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# An Investigative Approach: Enhancing Q-Switched Fibre Laser using Molybdenum Aluminium Boride (MoAlB) Thin Film as Saturable Absorber

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**ABSTRACT**

Over the past decade, fibre laser technology has garnered significant technological focus and benefits. They improve the instability, affordability of maintenance, efficient heat dissipation, simplicity, and reliability of existing bulk lasers. Q-Switched fibre lasers have recently garnered significant attention. They possess the capacity to generate pulses with considerable energy levels, making them valuable for a range of applications such as micro-machining, biomedical imaging, communication, remote sensing, laser range finding, and medical surgery. Fibre lasers may generate ultra-short pulses at repetition rates of millions and thousands of cycles per second by functioning in the mode-locked or Q-switched states. Molybdenum Aluminium Boride (MoAlB) is employed as a saturable absorber for investigating the lasing properties of erbium-doped fibre. Moreover, a Q-switched EDF laser is observed utilising a MoAlB thin film as a saturable absorber in the 1.55µm wavelength range. The Q-switched fibre laser can be realised using either a passive or active technology. In this investigation, the passive approach is a suitable technique because using a saturable absorber (SA) for passive Q-switching simplifies cavity construction and eliminates the demand for external Q-switching electronics. The laser cavity was built utilising Erbium-Doped Fibre Laser as the gain medium. Increasing the pump power to 980 nm allows it to get results of Q-switched pulses running at 1550 nm.

## 1. Introduction

The fibre laser has a history that spans nearly as old as the laser itself. The fibre laser, invented by Elias Snitzer in 1963, underwent over two decades of development before reaching its commercial stage in the late 1980s. Given its ability to generate a variety of wavelengths, lasers are frequently employed in industrial environments to perform activities such as cutting, marking, welding, cleaning, texturing, and drilling. Furthermore, they are utilised in diverse industries such as telecommunications and medicine.

The lasers utilised single-mode diode pumping and emitted a power output of many tens of milliwatts. Their significant advancements and capability to achieve single-mode continuous-wave

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(CW) lasing on specific rare-earth ion transitions, which were previously unachievable with the more commonly used crystal-laser type, garnered notice. An erbium-doped fibre laser operating at a wavelength of 1550 nm is the most widely recognised use of fibre laser technology.

Various other materials have been examined as saturable absorbers (SA), including semiconductor saturable absorbers (SESAM), carbon nanotubes (CNT), and two-dimensional nanomaterials like graphene. SESAMs, or semiconductor saturable absorber mirrors, were an early form of saturable absorber. However, their capacity to generate customisable pulses across a wide range of frequencies is limited because of their relatively narrow operational bandwidth. Carbon nanotube-saturable absorbers (CNT-SAs) can be easily manufactured and function effectively over a wider range of wavelengths. Nevertheless, the actual usefulness of carbon nanotubes in lasers is restricted since their response spectrum range relies on their chirality and diameter. Graphene-based saturable absorbers are rather costly but have a straightforward fabrication process. One major drawback of graphene (as well as carbon nanotube) pulsed fibre lasers is their tendency to disappear under moderate pumping conditions, which is attributed to their low saturating intensity and low damage threshold. Hence, the intricate manufacturing process, limited resistance to damage, insufficient purity, and inconsistent material quality collectively contribute to these SAs' performance deterioration.

Recently, fiber lasers have been recognised as compact, stable, practical lasers and play an essential role in lasers. A fiber laser is an active medium used in an optical fiber doped in rare elements, typically erbium, ytterbium, neodymium, thulium, praseodymium, holmium or dysprosium. As mentioned earlier, the fiber used as the central medium for your laser will have doped in rare-earth elements, and most often find, that is Erbium ($Er^{3+}$). For example, by doping fiber in Erbium, an energy level that can absorb photons with a wavelength of 980 nm is decayed to a meta-stable equivalent of 1550 nm. The rare-earth ions $Er^{3+}$ have a broad wavelength range of roughly 1.55 µm, which is particularly advantageous for optical communication applications. Thus, erbium-doped fiber (EDF) was researched in the twentieth century. In 1985, the first EDF was manufactured and reported [1]. All EDFLs can be pumped by tiny, efficient, and reasonably priced laser diodes operating at 980 or 1480 nm. They are compatible with various fibers and fiber optic components used in communications, which results in very low coupling losses. This property is very advantageous for fabricating a laser, coherent broadband sources, or amplification of signals with an emission wavelength of 1550 nm. For the first time, graphene's strong nonlinear optical feature is employed to inhibit EDF's mode competition, enabling the dual-wavelength Q-switched output to be realised [2]. The Er3+ ion is also often utilised as an active element because it operates in the low-loss 1550 nm area, which is appropriate for communication applications.

