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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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DEVELOPMENT OF Q-SWITCHER FIBER LASER USING MOLYBDENUM ALUMINIUM BORIDE (M0AIB) THIN FILM AS SATURABLE ABSORBER

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A project report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electronics Engineering Technology with Honours



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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DECLARATION

I declare that this project report entitled "Development of Q-Switcher Fiber Laser using Molybdenum Aluminium Boride (MoAlB) Thin Film as Saturable Absorber" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electronics Engineering Technology with Honours.



DEDICATION

Special dedication to my family members, my friends, my fellow colleague and all faculty members

For all your care, support and believe in me. Stay safe.



ABSTRACT

Fiber laser has been a prevalent topic for the past decade, attracting much technical attention with many benefits. They complement existing bulk lasers instability, simplicity, efficient heat dissipation, reliability and low maintenance. In recent years, Q-Switched fiber lasers have gained a lot of attention. They can create relatively high energy pulses, which are helpful in various applications such as remote sensing, laser range finding, communication, marking, micro-machining, biomedical imaging and medical surgery. Fiber laser can be operated in Q-switched or mode-locked regimes to emit short pulses and ultra-short pulses at repetition rates of kHz and MHz, respectively. The objectives of this project is to study the lasing characteristic of erbium-doped fiber, investigate the characteristic of MoAlB as a saturable absorber and demonstrate Q-switched EDF laser using MoAlB thin film as a saturable absorber in the 1.55µm region. The Q-switched fiber laser can be achieved using either passive or active technique. In this case, passive technique is the suitable technique that can be implement for this project because the use of saturable absorber (SA) for passive Q-switching simplifies cavity construction and eliminates the requirement for external Qswitching electronics. The laser cavity was constructed using Erbium-Doped Fiber Laser as the gain medium. The preliminary result of Q-switched pulses operating at 1550 nm can be readily generated when the 980 nm pump power is raised. VERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRAK

Fiber laser telah menjadi topik yang lazim selama satu dekad yang lalu, menarik banyak perhatian teknikal dengan banyak faedah. Mereka melengkapkan ketidakstabilan, kesederhanaan, pelesapan haba yang cekap, kebolehpercayaan dan penyelenggaraan laser pukal yang ada. Dalam beberapa tahun kebelakangan ini, laser gentian Q-switched telah mendapat banyak perhatian. Mereka dapat menghasilkan denyutan tenaga yang agak tinggi, yang berguna dalam pelbagai aplikasi seperti penginderaan jauh, penemuan jarak jauh laser, komunikasi, penandaan, pemesinan mikro, pencitraan bioperubatan dan pembedahan perubatan. Fiber laser dapat dikendalikan dalam rejim Q-switched atau mode-lock untuk memancarkan denyutan pendek dan denyutan ultra pendek pada kadar pengulangan kHz dan MHz, masing-masing. Objektif projek ini adalah untuk mengkaji ciri penyerapan serat erbium-doped, menyelidiki ciri MoAlB sebagai penyerap tepu dan menunjukkan laser EDF yang diubah Q menggunakan filem nipis MoAlB sebagai penyerap tepu di wilayah 1,55 µm. Laser gentian Q-switched dapat dicapai dengan menggunakan teknik pasif atau aktif. Dalam kes ini, teknik pasif adalah teknik yang sesuai yang dapat dilaksanakan untuk projek ini kerana penggunaan absorber tepu (SA) untuk peralihan Q pasif memudahkan pembinaan rongga dan menghilangkan keperluan untuk elektronik peralihan Q luaran. Rongga laser dibina menggunakan Erbium-Doped Fiber Laser sebagai media penguatan. Hasil awal denyut Q-switched yang beroperasi pada 1550 nm dapat dihasilkan dengan mudah apabila daya pam 980 nm dinaikkan.

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LIST OF SYMBOLS

μm	-	Micrometer
μs		Microsecond
dB		Decibel
GHz		Gigahertz
kHz	-	Kilohertz
MHz	-	Megahertz
ml		Milliliters
mV		Millivolt
mW		Milliwatts
nJ		Nanojoule
nm	-	Nanometer



LIST OF ABBREVIATIONS

ASE	-	Amplified Spontaneous Emission
CNT	-	Carbon Nanotubes
CVD	-	Chemical Vapor Deposition
CW	-	Continous-Wave
DI	-	De-ionized
EDF	-	Erbium Doped Fiber
EDFA	-	Erbium Doped Fiber Amplifiers
EDFL		Erbium Doped Fiber Laser
Er	-	Erbium
LIDAR	-	Light Detection and Ranging
LPE	-	Liquid Phase Exfoliation
MoAlB	-	Molybdenum Aluminium Boride
Mo-B	-	Molydenum-Boron
OSA	- 15	Optical Spectrum Analyzer
PVA	1	Polyvinyl Alcohol
RF	5-	Radio Frequency
SA	8 -	Saturable Absorber
SE	F -	Slope Efficiency
SESAM	E-	Semiconductor Saturable Absorber
SNR	000	Signal-To-Ratio
WDM	211	Wavelength Division Multiplexer
ZrB_2	151	Zirconium Diboride
	ملاك	اويوم سيتي تتكنيكا مليسيا

