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Q-SWITCHED ERBIUM-DOPED FIBER LASER VIA VANADIUM PENTOXIDE POLYETHYLENE GLYCOL SATURABLE ABSORBER IN A LONG BAND REGION

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Abstract— Short pulse erbium-doped fiber laser in anomalous group delay dispersion has been shown to generate soliton output at 1562.4 nm wavelength with 0.4 nm spectral bandwidth. The Q-switching operation was induced by a vanadium oxide polyethylene glycol (V2O5-PEG) film saturable absorber (SA) for all-fiber ring cavity configuration. The pulsed laser has maximum pulse energy of 3.2 nJ, the shortest pulse width of 4.7μs, and maximum output power of 0.4 mW. These findings show that the fabricated vanadium pentoxide film can be an alternative SA device for generating a pulsed laser.

I. Introduction

Q-switched fiber lasers have gained considerable attention in recent years owing to their inherent features of the alignment-free structure, good mode confinement, and high stability [1]. They can be used in many applications, including material processing, microfabrication, range finding, remote sensing, optical communications, skin treatment, and medical surgery [2-5]. Q-switched pulse can be generated via an electro-optic or acousto-optic modulator to actively modulate the loss within the cavity [6, 7]. However, this modulator is made of bulky and costly components, which increases the complexity and manufacturing cost of the laser system. In contrast, the passive technique with a saturable absorber (SA) offers a compact, low-cost, simple, and reliable alternative method to generate Q-switched [8]. Furthermore, the lightweight properties and low energy consumption have made it more suitable for the practical applications of some portable devices such as a range finder and a laser marker.

Typically, semiconductor saturable absorber mirror (SESAM) [9] and carbon-based nanomaterials [10, 11] are deployed into a laser cavity as SA for Q-switched pulse generation due to their exceptional nonlinear optical responses. However, the synthesis of these materials is expensive and complicated. Additionally, SESAMs have a narrow operation wavelength band which reduces the applicability and flexibility of this SA. The carbon-based materials such as carbon nanotube [10], graphene [12], and graphene oxide [11] have their shortcomings, e.g. diameter control needed for carbon nanotube and lower modulation depth for graphene. Therefore, tremendous research effort has been devoted to searching for new alternative SA materials accompanying high operation performance and simple SA fabrication methods.

Recently, 2D nanomaterials such as Transition metal dichalcogenides (TMDs) and Black phosphorus (BP) have also been reported as alternative SAs in many laser systems [13] [14]. TMDs have excellent physical properties such as fast response time, good electron mobility, and high superconductivity [15]. For instance, Molybdenum disulfide (MoS_"2") and Tungsten disulfide have a relaxation time of about 30 fs, and thus they were widely explored for pulse generation [16, 17]. These materials require a particular fabricating procedure based on mechanical exfoliation to obtain a monolayer structure, which has a bandgap corresponding to the production of the near-infrared laser [18]. But this fabrication procedure is complex because the mechanically exfoliated material contains an inconsistent powder-like layer that is difficult to handle. On the other hand, BP has these unique properties, but it is sensitive to air and water, which affects its performance [14].

Transition metal oxide (TMO) materials have also gained explosive growth of advertence in the past few years due to their excellent electronic and optical properties. They can enable high-performance optoelectronic devices due to their high carrier mobility and broadband light absorption. The TMO, in its low-dimensional form, demonstrates good abilities in the field of nonlinear optics. It is characterized by large third-order nonlinear interchangeability, ultrafast response time in a narrow range, a high damage threshold, and a broad absorption band [19]. Apart from that, the TMO bandgap can be set via the thickness and controlling particle size [20]. Several TMO-SAs have been proposed for producing Q-switched pulses, such as zinc oxide [21, 22], titanium dioxide [23], copper oxide [24], and molybdenum oxide [25].

Vanadium pentoxide (V2O5) is one of the essential transition metal oxides [26]. It was reported to have an excellent nonlinear optical absorption characteristic and thus suitable for SA applications [27]. In this paper, a Q-switched fiber laser is demonstrated using a newly developed V2O5 SA utilizing PEG as a host material. The SA was prepared by embedding V2O5 material into polyethylene glycol (PEG) to compose a film absorber, which was then inserted between two fiber ferrules. The V2O5 PEG film could be used as a nonlinear optical modulator in Erbium-doped fiber laser (EDFL) cavities.

II. Laser Configuration

Passively Q-switched pulse is generated in an EDFL cavity using the V2O5 SA as a Q-switcher. The EDFL is constructed to study the performance of the V2O5-PEG SA, as shown in Figure 1. The ring cavity is formed by splicing 2 m EDF, a polarization-insensitive isolator, a V2O5-PEG SA, a 90/10 fiber-fused optical coupler, and a 980/1550nm wavelength division multiplexing (WDM). An optical isolator was placed in between the gain medium and the SA to allow unidirectional light propagation inside the ring resonator. The prepared V2O5 PEG film was sandwiched between two FC/PC fiber ferrules and inserted into the laser cavity to function as Q-switcher. 10% of the output laser was extracted through a 90:10 couplers for analysis. The output spectrum of the laser was detected by an optical spectrum analyzer (OSA, Yokogawa AQ6370B) with a spectral resolution of 0.02 nm. The frequency and time-domain of the signal can be detected by a 1.3 GHz photodetector (Thorlabs, DET10D/M) in conjunction with a 7.8 GHz RF spectrum Analyzer (Anritsu) and a 350 MHz digital oscilloscope (GWINSTEK: GDS-3352), respectively. The total length of the cavity for Q-switching operation is about 5 m.

