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Pulsed Laser Performance of Erbium Doped Fiber Laser Using Titanium Dioxide Nanoparticles as Saturable Absorber

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Abstract. In this work, titanium dioxide TiO₂ nanoparticles embedded in thin composite film was used as saturable absorber (SA) in erbium doped fiber (EDF) laser. The thin film was prepared by mixing TiO₂ nanoparticles with polyvinyl alcohol (PVA) as host. Upon inserting the SA in a laser cavity, the output spectrum shifts to 1533.4 nm from 1563.8 nm. The laser performance was evaluated in the pump power range of 76 mW – 131 mW. The repetition rate of the mode-locked pulses was 989.0 kHz with a pulse width of 1.26 ps measured. The slope efficiency of the system is 8.58%. Maximum average power and peak power generated from the laser is 11.69 mW and 9.41 kW, respectively. This work explored the potential of TiO₂-PVA thin film as saturable absorber for 1.5 μm laser system.

1. Introduction

Nowadays, variety applications such as material processing and medicine highly demand passively pulsed laser as the laser source [1]. In achieving this, Q-switching and mode-locking in fiber lasers have historically been performed by actively modulating losses inside the active laser cavity using acousto-optic or electro-optic modulators [2]–[4]. However, this alternative was quickly rendered unsuitable for most real-world applications by the bulky design of the modulators, as well as their relatively high cost. As such, research efforts were aimed at developing passive fiber laser system, which provided a comparable performance but in a far more compact way. Saturable absorber (SA) is one of material that can be used to generate both Q-switched and mode-locked pulses. Through many years of the progression of SA research, some materials have proven potential to achieve mode lock pulsed laser: semiconductor saturated absorber mirrors (SESAMs) [5], [6], zinc oxide [7], black phosphorus [8] and graphene oxide [9].

However, SESAM has disadvantages in complex fabrication and size not quite applicable for fiber laser [10]. Moreover, black phosphorus is poisonous hence need cautious handling [11]. In addition, Graphene oxide has a low modulation depth due to layer dependent [12]. Titanium dioxide (TiO₂) nanoparticles on the other hand had shown promising nonlinear properties making it an excellent candidate as SA in fiber laser system [12]. It has good optical properties such as high refractive index



and better transmission in the near-infrared region [13]. In this article, a mode locked EDF laser using TiO_2 nanoparticles embedded in Polyvinyl alcohol (PVA) as saturable absorber is reported.

2. Sample preparation

For this study, TiO_2 nanoparticles with an average size of 28nm were used. The nanoparticles were produced by Nanografi Nano Technology. PVA was used as the matrix to contain the nanoparticles. To produce the PVA solution, 1 gram of PVA powder was mixed with 120 ml of deionized water. After that, the solution was stirred using magnetic stirrer with a rotation speed of 350 rpm, and the solution was heated at 80 – 90 °C for 1 hour simultaneously. 60 mg of TiO_2 nanoparticles powder was mixed with 30 ml deionized water. The mixture stirred using a magnetic stirrer at room temperature for 3 hours. After that, the mixture put into an ultrasonic bath for 1 hour to make sure the mixture is blended well. Now both 10 ml of PVA solution and 20 ml TiO_2 mixture were mixed and stirred for 1 hour. Then, the TiO_2 -PVA mixture is put in the ultrasonic bath for 30 minutes. The mixture is poured into a small petri dish and left it dry for 48 hours to form a composite film.

3. Experimental setup

The laser cavity was pumped with 974 nm laser diode between 76 – 131 mW pump power passing through the wavelength division multiplexer (WDM). An erbium doped fiber (EDF) with 3m length is used as the gain medium and spliced with 200m single mode fiber. The TiO_2 thin film with dimension about 1mm x 1mm was sandwiched between FC to FC fiber optic adapter as passive mode locker. The output laser extracted using output coupler with ratio of 90:10. 10 % of the intracavity light extracted from the cavity as the laser output. The 90 % remaining channeled back into the cavity through isolator to make sure unidirectional light propagation. The laser output was connected to oscilloscope (YOKOGAWA AQ6370C) for pulse train measurement. The laser output was coupled to optical spectrum analyzer (YOKOGAWA DLM2054) to observe the optical spectrum. After that it will be connected to power meter (Thorlabs PM100D) to measure its output power. Lastly, for pulse width measurement the fiber was coupled to auto correlator. The schematic diagram of the experimental setup used in this work is shown in Figure 1.