There are two techniques to generate the Q-switching pulses: active and passive techniques. Passive techniques require a saturable absorber (SA) device. They are preferable to active techniques because of their advantages, such as smaller size, high efficiency, reliability and ease of fabrication. Furthermore, the passive techniques require no external pulse triggering signal, while the active technique needs external acousto-optic modulators to control and modulate the intra-cavity loss.

Q-Switcher lasers are versatile and can be used for various purposes such as trace gas monitoring, LIDAR for range finding and autonomous driving, biomedical devices, and nonlinear optics. Additionally, lasers are used in various industries for cutting or drilling purposes. They are also utilised in hospitals for clinical procedures like tattoo or nevi removal [3]. One advantage of fibre lasers compared to other lasers is that the laser light is produced and transmitted through a naturally flexible medium, which enables easier delivery to the desired concentrating area and target. Laser cutting, welding, and folding metals and polymers can be crucial. Another advantage is greater output power compared to other types of lasers. Fibre lasers possess an active area that yields exceptionally high optical gain. The compactness of fibre lasers is attributed to their ability to be bent and coiled, distinguishing them from solid-state or gas lasers with similar power output. This study presents the utilisation of a MoAlB film as a saturable absorber (SA) for producing a Q-switched fibre laser operating at a wavelength of 1.55µm.

## 2. Method of SA Film Fabrication

The MoAlB-PVA film was formed using the casting method. The thin film was created by dissolving MoAlB powder into a PVA solution. Figure 1 shows the casting method used to fabricate the MoAlB thin film.

