $d_t = 248/\omega_{RBM}$, [14, 15] where d_t is tubes diameter and ω_{RBM} is Raman shift for radial breathing mode (RBM). Each channel in AWG is operated in different wavelength and the repetition rate will be varies for different wavelength depending on the SWCNT diameter consist in the SWCNT-SA polymer composite which is randomly distributed.

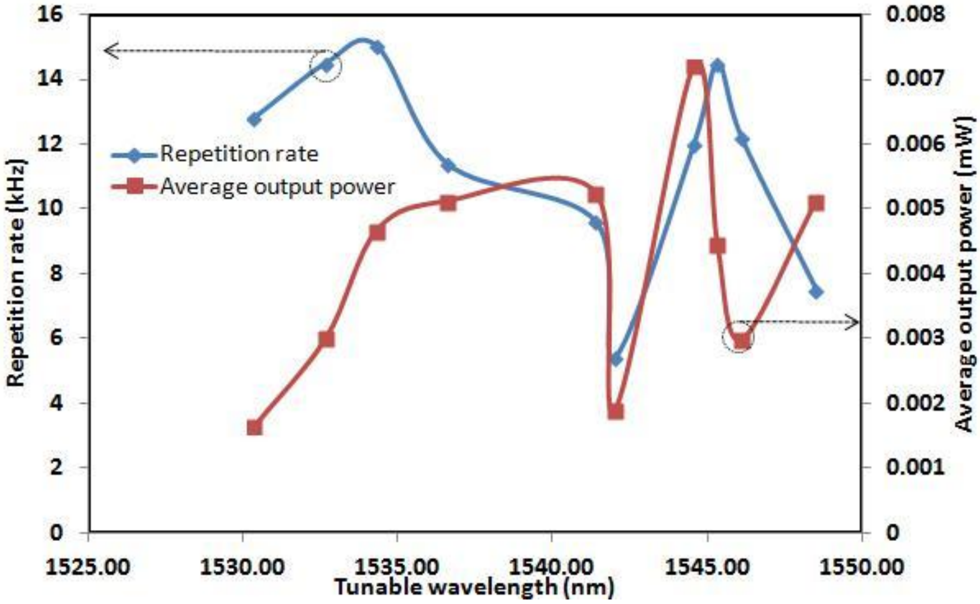


Figure 6. Pulse repetition rate and average output versus tunable wavelength

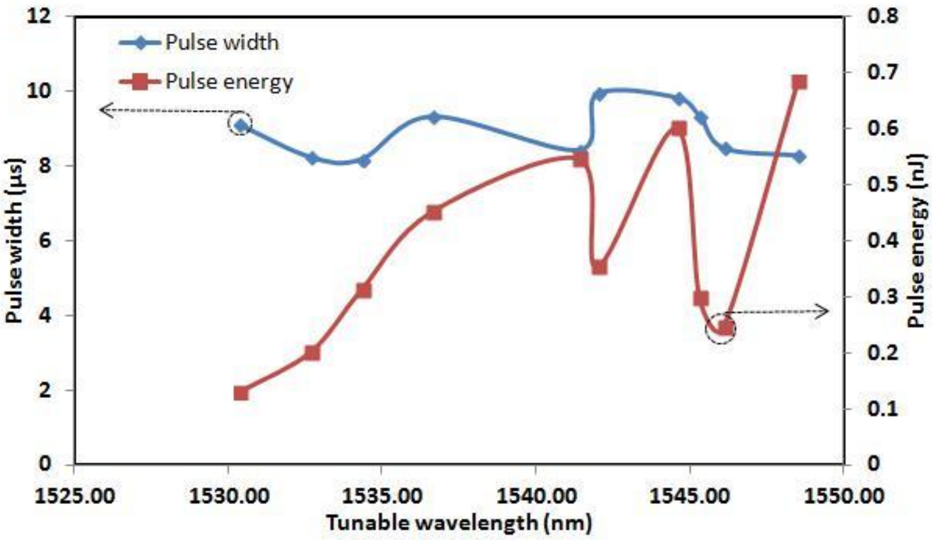


Figure 7. Pulse width and energy versus tunable wavelength

Figure 6 shows a repetition rate and average output power versus tuneable wavelength. The repetition rate of the tuneable wavelength is fluctuated with the maximum repetition rate is 15 kHz and the minimum is 5.4 kHz. The highest average output power is around 0.007

mW. Figure 7 shows a pulse width and pulse energy versus tuneable wavelength. The maximum pulse energy is 0.7 nJ and the minimum pulse width generated in this proposed set up is around 8 µs. The fluctuation of the calculated and recorded data as plotted in Figure 6 and Figure 7 is due to different insertion loss of each channel in AWG which represent different tuneable wavelength.

Conclusions

A stable Q-switched operation is demonstrated using a simple deposition droplet of SWCNT-PEO polymer composite droplet to the end of fiber ferrule and act as a passive saturable absorber. To tune the wavelength, AWG was used as selective element and it's demonstrated the capability to tune around 18 nm. The repetition rate of the tuneable wavelength is fluctuated from 5.4 kHz to 15 kHz. The highest average output power is around 0.007 mW, the maximum pulse energy is 0.7 nJ and the minimum pulse width is around 8 µs. The major merit of the SWCNT-PEO saturable absorber is ease of fabrication compare to SESAM, easy integration in the fiber laser and broad tuneable wavelength

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