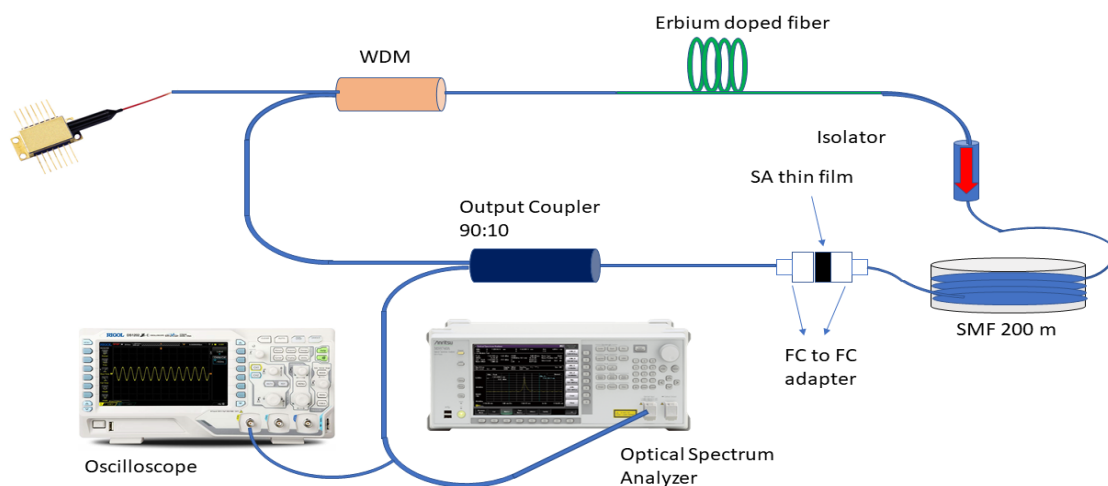


Figure 1. Experimental setup of EDF laser system

4. Result and discussion

Figure 2 shows the OSA traces of the both continuous wave (CW) and mode-locked outputs obtained. The CW output was taken without the SA in the cavity. In continuous wave mode, the laser output wavelength was centered at 1563.8 nm with linewidth of 2.6 nm. For the mode-locked output, the laser wavelength shifted to short wavelength at 1533.4 nm and its linewidth was 4.8 nm.

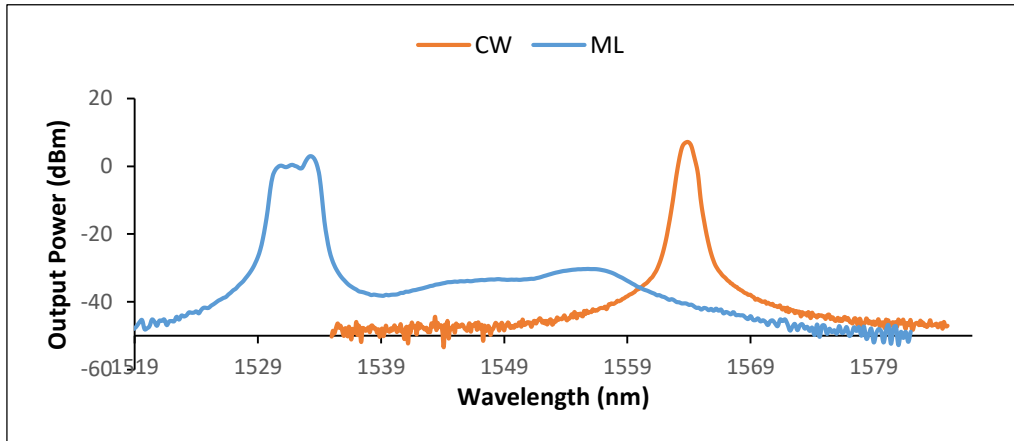


Figure 2. Spectrum of EDF laser

Figure 3 shows the oscilloscope trace of the laser output pulses at pumping power of 85 mW. The repetition rate of the laser was 989.0 kHz. RF signal used to make sure the validity of repetition rate and the RF signal of the laser output is shown in Figure 4. From the Figure, the first peak is exhibit at 989.1 kHz hence agrees with the result from oscilloscope. Signal to noise ratio in the RF spectrum is 68.94 dB that indicates a stable laser operation.