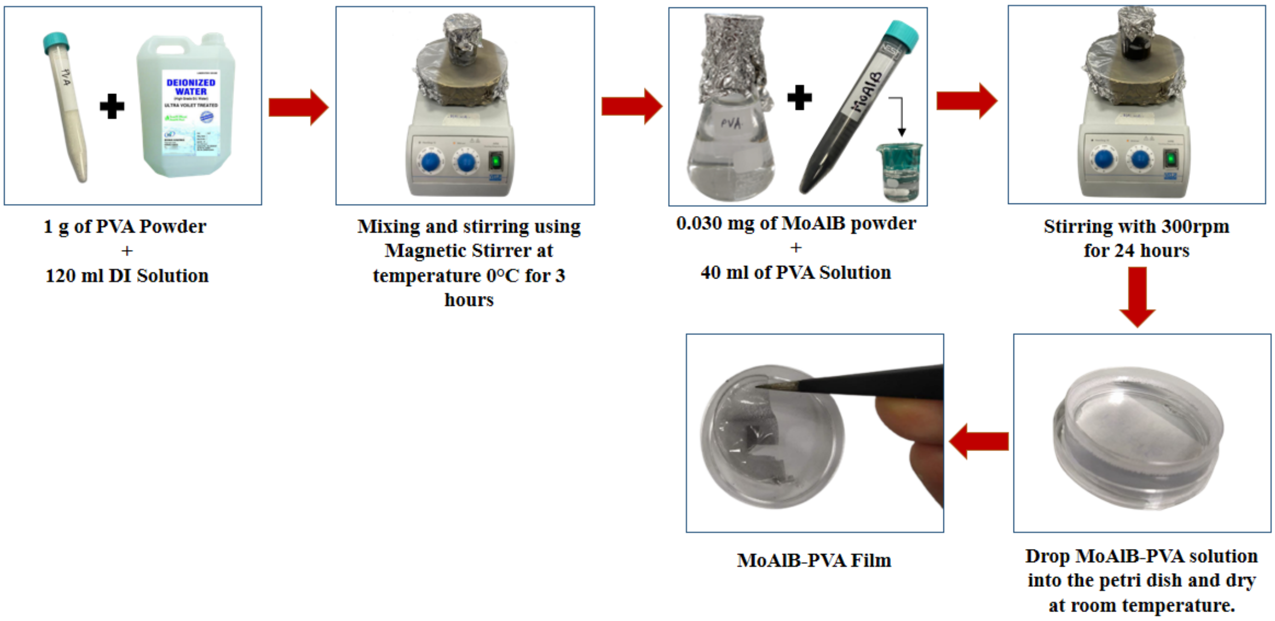


**Fig. 1.** Fabrication process to develop MoAlB thin film

Firstly, polyvinyl alcohol (PVA) was chosen as the host polymer due to its non-toxic nature and ability to connect with other metals. The 1g of polyvinyl alcohol (PVA) powder and 120 ml de-ionised (DI) water with the aid of a magnetic stirrer at room temperature. Stirring was continued until the PVA powder was disseminated entirely, and the PVA solution became homogenous. To reiterate, when using this method, the user should wear suitable safety equipment such as eyeglasses, gloves, and a lab coat to prevent unintended chemical reactions.

Then, 30 mg of MoAlB powder was added to 40 ml of PVA solution and carefully mixed for about 24 hours using a magnetic stirrer. The MoAlB suspension was gently poured and distributed onto a well-covered petri dish to avoid trapping air bubbles. It was then dried for 48 hours at room temperature to form MoAlB composite film.

From Table 1, the various concentrations of MoAlB were analysed to determine whether or not the material was in excellent compound. This will have an effect on the concentration of MoAlB. Additionally, if the thin layer is too thin, it may affect how quickly a thin coating burns. If the thin coating is too thick, the laser will have difficulty passing light through it.

**Table 1**
Comparison between the concentration of MoAlB

| MoAlB Powder (g) | PVA Solution (ml) | Thickness |
|---|---|---|
| 0.015 | 40ml | Too thin |
| 0.030 | 40ml | Thin |
| 0.045 | 40ml | Too thick |

## 3. Laser Configuration and Performances

Figure 2 illustrates the laser configuration or laser cavity. In order to provide further explanation of the laser's information, it is essential that the process within the ring cavity runs all of the components.

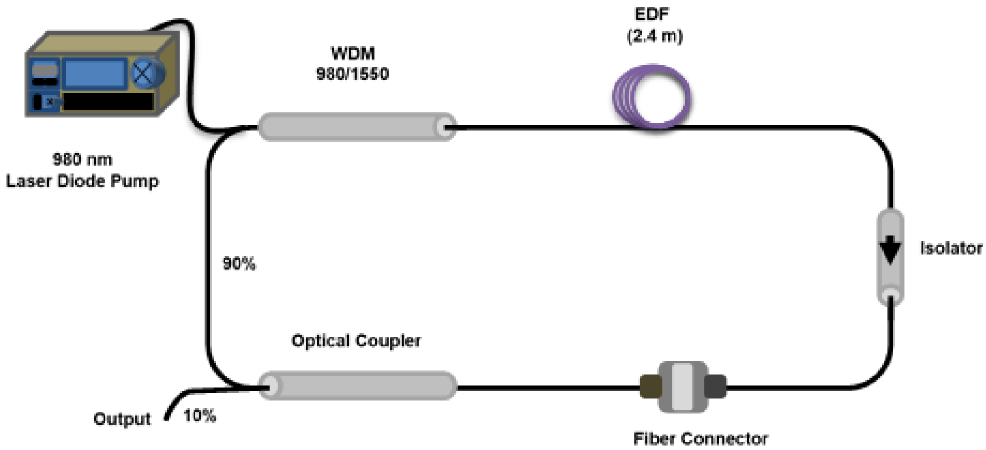


**Fig. 2.** Ring Laser Cavity Configuration

It began with the characterisation of a laser diode. The technique of laser diode characterisation was required to determine whether or not the laser diode was functioning properly. The power of the laser diode was measured, and the efficiency slope should be more than 50% to ensure the laser diode is operating properly. The operating laser diode had a wavelength of 980 nm. It was because generating a laser with a wavelength of 1550 nm required a pump laser diode with a wavelength of 980 nm. Following that, the process of WDM characterisation begins. The laser diode pigtail was connected to a 980 nm wavelength cable WDM. The laser that emerged from WDM was connected through a standard pigtail. The power production from WDM is recorded, and the power's slope efficiency should be more than 50%.

