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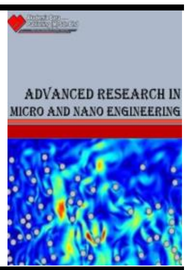


# Passively Q-Switching Mechanism with Gadolinium Oxide ($Gd_2O_3$) Film Based Saturable Absorber

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**ABSTRACT**

A Q-switched erbium-doped fibre laser (EDFL) was successfully exhibited using gadolinium oxide ($Gd_2O_3$) as a saturable absorber (SA). The polyvinyl alcohol (PVA) solution and $Gd_2O_3$ powder were combined and the combination was then sonicated for around 6 hours. A micro-film was created by allowing the solution to dry out over the period of 48 hours. The $Gd_2O_3$-SA was inserted into an EDFL configuration to produce a steady passively Q-switched pulse train. This made it possible to adjust the pump power of the 980 nm pump to be between 24.58 and 76.75 mW. The operational wavelength of the laser was 1562.9 nm and the repetition rate increased rapidly from 51.9 to 77.1 kHz.

## 1. Introduction

The Q-switched fibre lasers have attracted enormous work interest over the past 20 years. This is explained by their ability to support the majority of industrial applications, including optical communication, material processing, healthcare, and optical sensors are taken from [1-3]. By varying intracavity losses associated with the laser resonator's Q-factor, Q-switched pulses are produced. Compared to mode-locked pulses, they have longer pulse durations, slower pulse repetition rates, and higher pulse energy. Cost savings and increased operational effectiveness compared to mode-locking are other advantages of Q-switching (which requires a proper balance of dispersion and non-linearity). Traditionally, intracavity loss is modulated and pulses are generated by using an electrical signal to achieve Q-switched lasers. Other tools, such as mirrors, have frequently been used in the

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active technique as a mechanical transition. Due to their portability, simplicity, robustness, and affordability in architecture without much care for non-linearity and dispersion compared to the active technique, passive methods are now chosen for the creation of pulsed lasers [4].

In the passive method, the modulator is often replaced with a saturable absorber (SA) inside a ring laser cavity. Several substances (SA) have recently been proposed and shown to create Q-switched pulses in a variety of laser cavities. Carbon-based materials [5,6], two-dimensional allotropes [7-9], transitional metal dichalcogenides (TMDs) taken from the previous studies [10,11], topological insulators [12,13], and quantum dots (QDs) [14] are some of these substances. Due to its unique properties, including quick nonlinear optical response, excellent thermal stability, and broadband absorption, graphene is highly favoured among these materials [15,16]. The extraordinarily low second-order nonlinearity of graphene, on the other hand, necessarily limits pulse efficiency in the laser cavity. Its modest modulation depth (2.3% per layer) and nearly nonexistent band gaps further prevent it from being used in high-power lasers. As a result, research has moved its attention to different kinds of materials, like transition metal oxides (TMOs).

For instance, different Q-switched fibre lasers also used SAs based on zinc oxide (ZnO) [17], aluminum zinc oxide (AZO) [18], nickel oxide (NiO) [19], titanium dioxide ($TiO_2$) [20], and europium oxide ($Eu_2O_3$) [21]. In order to make their integration into various laser cavities easier, these materials are typically incorporated into polyvinyl alcohol (PVA). Due to its favorable physical qualities, including hydrophilicity, biocompatibility, and strong chemical resistance, PVA is chosen because it has a good film-forming ability [22]. Gadolinium oxide ($Gd_2O_3$) is a rare-earth oxide with a high degree of thermodynamic and chemical stability that has been used as a contrast agent in magnetic resonance imaging (MR) [23]. It is an advantageous SA material for the creation of Q-switching pulses due to its good optical properties. Here, we describe a $Gd_2O_3$ film that acts as the Q-pulse switcher's initiator in the EDFL cavity.

## 2. Preparation and Characterization of $Gd_2O_3$ SA

The casting process was selected for the fabrication of the rare-earth metal oxide film in this study due to the ease with which it could be carried out as well as the low cost involved. In order to manufacture the material, commercial $Gd_2O_3$ powder particles were encapsulated inside polyvinyl alcohol (PVA). To start making the PVA solution, initially, 1 gram of PVA powder was dissolved in 120 ml of deionized (DI) water. Moreover, to fully dissolve all of the powder particles, the liquid was agitated with a magnetic stirrer at room temperature for approximately one day. The PVA solution that had been prepared was then diluted with 50 mg of $Gd_2O_3$ powder in 50 ml DI water. The $Gd_2O_3$-PVA solution was mixed with a magnetic stirrer for at least an additional twenty-four hours after the initial stirring. After the components were combined, the solution was placed in an ultrasonic bath for at least 6 hours. This operation completely dispersed the powder by severing the van der Waals force-bound connections that were previously holding the molecules together.