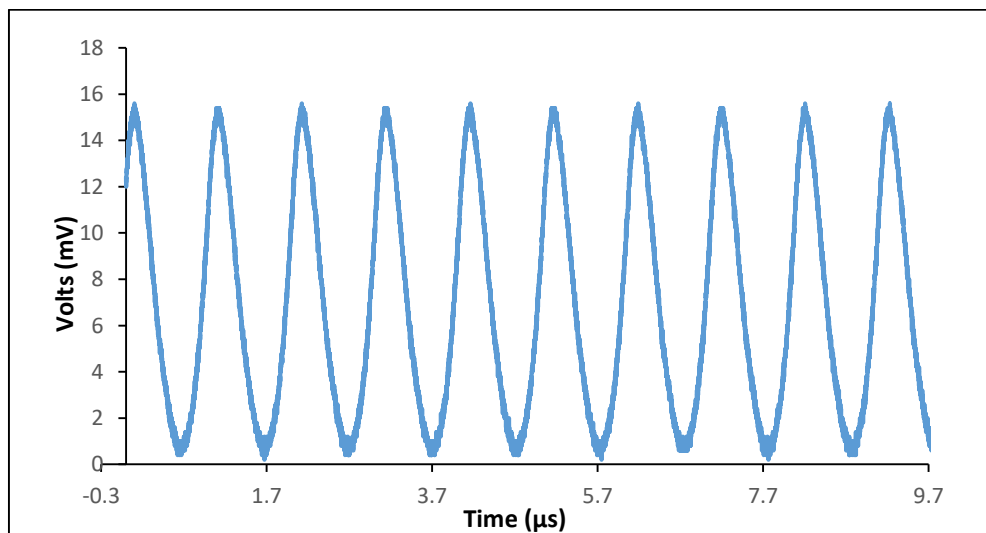


Figure 3. Oscilloscope reading at 85 mW pumping power

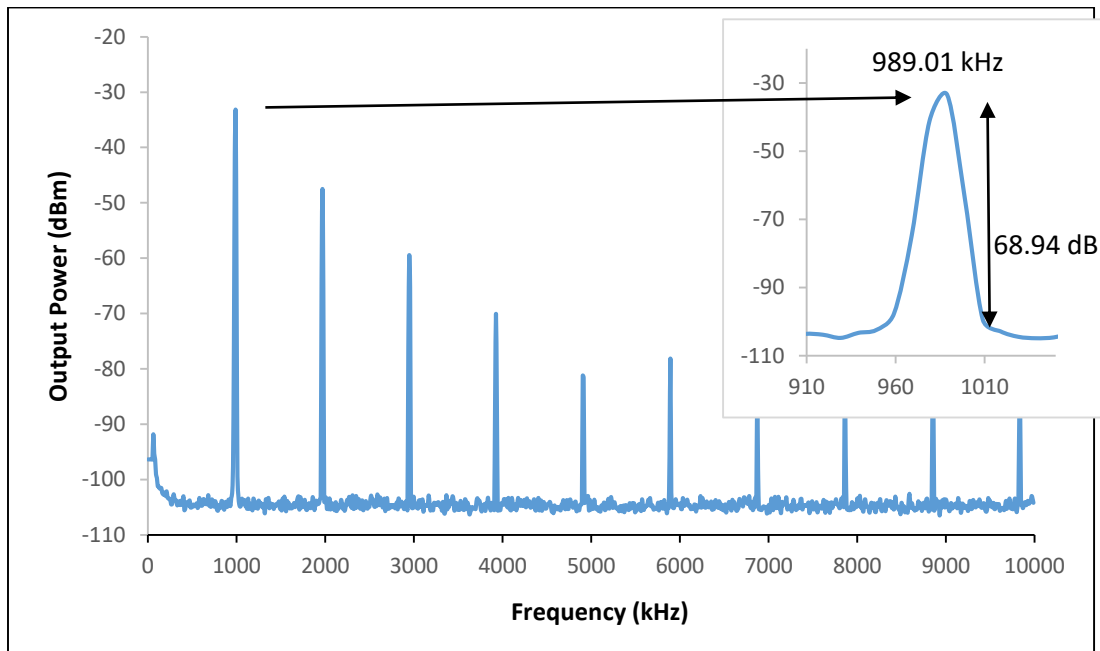


Figure 4. RF signal of EDF laser

The performance of the laser can be represented through slope efficiency of the graph that is 8.58 % as shown in Figure 5. The range of laser output power produced was 6.99 to 11.69 mW. Furthermore, pulse energy produced from this system are between 7.08 – 11.58 nJ.