The common pigtail was spliced with 2.4 m of Erbium Doped Fiber. It is essential due to the development of 1550 nm wavelength lasers, often created using an EDF gain medium. Previous research determined the duration of EDF. It should result in Amplified Spontaneous Emission (ASE) through the gain medium. The functioning laser will decide the form of ASE. If ASE does not exist, the length of ASE should be checked once again. Following that, the ASE was spliced using Isolator. The purpose of the isolator was to ensure that the laser travelled in one direction and did not reflect, hence minimising damage to the laser diode caused by backscattering.

Following that, the isolator was spliced with an optical coupler equipped with a 90:10 separation cable. 10% of the cavity exited via this coupler, forming the laser output. The remaining 90% of laser energy was returned to the 1550 nm laser wire through WDM. The 10% fiber ferrule output resulted in the construction of a Continuous-Wave laser. If the CW laser did not develop, it was due to the absence of the ASE. The development of CW laser performances was monitored using an optical spectrum analyser and an output power meter. Following the construction of the CW laser, SA was injected into this ring cavity laser. The SA was put between two fiber ferrules at the fiber connector. The pulsed laser was generated by inserting SA. The SA that has been synthesised is Molybdenum Aluminum Boride (MoAlB). Optimise the insertion of SA if a pulse fiber laser was not created. The optical spectrum analyser, oscilloscope, radio frequency (RF) spectrum analyser, and optical power meter were used to measure the pulse laser's performance.

Next, a Q-switched laser may be formed when any SA is sandwiched between two fiber ferrules. The film being analysed is Molybdenum Aluminum Boride (MoAlB). The optical spectrum analyser is used to determine the spectrum of the Q-switched laser (OSA). The cavity was first investigated without consolidating the SA, implying no pulse was detected on the oscilloscope. When SA is injected into the laser cavity, and the pump power level is gradually increased, steady Q-switching is produced at 74.14 mW pump power and remains present until 110.66 mW pump power is reached. Figure 3 (a) shows the output spectrum of the Q-switching pulse in EDFL at the threshold pump power, with a wavelength of 1559.10 nm as its centre. The Q-switching pulse train functioning remained steady when the pump power was increased to 110.66 mW. The Q-switched laser's repetition rate and pulse width were measured from the initial formation of the pulsed laser until it was destroyed. The data was gathered by using an oscilloscope and a MoAlB thin film. As the pulsed laser formed on 74.14 mW pump power, the initial repetition rate was 22.73 kHz. On 20.3µs, the first pulse width was also recorded. When the pump's power was raised, the repetition rate increased monotonously while the pulse width decreased. The repetition rate increased from 22.73 kHz to 43.67 kHz as a consequence, while the pulse width decreased from 20.3µs to 7.425µs. The plotted graph in Figure 3 (b) also demonstrated the typical signature of Q-switching laser operation where the repetition rate and pulse width are dependent on input power.

Then, an optical power metre was used to determine the output power of the Q-switched laser. The output power measurement will be used to calculate the Q-switching laser's slope efficiency (SE). The greater the SE value, the better the laser's performance. The relationship between output power pulse energy and pump power is shown in Figure 3 (c) for a Q-switched laser generated using MoAlB-based SA. It is obvious from the Figure 3 (c) that when the input pump power is raised, the output pump power and pulse energy rise. The output power increased linearly from 0.33 mW to 1.8 mW as the pump power was raised from 74.14 mW to 110.66 mW. This shows the cavity efficiency of 4.03% obtained by utilising MoAlB as a saturable absorber. The highest pulse energy was also determined to be 41.18 nJ when the pump was operating at full pumping power.

Radio Frequency (RF) spectrum has been recorded using a 3 GHz RF spectrum analyser. RF spectrum analysis intends to determine the stability of a Q-switched laser. The outcome of SA's stability analysis will be described in this section.