Last but not least, the consistent solution was transferred to a petri dish. It is possible that it will generate micro-film of the SA for approximately 48 hours or two days at room temperature. Then, will be easy to insert a micro size of SA into an EDFL cavity. As seen in Figure 1 (a), the physical image of white film has an equally dispersed SA. In addition, as can be seen in Figure 1 (b), the microfilm surface was magnified and examined using FESEM. Also, it has been observed that the $Gd_2O_3$ material used in the film is distributed uniformly throughout. The results of the Energy Dispersive X-ray (EDX) analysis are displayed in Figure 1(c), and they show that the concentration of gadolinium and oxygen in the film is roughly 32.4% and 24.30%, respectively. In order to produce an SA device that is compatible with fibre, a little piece of $Gd_2O_3$-PVA film measuring 1 mm by 1 mm was cut into and shaped to fit FC / PC fibre ferrule. This was done in accordance with Figure 1 (d).

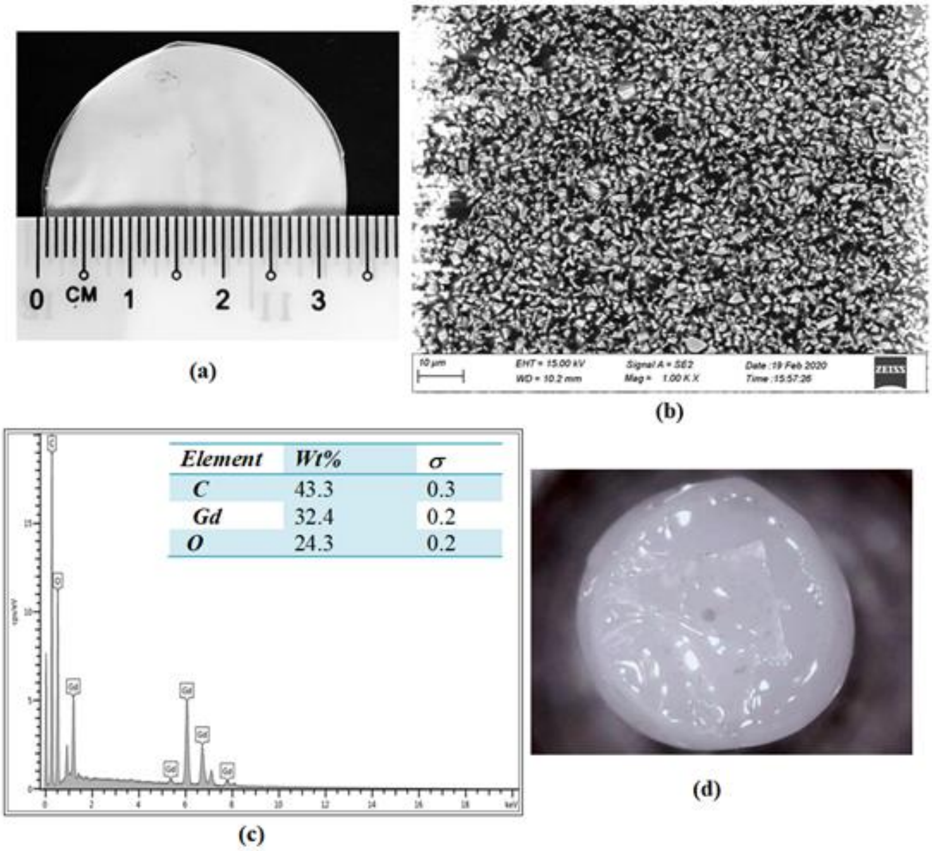



**Fig. 1.** $Gd_2O_3$ PVA film (a) physical image (b) FESEM image (c) EDX analysis result (d) the tiny part of the film attached to FC/PC fibre ferrule

## 3. Laser Configuration

The laser configuration of the $Gd_2O_3$ micro-film as SA for the Q-switched fibre laser will be detailed in this section. For it to function in the 1.55-micron range, it made use of a gain medium known as erbium-doped fibre (EDF). Figure 2 depicts the configuration of the forward-pumped ring cavity technique that forms the basis of the Q-switched EDFL that was proposed. As the pump source, a 980 nm laser diode (LD) was utilized. This LD was coupled with a 980/1550 nm wavelength division multiplexer (WDM) coupler before being introduced into the gain medium. The optical isolator guaranteed that light travelled in only one direction within the cavity of the laser ring resonator to prevent any potentially harmful effects from occurring within the device. The suitable SAs were manufactured by cutting a tiny portion of the prepared gadolinium PVA SA film and putting it between two clean FC/PC fibre ferrules through a fibre adapter.