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CHAPTER 1

INTRODUCTION

1.1 Basic Principles of Fiber Laser

The fiber laser has a long history, almost as long as the laser itself. After Elias Snitzer's invention in 1963, the fiber laser took nearly two decades to develop in the late 1980s, with the first commercial system. Due to the range of wavelengths they may create, they are often used in industrial settings to conduct tasks like as cutting, marking, welding, cleaning, texturing, and drilling. Additionally, they are employed in a variety of other sectors, including telecommunications and medical.

These lasers employed single-mode diode pumping and emitted a few tens of milliwatts. They gained attention because to their huge improvements and the ability to perform single-mode continuous-wave (CW) lasing on certain rare-earth ion transitions that were previously unattainable with the more popular crystal-laser type. The most well-known use of fiber laser technology is in an erbium-doped fiber laser with a wavelength of 1550 nm.

Numerous recent research have concentrated on developing pulse lasers for a variety of industrial and communication applications utilising active or passive Q-switching or mode-locked lasers. Inside the cavity, a power controlled modulator was used as an active approach. On the other hand, passive mode-locking uses a saturable absorber to create a mode-locked or Q-switch pulse.

A saturable absorber is a passive device that absorbs low-intensity light while transmitting high-intensity light. In other words, when light intensity increases, the degree of absorption of a saturable absorber decreases. Semiconductor materials can also be used to create a saturable absorber. However, the operating wavelength must be matched by the bandgap of the semiconductor materials. As a result, the saturable absorber, quick relaxation period, and wideband operability of Molybdenum Aluminum Boride make it an attractive option for the saturable absorber.

The ternary transition metal boride Molybdenum Aluminum Boride (MoAlB) has intriguing aeronautic and nuclear uses. Molybdenum-Boron (Mo-B) lattice is interleaved by alternating layers of Aluminum in the MoAlB structure (Al). As a result, it has certain unique qualities, like high-temperature oxidation resistance and damage tolerance. Furthermore, it has features inherent in binary transition metal Borides (e.g., Mo-B, ZrB₂), such as high hardness, high melting temperature, electrical conductivity, chemical resistance, etc.

1.1.1 Fiber Optic Fundamental

Fiber lasers are a subcategory of diode-pumped solid state lasers that amplify light using a doped optical fiber core. They include a spool of fiber optic cable with a core doped with a range of rare earth elements from the periodic table's lanthanide family. Ytterbium and erbium are often utilised. To attain a desired lasing wavelength and power level, the fiber doping element is chosen and doped into the ultra-pure glass fiber core. The fundamental principle underlying the interactions of fiber optics and lasers, Snell's Law is a critical concept to understand in order to fully understand how a fibre laser works. It is the formula that describes how light bends or refracts when it travels across the boundary between two transparent materials. Snell's Law is important in modelling how a laser source enters and travels down an optical fibre in the context of fibre lasers. More precisely, it defines how a laser source enters and travels along many fibres that are adjacently wrapped. As mentioned before, in a fiber laser, dopants are added to the ultra-pure glass that forms the core of the optical fiber.

In a simple setup, the fiber's core is doped but the surrounding layers of glass are kept undoped. The application of a dopant, such as erbium, affects the refractive index. Light will bend at specific angles depending on the refractive indices of two different materials, such as doped and undoped glass. Snell's law may be used to calculate these angles. These angles are measured in relation to a perpendicular normal line to the boundary.

1.1.2 Laser Fundamental

To begin, when energy in the form of light is provided to an atom, the electrons circling the nucleus of the atom absorb the light energy and get excited. In the case of a fibre laser, the most often used atom as an excitation source is erbium (Er). In a fiber laser, Er atoms are inserted (doped) into the fiber core. This excitation of the electrons of the erbium atom leads them to shift their energy level from their initial ground state of equilibrium to a new, higher energy state. The energy source for Er doped fiber lasers is commonly a 980 nanometer diode laser pump source. Because Er atoms absorb the wavelength 980 nm extremely well, they are often employed as a doping agent. Electrons will back to their ground state when the energy source is eliminated. When they return to their ground state, the rule of conservation of energy is applied, and the excited electrons must dissipate the energy obtained. This energy is produced as a photon. This newly formed photon will have a vibrational frequency and wavelength determined on the energy level at which it was emitted.