RF spectrum analysis can verify the stability of the pulse generated from SA. The RF spectrum was acquired at a pump power of 110.66 mW and a frequency of 350 kHz, as seen in Figure 3 (d). The RF spectrum revealed that SA generated six harmonics with a fundamental frequency of 43.67 kHz. The fundamental frequency is broadly agreed upon as 23µs with the same pump power as illustrated in Figure 3 (d). Additionally, the fundamental frequency has an SNR of 30 dB, indicating that the Q-switched laser production is stable.

A 300 MHz digital oscilloscope was used to capture the characteristics of a Q-switched laser produced from a MoAlB thin film. The oscilloscope of the content will be analysed in this sub-topic to determine the spacing between pulses. The traces are shown in three different pump powers to make sure there are changes in the shape of the traces.

Figure 4 shows the Q-switching laser trace created when MoAlB thin film was used. The repetition rate was 22.73 kHz when the pump power reached 74.14 mW. The repetition rate increased by 34.25

kHz when the pump power reached 95 mW. The repetition rate was 43.67 kHz at the highest pump power of 110.66 mW.

The Figure 4 shows the distance between pulses and the pulse width for a single pulse, depending on the pump power differential. The delay between two pulses was 44 µs at the initial pump power, corresponding to a repetition rate of 22.73 kHz. Additionally, the pulse width was 20.3 µs. When the pump power was set to 95 mW, the interval between two pulses was 29.2 µs with a pulse width of 10.47 µs. The data indicates that it is comparable in terms of repetition rate, which is 34.25 kHz on average.

Additionally, the Figure 4 indicates that the time interval between two pulses while the pump's power is at its maximum is 23 µs, which corresponds to the pump's repetition rate of 43.67 kHz. The pulse width of the trace was determined to be 7.43 µs. The increase in repetition rate as a function of pump power demonstrates the Q-switched laser's feature.

The Q-switching laser has been eliminated when the pump power is raised over 110.66 mW. The damaged threshold for MoaAlB thin film as a saturable absorber was discovered to be 110.66 mW. The film was removed from the cavity configuration to demonstrate that it was responsible for the creation of the Q-switching laser.