At the connection, a minute amount of index matching gel was utilized to attach the film onto the ferrule tip and decrease the undesired parasitic reflection. The SA device was cut and put on top of the fibre ferrule. The 90/10 coupler removes 10% of the laser from the cavity, while the 1550 nm port of the WDM keeps the remaining 90% of the laser in the cavity. In addition, the activity of the generated Q-switched was evaluated using a 350 MHz digital storage oscilloscope and a radio frequency (RF) spectrum analyser utilizing a 7-GHz InGaAs photodetector. A power meter with the

InGaAs powerhead of the pulse laser is used to determine the power output of the pulse. The length of the laser cavity was approximately 13.5 m.

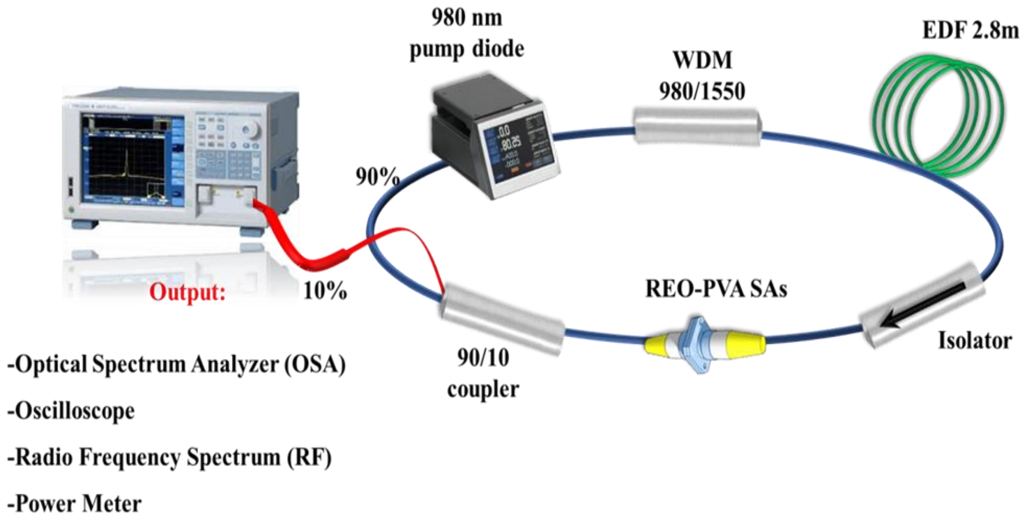
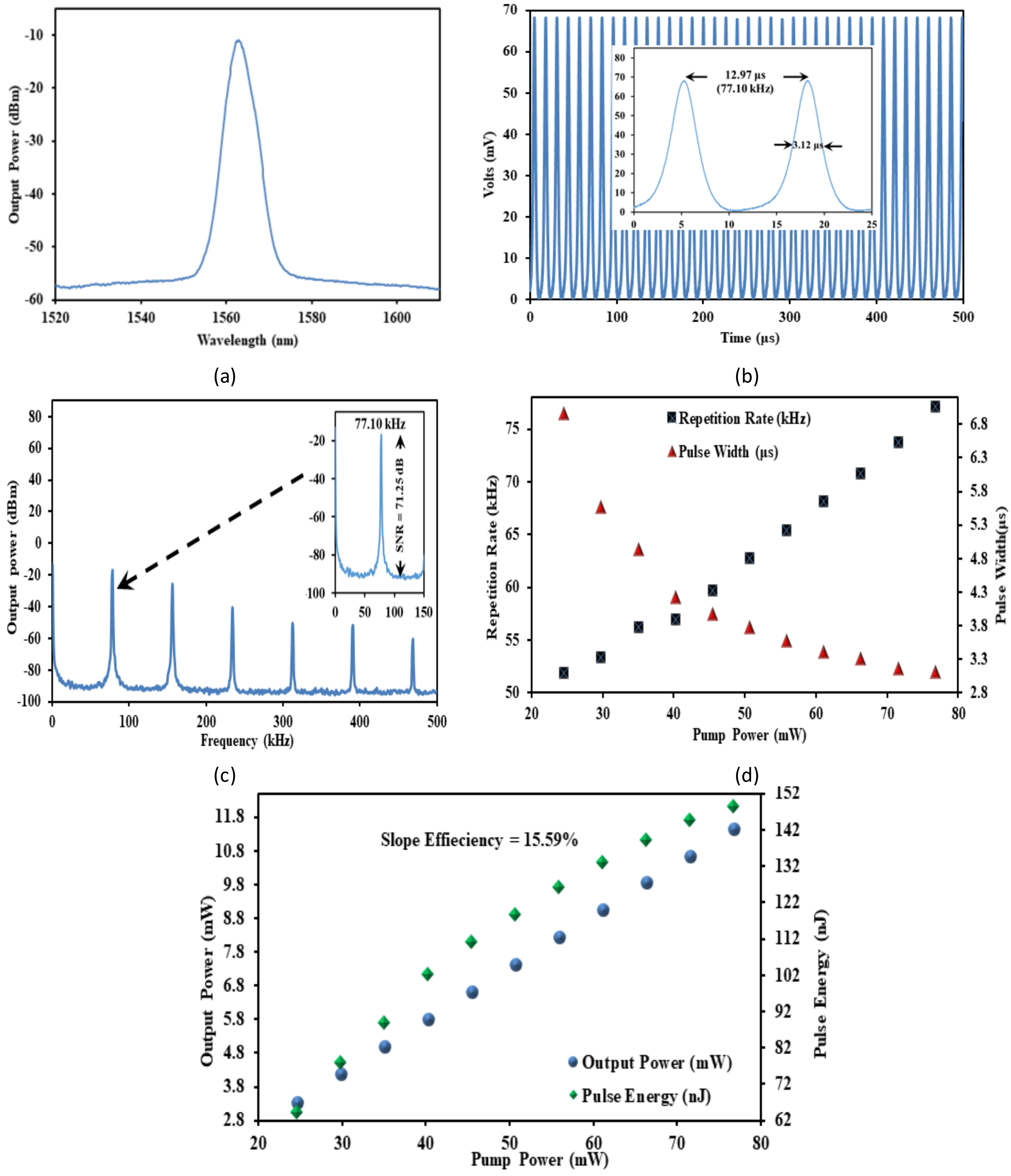



