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Q-switched Erbium-Doped Fiber Laser Incorporating Multi-Walled Carbon Nanotubes as a Saturable Absorber

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Q-switched Erbium-Doped Fiber Laser Incorporating Multi-Walled Carbon Nanotubes as a Saturable Absorber

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Abstract. We demonstrate the generation of Q-Switched erbium-doped fiber laser (EDFL) by employing a multi-walled carbon nanotubes-polyvinyl alcohol (MWCNTs-PVA) as a saturable absorber (SA). The SA was prepared by embedding MWCNTs into PVA via stirring and ultrasonication. A stable Q-Switched pulse train operating at 1559.4 nm was successfully generated by employing MWCNTs-PVA SA into a laser cavity. The repetition rate and pulse width of the laser were 52.85-151.9 kHz and 6.313-2.395 μ s, respectively. The maximum output power and maximum peak power obtained are 52 μ W and 142.94 μ W, respectively at a pump power of 63 mW. This demonstration proves that the MWCNTs-PVA based SA is suitable for the generation of Q-Switched fiber laser at 1.55 μ m region.

1. Introduction

Pulsed laser is a potential device for vast industrial applications including biomedical, micromachining, and laser cutting technology. It can be realized using passive or active technique. The latter suffer from few drawbacks including bulky, costly and frequent maintenance configuration. Therefore, the passive approach is preferable due to its simplicity, maintenance-free operation and portable. Passively Q-switched is initiated using the modulation of Q-factor in the laser cavity by a saturable absorber (SA). Various materials are incorporated inside an all-fiberized laser cavity as a SA such as nanoparticles [1], inorganic compound [2], and 2-dimensional materials [3, 4]. However, those materials possess few limitations such as low-operating bandwidth, complex fabrication procedure and immature SA device.

Carbon nanotubes (CNTs) is one of the most investigated material in recent years [5, 6]. CNTs is an atomically arranged carbon with sp^2 hybridized hexagonal honeycomb lattice structure. It owns an outstanding physical and chemical characteristics alike graphene. The superiority of CNTs including; a very thin structure, strong material, high electrical conductivity ($0.34-1.10^4 \Omega\text{cm}$), high melting temperature, lightweight material, tuneable electronic structure, flexible, and possesses a high thermal conductivity than graphene (3000 W/K) [7]. CNTs can be classified into two; single walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs). SWCNTs has a diameter of approximately 1-2 nm whereas MWCNTs owns a diameter of 2-50 nm. CNTs had been manipulated in



various field such as sensor, membrane, energy storage for lithium ion-batteries, electrodes of supercapacitor, fuel cell components, candidates for molecular electronics, electron-field emitter, composite fibers, biomedical applications, saturable absorber (SA), etc.

SWCNTs, CNTs and graphene was the most investigated SA as they own unique optical and physical properties. Vast research works demonstrated Q-switched generation using MWCNTs as a passive SA. MWCNTs was proposed to be an efficient SA in ytterbium-doped fiber laser (YDFL) [8], erbium-doped fiber laser (EDFL) [9] with nanotube diameter less than 8 nm, thulium-doped fiber laser (TDFL) [10], multi-walled carbon nanotubes-polyethylene oxide (MWCNTs-PEO) for Q-switched EDFL [11], high power Q-switched TDFL [12], MWCNTs doped bismuth telluride as SA for multiwavelength generation [13], and dual-wavelength generation [14]. Here, we demonstrated Q-switched erbium-doped fiber laser incorporating multi-walled carbon nanotubes-polyvinyl alcohol (MWCNTs-PVA) as SA. Our SA generates stable Q-switched with an operating wavelength of 1559.4 nm, maximum repetition rate of 151.9 kHz, and minimum pulse width of 2.395 μ s.

2. Preparation of MWCNTs-PVA

The MWCNTs used has a 99.99% purity, a 1-2 μ m length, and a 10-20 nm diameter. Synthesis of SA starts with the preparation of functionalizer solution. The solution was produced by dissolving 4 g of natrium dodecyl sulphate in a 400 mL of deionized (DI) water. The functionalizer act as a solvent for the MWCNTs to mixed with water. Next, approximately 250 mg of MWCNTs was added to the functionalizer solution. The solution was then ultrasonicated at 50 W for 6 min, thus a homogeneous dispersion of MWCNTs was produced. The prepared solution was further centrifuged at 1000 rpm to get rid of the large particles from MWCNTs. The distributed suspension was stable for few weeks. The MWCNTs-PVA composite was fused with PVA to produce a free-standing thin film. PVA was chose as a host as it owns excellent film forming, good adhesive properties, ease to emulsify, high tensile strength, flexible, contain high oxygen and aroma barrier. First, the PVA solution was prepared by dissolving 1 g of PVA into 400 mL of DI water. The solution was further mixed with the prepared MWCNTs suspension. A 2:3 composition was used to produce MWCNTs-PVA. The mixture was then ultrasonicated for 1 hr. The ultrasonication allows the production of a precursor with enough viscosity for thin film preparation. Finally, the precursor was distributed over a glass substrate and left to dry at room temperature for few days. The dried MWCNTs-PVA was then peeled off from the glass and employed into the laser cavity for pulse generation.