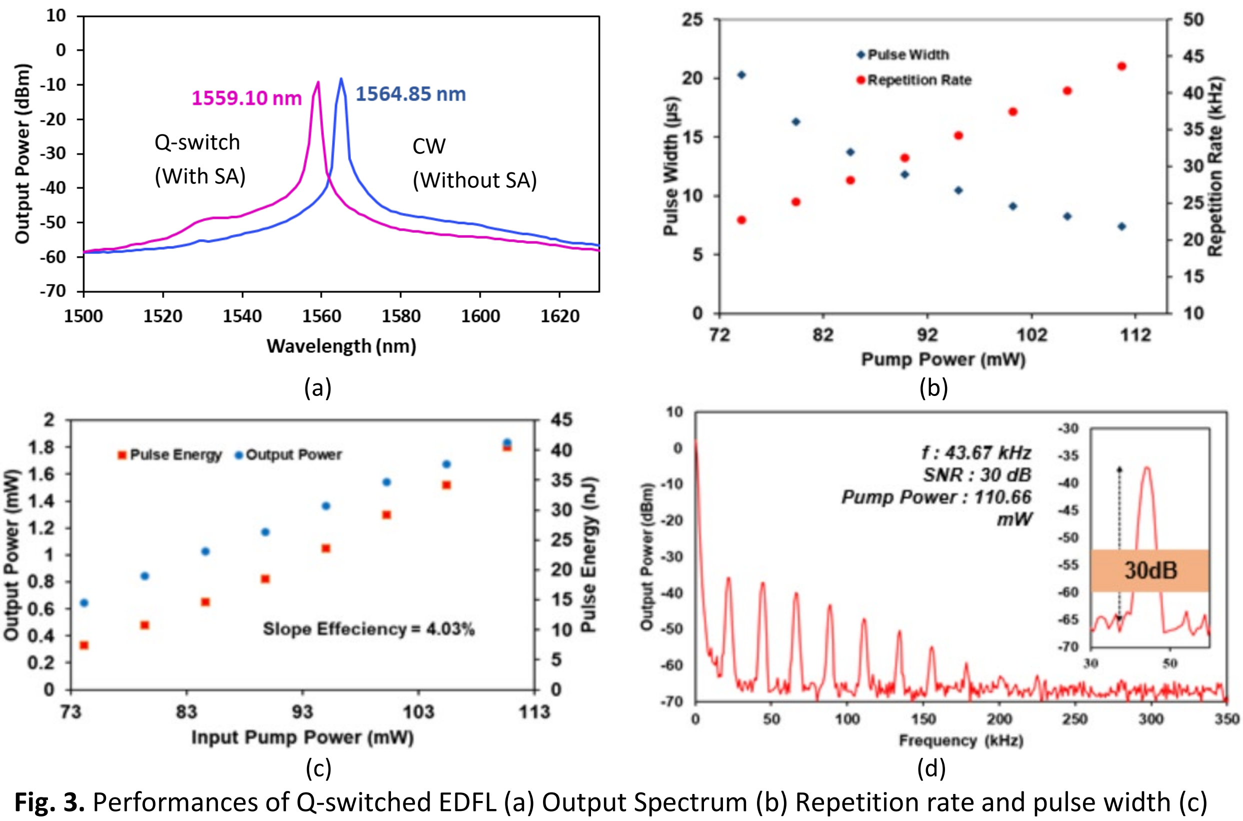


**Fig. 3.** Performances of Q-switched EDFL (a) Output Spectrum (b) Repetition rate and pulse width (c) Output power and pulse energy (d) RF Spectrum