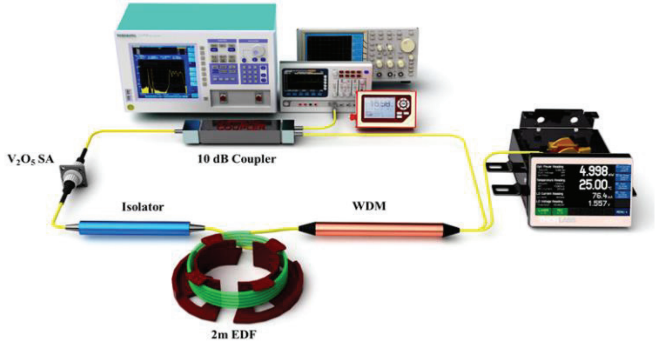


Figure 1: Schematic diagram of the experimental setup for the Q-switched EDFL with V2O5 SA

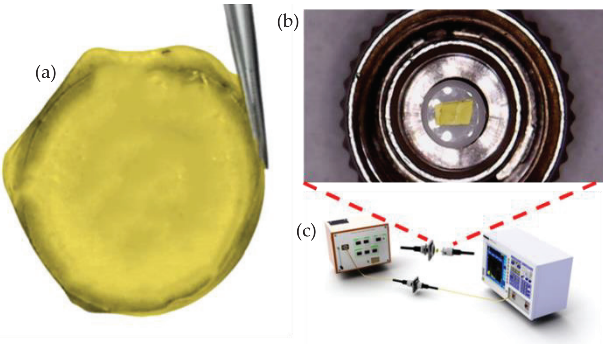


Figure 2: (a) A light yellow solid thin film of V2O5 (b) the SA film placed onto a fiber ferrule tip (c) the linear saturable absorption measurement set-up

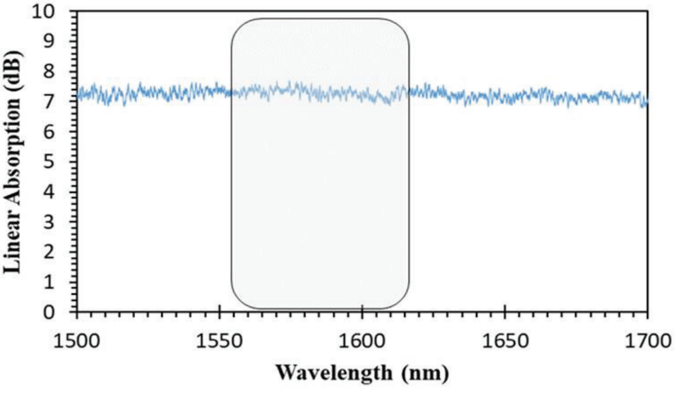


Figure 3: Linear saturable absorption curve for the V2O5-SA film

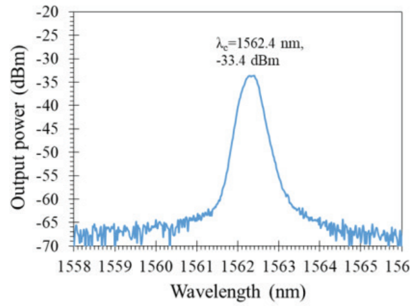
The V2O5 SA used in this work is a clear film with an even surface. Through drop-casting, the V2O5 film was fabricated by mixing the synthesized V2O5 to polyethylene glycol (PEG) solution under constant stirring for 2 hours. Then, the mixture solution containing V2O5, and PEG was cast on the petri dish and form to film by drying this mixture solution in a vacuum oven, as illustrated in Figure 2(a). The positioning of the SA film on the fiber in an enlarged image is shown in Figure 2(b). Figure 3 depicts the linear absorption profile for V2O5 film., measured using the set-up as shown in Figure 2(c). This characteristic of SA is important to determine the ability of fabricated film to work as SA. The linear absorption profile of V2O5 film was obtained at the 1.55-micron region, about 7dB was observed at 1550 nm.

A. Laser Performance

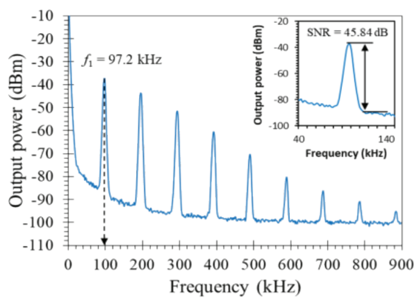
The thin films V2O5-PEG SA is fusing into the cavity; a laser is firstly generated in the EDFL at pump power of 40 mW. Advance increasing the pump power to 110.9 mW,; the EDFL delivers a train of Q-switched microsecond laser pulses.