3. Erbium Doped Fiber Laser Ring Cavity

Erbium-doped fiber laser cavity for the generation of Q-switched was drawn in Figure 1. The incorporation of SA inside an EDFL cavity was done by sandwiching a 1 mm x 1 mm thin film of MWCNTs in between two fiber-ferrule. The fiber-ferrule surface was applied with a sol-gel before the SA was incorporated to ensure less friction between the two surfaces of fiber-ferrule. A light was pumped via a 980 nm port of wavelength-division multiplexer (WDM) using a 980 nm laser diode pump. An EDF with an absorption coefficient of 23-27 dB/m, a numerical aperture (NA) of 0.16, a core diameter of 4 μ m and a cladding diameter of 125 μ m was used as a gain medium. The isolator was connected to the EDF thus allowing unidirectional light to propagate inside the laser setup. The light was then converged to the MWCNTs-PVA as SA for the purpose of Q-factor modulation inside the cavity. Then, the light was allowed to pass through an optical coupler with the signal division ratio of 90/10. A 90% of the signal cycles back into the cavity via 1550 nm port of WDM. Remaining 10% of the light was tapped out of the cavity for analysis purposes. The stability of the signal was evaluated using radio frequency spectrum analyzer (RFS) (ANRITSU, MS2683A). Digital oscilloscope (GWINSTEK, GDS-3352) was used to measure the temporal performance of the pulses. Both oscilloscope and RFS was connected to the 10% output from the cavity via a 1.2-GHz InGaAs photodetector. The spectral performance was recorded using optical spectrum analyzer (YOKOGAWA, AQ6370D) with the resolution of 0.03 nm. The output power was also recorded using an optical power meter.

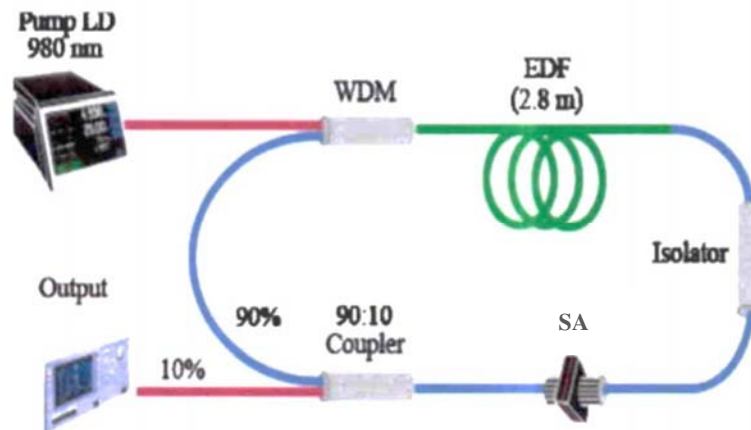


Figure 1. Experimental setup for Q-switched erbium-doped fiber laser using MWCNTs-PVA as saturable absorber.

4. Result and Discussion

The laser cavity starts to generate continuous wave (CW) at a pump power of 20 mW. Figure 2 (a) displayed a CW spectrum of laser cavity without the incorporation of SA at a pump power of 30 mW. The CW has a center wavelength of 1571.6 nm. As the SA was deployed into the laser cavity, the center wavelength shifted to 1559.4 nm. This is due to the increment of loss induced by the MWCNTs-PVA as SA in the EDFL cavity. The Q-switched EDFL possessed a 3dB spectral bandwidth of 1.4 nm as depicted in Figure 2 (b). The graph of output power against wavelength was obtained at a pump power of 59 mW. Oscilloscope trace of Q-switched at a pump power of 59 mW was shown in Figure 2 (c) with inset of two pulses envelope was also plotted. It was observed that the pulse generated has a full-width half maximum (FWHM) of 2.48 μs with a peak-to-peak distance of 7.3 μs . RF spectrum shown in Figure 2 (d) exhibit signal-to-noise ratio (SNR) of 34.12 dB which indicates stability of the pulses generated. The fundamental frequency measured was 137.1 kHz, which is in a good agreement with the oscilloscope trace.