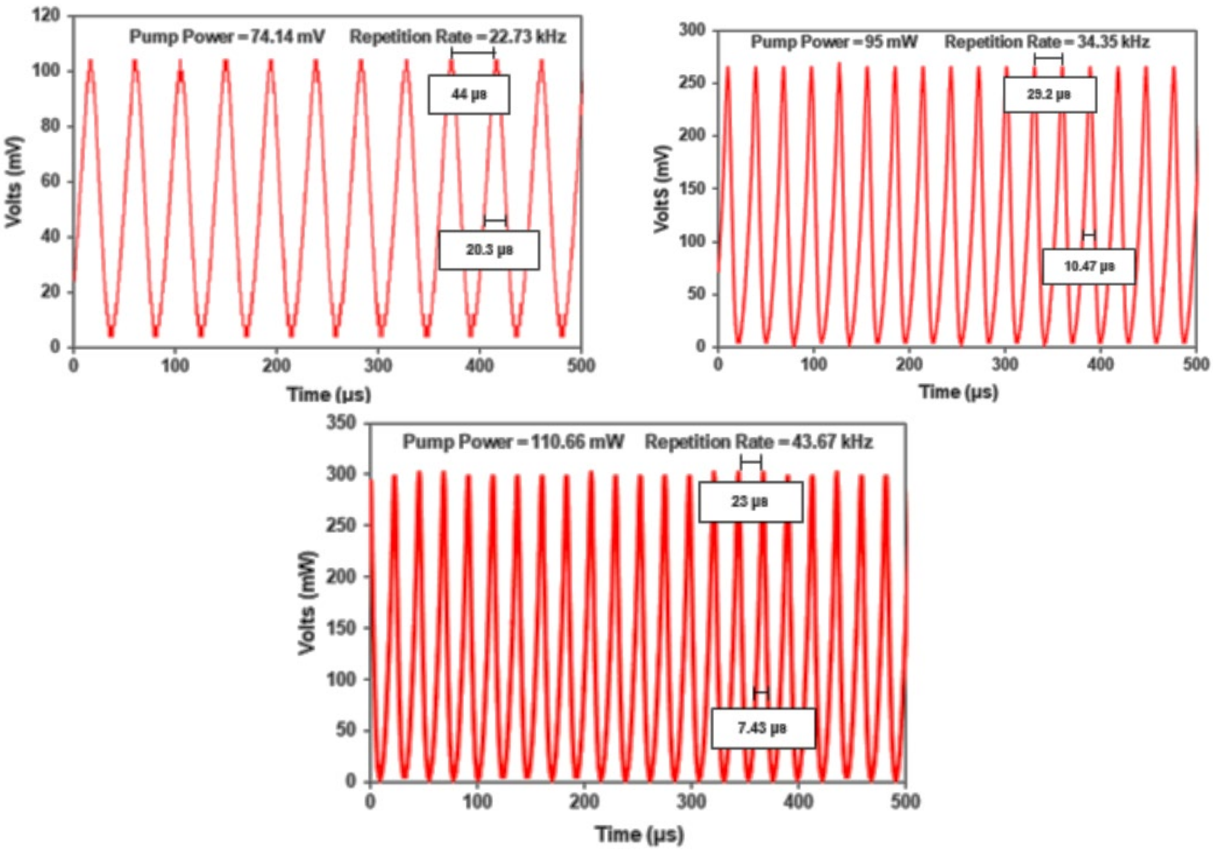

**Fig. 4.** Pulse train

In summary, the pulsed laser has been analysed, and the SA has developed a Q-switching pulse laser. The laser performance has been discussed precisely. The MoAlB saturable absorber succeeds in forming a pulsing laser. The repetition rate and pulse width of the lasers have been discussed comprehensively. The shape of pulsing with different pump powers is also discussed in this chapter. The stability of the lasers has been achieved and is being discussed in this chapter. The laser's output power and pulse energy have been recorded and calculated accurately using an optical power meter. The Table 2 below shows a comparison of SA using other materials.

**Table 2**
Comparison of SA by using other material

| SA | Max pump power (mW) | Repetition rate (kHz) | Pulse width (µs) | Pulse energy (nJ) | Output power (mW) | λ (nm) | Ref |
|---|---|---|---|---|---|---|---|
| Graphene | 151.47 | 67.8 | 6.02 | 206 | 32 | 1558.3 | [3] |
| CNT | 209.6 | 70.4 | 4.5 | 81.3 | 5.7 | 1563.1 | [4] |
| BP | 170 | 44.33 | 7.04 | 134 | 5.94 | 1552.9 | [5] |
| $MoS_2$ | 170 | 38.43 | 5.02 | 141.3 | 5.43 | 1551.4 | [5] |
| $Ti_3AlC_2$ | 94 | 112 | 3.93 | 75 | 8.4 | 1560.2 | [6] |
| $Na_2CO_3$ | 162 | 94.7 | 1.2 | 31 | 2.9 | 1560 | [7] |
| MoAlB | 110.66 | 43.67 | 7.43 | 41.22 | 1.8 | 1559.10 | This work |

## 4. Conclusions

Q-switched fiber lasers, which led to short pulses in the region of 1550 nm, have been successfully demonstrated in this research. This ultra-short pulse laser has been successfully developed from passive SA devices and an optimised laser cavity. The three objectives as a guideline for this study are accomplished by the comprehensive implementation of the process and techniques through the experiment.

The saturable absorber SA used in this work is fabricated and prepared from rare earth material. The rare earth material from the group lanthanide series is utilised as a base material for the SA device. The material that has been used is Molybdenum Aluminium Boride (MoAlB). The MoAlB SA was fabricated through a casting process to form a thin film. The concentration between MoAlB and PVA has become the key scope for this research to identify which concentration can make the stable and good performance of a Q-switching pulse fiber laser. Fabrication of MoAlB-based passive SA was also demonstrated. The MoAlB-PVA of SA has managed to develop the Q-switching pulse laser.

MoAlB is indeed a promising material to be used in generating pulsed lasers. Therefore, further research should be carried out to enhance laser performance based on this research. Among the parameters that influence laser performance, the material's band gap is the most important criterion. A lower band gap material is more desirable as it provides broad spectrum absorption. As far as we know, graphene has a zero band gap, and since MoAlB has a large band gap but with large exaction energy, combining both materials as passive SA could help provide new applications. In the next research, we must develop a new formula to construct a suitable saturable absorber so that the laser performance remains steady and good. In addition, since ultra-short pulses are important for many applications, MoAlB-based passive SA could be integrated into a mode-locked laser as its modulation depth is relatively high. Commercialising the suggested Q-switched laser in the telecommunications and medical fields is possible.

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