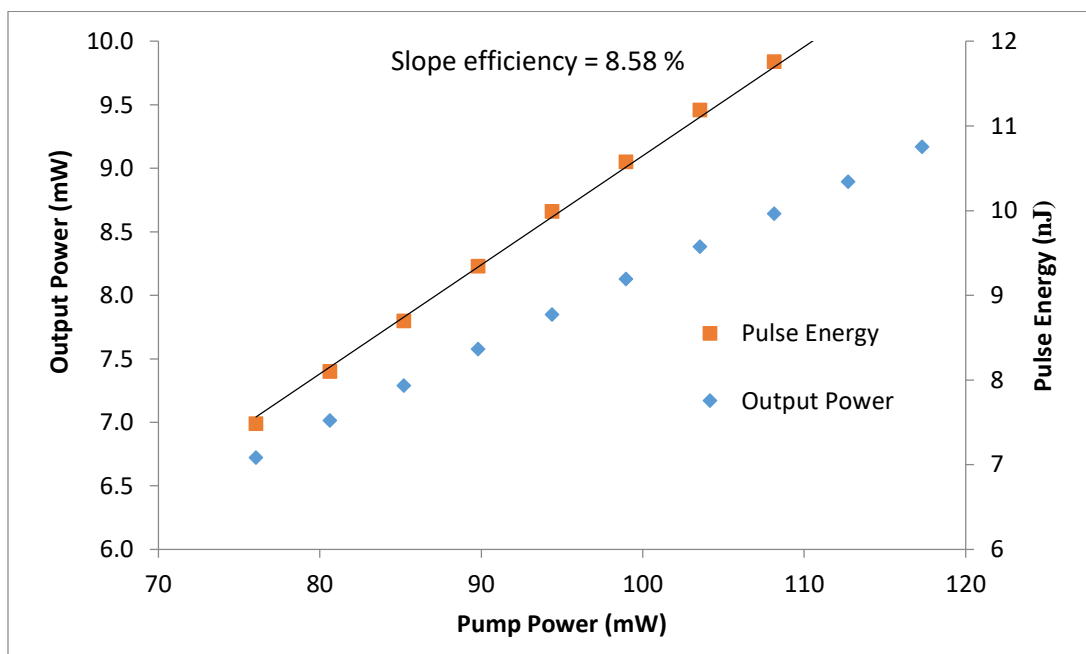


Figure 5. Output power vs pump power (Orange) & pulse energy vs pump power (Blue)

From Figure 6, increasing of pump power of the diode laser, the peak power of the laser also increases. The range of peak power is from 5.6 to 9.4 kW.