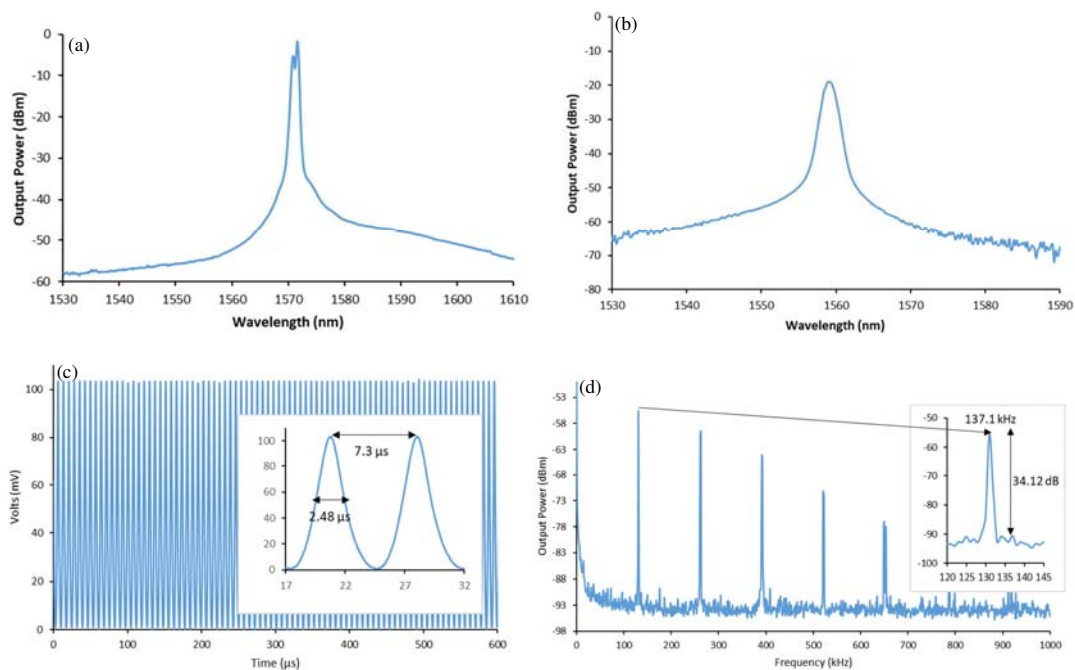


Figure 2. Spectral and temporal performances; (a) continuous-wave spectrum, (b) Q-switched spectrum, (c) typical oscilloscope trace with two pulses envelopes, and (d) RF spectrum of the Q-switched laser at 59 mW pump power.

The Q-switched pulse was investigated over a variation of pump power. As the pump power raised from 30 to 63 mW, stable pulses observed on the digital oscilloscope. The pulses minimized and eventually disappeared as the pump power adjusted above 63 mW. As the pump power increased from 30 to 63 mW, repetition rate of the pulses increased from 52.85 to 151.9 kHz whereas pulse width decreased from 6.313 to 2.395 μ s. The relationship between pulse width and repetition rate with pump power was shown in Figure 3 (a). Figure 3 (b) shows measured output power which was 17 to 52 μ W plotted against the pump power. Whereas, calculated peak power was also plotted in the same figure as the pump power increased from 30 to 63 mW. The Q-switched generated exhibit a peak power of 50.95 to 142.94 μ W.

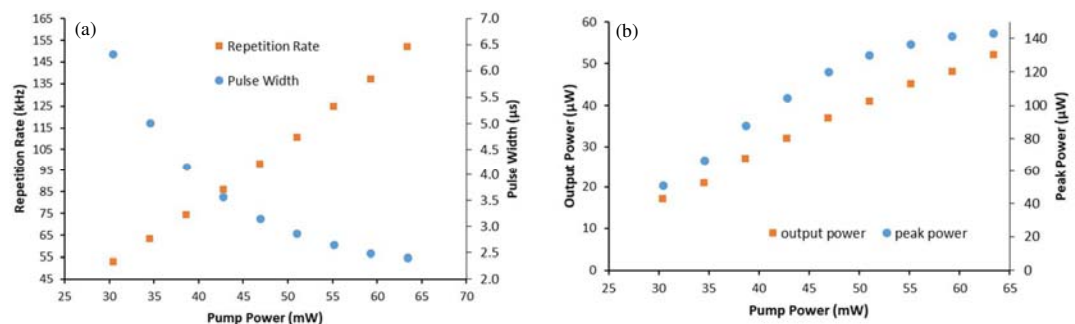


Figure 3. Q-switching performance; (a) repetition rate and pulse width against pump power and (b) output power and peak power against pump power.

5. Conclusion

We presented Q-switched erbium-doped fiber laser using MWCNTs-PVA incorporated into a laser cavity as a saturable absorber. The SA was prepared by embedding MWCNTs with PVA. A spectrum with an operating wavelength of 1559.4 nm captured on the optical spectrum analyzer. A stable Q-switched generated pulse width of 6.313 to 2.395 μ s within the pump power of 30 to 63 mW. The repetition rate recorded within the same pump power was 52.85 to 151.9 kHz. SNR measured was 34.12 dB indicating stability of the laser. The maximum output power generated was 52 μ W with the maximum peak power of 142.94 μ W.

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