**Fig. 2.** The proposed ring configuration for realizing Q-switched pulse using $Gd_2O_3$ SA

## 4. Results and Discussion

At a threshold pump power of 24.58 mW, it was found that the EDFL starts to deliver a Q-switched pulse train. This was a really interesting observation and the Q-switching process was able to continue all the way up to 76.75 mW even as the pump power was steadily being increased. With a pump power of 76.75 mW, the wavelength spectrum of a $Gd_2O_3$-based Q-switched EDFL is shown in Figure 3(a). The laser has a wavelength of 1562.9 nm when it is functioning properly, as can be shown in Figure 3(a). When the pump sources started at 24.58 mW and went all the way up to 76.75 mW, steady pulse trains were recorded. The oscilloscope traces of a Q-switched pulse train can be shown in Figure 3(b), which was taken with the pump power set to 76.75 mW. An inset view of two pulses envelop from the matching pulse train is shown in Figure 3 (b), which bears the same number. The pulse had a full width at half maximum (FWHM) of approximately 3.12 µs and a pulse period of approximately 12.97 µs, which is equivalent to a repetition rate of 77.1 kHz. Within the frequency range of 500 kHz, the fundamental frequency, which was measured to be 77.1 kHz, is depicted in Figure 3(c).

On top of that, the Signal noise-to-ratio (SNR) was greater than 70 dB, which is indicative of the stable operation of the Q-switching mechanism. The relationship between the pulse width and repetition rate as a function of total pump power is shown in Figure 3(d). As the pump power increased from 24.58 to 76.75 mW, the Q-switched EDFL's repetition rate was able to be tuned from 51.92 to 77.10 kHz, which is a significant range. Furthermore, the pulse width decreased from 7.0 to 3.12 µs while the pump power was increased within the same range. As a function of the pump power, Figure 3(e) illustrates the relationship between the output power and the pulse energy. The pump power increased from 24.58 to 76.75 mW while the output power increased from 3.34 to 11.46 mW. The greatest possible pulse energy was measured to be 148.64 nJ at 76.75 mW. The pump efficiency was 15.59% during this entire process and the output power steadily increased from 3.34 to 11.46 mW.




(e)

**Fig. 3.** (a) A typical pulse train (b) The output spectrum (c) RF frequency spectrum with a 500 kHz span (d) repetition rate and pulse width performances against pump power (e) average output power and single pulse energy as a function of pump power

## 5. Conclusions

In conclusion, an EDFL cavity with $Gd_2O_3$ as the SA was successfully demonstrated to produce a Q-switched pulse at 1562.9 nm. Besides that, to enable a Q-switched pulse, $Gd_2O_3$ film was using the casting technique and placed inside the EDFL ring cavity. By regulating the gain and loss in the cavity, stable Q-switched functioning was attained and a stable Q-switched laser with an output power of

11.46 mW on average at 1562.90 nm. Moreover, the minimum pulse width of 3.12 µs was produced by using $Gd_2O_3$ which acts as SA.

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