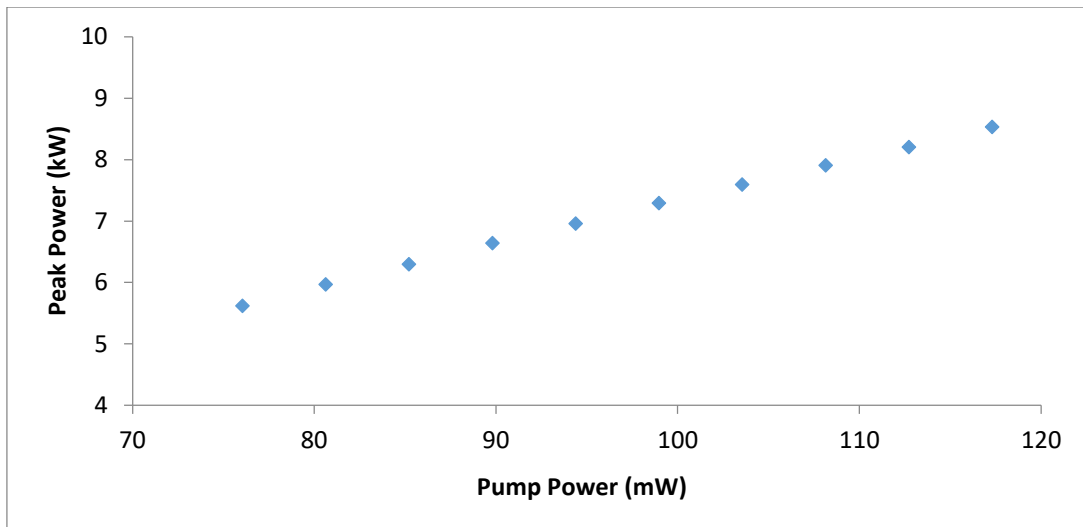


Figure 6. Peak power vs pump power

The pulse width of output laser can be measured using auto correlator. From Figure 7, the pulse width of the laser is about 1.26 ps. However, the fitting is not good might due to different modes of light oscillating inside the laser cavity. The time bandwidth product value for the laser pulse was 0.4018, which is slightly higher than the sech^2 transform-limited value of 0.315.

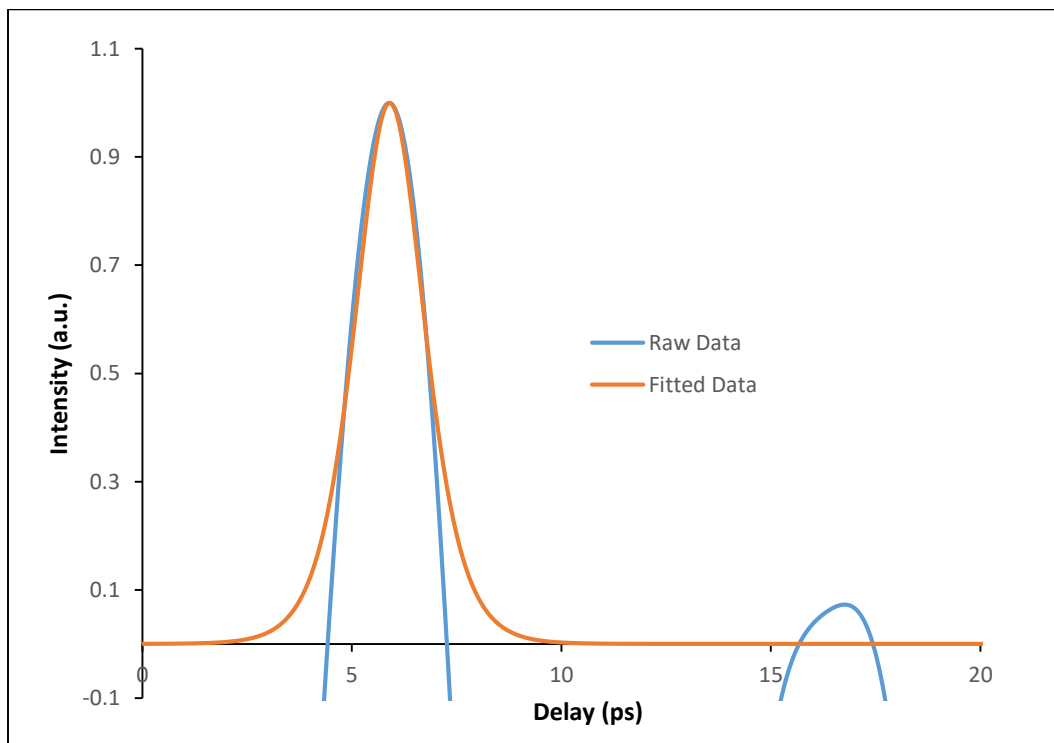


Figure 7. Auto correlator reading

Compared to previous work done with TiO_2 nanoparticles SA, pulsed width of laser produced for this system is much more shorter about 8.48 ps difference [12]. Also, maximum pulsed energy achieved

using this system is higher which is some improvement. However, some modification needed because the output spectrum has many modes oscillate in laser cavity. So, it contributes in fitting the actual pulse width in auto correlator.

5. Conclusion

TiO₂-PVA thin film have potential to use as saturable absorber in EDF laser system. It manages to modulate the laser to produce mode locked pulsed laser. From results the slope efficiency of this system is 8.58 %. Pulse energy produced in range of 7.08 – 11.58 nJ and pulse width achieved is 1.26 ps.

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