Figure 4(a) shows the output spectrum of the laser at a pump power of 138.7 mW. The laser wavelength is centered at 1562.4 nm with a 3-dB bandwidth of 0.4 nm., and peak intensity of -33.4 dBm. Figure 4 (b) illustrates the corresponding RF spectrum, which indicates that the repetition rate of the pulses is 97.2 kHz at 138.7 mW pump power. The signal-to-noise ratio of the fundamental frequency is observed to be higher than 45 dB, which confirms the stability of the Q-switched. In addition to that, the experiment was conducted by increasing the pump power beyond its maximum available pump. No Q-switched pulse could be detected as the pump power rose beyond the maximum level of 166.5 mW. When the pump power decreased back to the Q-switched operating pump power (110.9-166.5 mW), a stable pulsed laser with almost similar Q-switching characteristics as demonstrated earlier emerged again. This phenomenon, not only verified that the film SA was still in good condition but also suggested that the laser operation was conducted below the SA optical damage threshold with the SNR at 45 dB which is an acceptable range for the fiber laser stability.

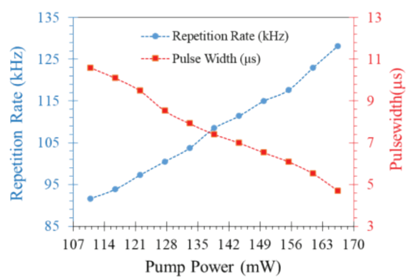
The evolution of the Q-switched pulses with the change of pump power is also investigated. As illustrated in Figure 4 (c), by gradually varying the pump power from 110.9 mW to 166.5 mW, the repetition rate enlarges from 91.7 kHz to 128.2 kHz while the pulse duration shortens from 10.6 µs to 4.7 µs, which is the typical characteristic of the passively Q-switched operation. However, this operation becomes unstable, and a continuous wave appears on the top of the spectrum at higher pump powers. The average power and calculated single pulse energy of the Q-switched EDFL versus pump power are described in Figure 4 (d). One can observe that the output power almost increases monotonously from 0.24 mW to 0.40 mW, and the single pulse energy increases from 2.6 nJ to 3.2 nJ. The maximum value of light conversion efficiency is about 0.3 %. The low efficiency might be due to the large cavity loss induced by the SA film.



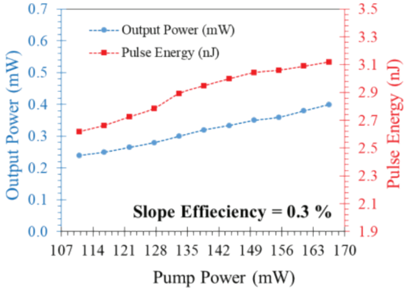
(a) Output spectral



(b) Q-switching performances of the V2O5 based EDFL against pump power



(c) Repetition rate and pulse width



(d) Average output power and single pulse energy

Figure 4: Laser performance results

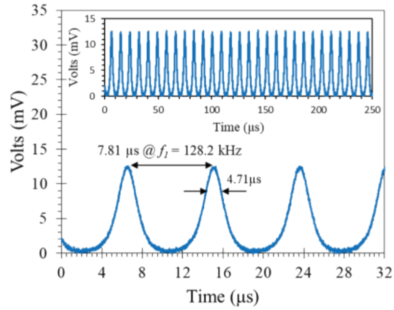


Figure 5: Typical pulse train of the Q-switched EDFL at 166.5 mW

To confirm whether the Q-switching operation is purely induced by the V2O5 PEG film, the SA was replaced with a pure PEG film. However, Q-switched pulses were not observed in any cases, despite tuning laser diode over a full range. The results indicate that the proposed material has the potentials to become an alternative SA for fiber laser development and application. The long-term stability of the SA was examined by monitoring the condition of the Q-switching at a moderate pump power of 110 mW for several hours as shown in Figure 5. Throughout the experiment, the Q-switched pulse remained stable without any sign of pulse destruction, indicating that the SA was still in a good condition, and it has potential in a real application in industrial.

III. Conclusion

Q-switched fiber laser has been successfully demonstrated by using the V2O5 film as a SA. The SA was obtained by embedding the synthesized V2O5 into a PEG polymer film. A Q-switched EDFL by using V2O5 film as SA was then experimentally demonstrated. The Q-switching operation was obtained from a pump power range of 110.9 – 166.5 mW. The pulse repetition rate shows an increasing trend from 91.7 kHz to 128.2 kHz, whereas the pulse width exhibits a decreasing trend from 10.6 µs to 4.7 µs. The highest pulse energy of 3.2 nJ is obtained at the pump power of 166.5 mW. The easy fabrication, good stability, and robust structure of V2O5 based SA will facilitate many more potential nonlinear photonic applications, which are expected to work towards ultrafast photonics and play a key role in various optical telecommunications and measurement applications.

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