1.1.3 How a Fiber Laser Works

After reviewing the principles of optics and lasers in the previous section, we can now apply these concepts to the fiber laser category in order to understand how they work. Fiber lasers amplify light using a doped fiber core. Multiple semiconductor laser diodes are spliced into the spool of doped fiber to function as the amplifying medium. Pumps are the technical term for these laser diodes. The pumps operate in the 915nm to 980nm wavelength range and may generate optical power ranging from 500 mill watts to around 600 watts per laser diode. Multiple pump laser diodes are often spliced into the fiber.



Figure 1.1: Fiber Laser Block Diagram

1.2 Problem Statement

Numerous other materials have been studied as saturable absorber (SA), including semiconductor saturable absorbers (SESAM), carbon nanotubes (CNT), and twodimensional nanomaterials such as graphene. SESAMs were one of the early types of saturable absorber, but their relatively low operating bandwidth limits their ability to generate broad-band adjustable pulses. Carbon nanotube-saturable absorber (CNT-SA) are simple to produce and operate across a broader wavelength range. However, they have limited practical applicability in lasers due to the fact that the response spectrum range of carbon nanotubes is dependent on their chirality and diameter. Saturable absorbers made of graphene are expensive but easy to fabricate. The primary disadvantage of graphene (and also carbon nanotube) pulsed fiber lasers is that they may vanish at modest pumping due to their low saturating intensity and low damage threshold. Therefore, a difficult production process, a low damage threshold, inadequate purity, and non-uniformity of the materials all contribute to the degradation of these SAs' performance.

1.3 Project Objective

The objectives of this project are:

- a) To study the lasing characteristic of erbium doped fiber.
- b) To investigate the characteristic of MoAlB as a saturable absorber.
- c) To demonstrate Q-switched EDF laser using MoAlB thin film as a saturable absorber in the 1. 55µm region.

1.4 Scope of Project UNIVERSITI TEKNIKAL MALAYSIA MELAKA

The element that focusing in this project is separated in two:

- i. Laser Performances
- ii. Saturable Absorber Performances

In laser performance, first scope that will consider is the wavelength region that laser will produce. This project will develop Q-switched fiber lasers using erbium doped fiber in the 1550 nm region where the Q-switch laser generates regular pulse trains via repetitive Q-switching. The repetition rate of the pulse is generally between 1 and 100 kHz and the pulse width has reached pulse durations far below one nanosecond. The pulse repetition rate and the pulse width can be measured by an Oscilloscope. Passively Qswitching, the losses are automatically modulated with a saturable absorber. Thus, the pulse energy and duration are fixed, and changes in the pump power only influence the pulse repetition rate. The power of the pulse laser can be measured by Optical Power Meter. The effectiveness of laser can be shown at Power of the pulsed laser. The stability of the pulse laser can be measured by using Radio Frequency Spectrum Analyzer.

In saturable absorber performances, Molybdenum Aluminium Boride (MoAlB) is that material were used to develop MoAlB as saturable absorber. MoAlB powder was used and mixed with Polyvinyl Alcohol (PVA) to develop MoAlB-PVA saturable absorber. The method of fabricating the saturable absorber was futher described in Chapter 3.

1.5 Thesis Organization

This thesis is divided into five chapters, which completely demonstrate the generation pulsed laser that come from Molybdenum Aluminium Boride saturable absorber. Chapter 1 introduces the introduction of the project briefly. It includes the project's background of pulsed laser with problem statement, objectives and the scope of the project will clearly explain in this chapter. Next, Chapter 2 will provide a full detailed the fundamental and knowledge about generating laser. This chapter also discusses several types of laser operation and pulsing methods.

Chapter 3 is the chapter that will gives an overview the method and process on making the pulsed laser using Molydenum Aluminium Boride (MoAlB) as saturable absorber. It will be divided into 2 process. The first process is the process of making the saturable absorber film and the other one is the process on set up the cavity of the laser. In this chapter also including the overall flowchart for the making of this project. Furthermore, chapter 4 will discuss about the result from the experiment. It will be discussed in term of analysis including measurement and calculation of the result. The last chapter will be chapter 5, it will include overall conclusion about the project. Performance and future improvement will also be described in this chapter and will give a list of references in making this project.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A literature review is a section of a scholarly article that summarises existing knowledge, including experiment findings, as well as theoretical and methodological contributions to this work. This chapter analyses papers and journals to get a better understanding of the concepts necessary to perform this project, such as the meaning and history of lasers, continuous and pulse modes of operation, and the kind of laser used in this experiment. Several journal of previous research study that involved with passive Saturable Absorber (SAs) and related to Molybdenum Aluminium Boride (MoAlB) were discussed and compared.

2.2 Fiber Laser

Recently, fiber laser has been recognized as compact, stable, practical lasers and play an important 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.

Compared with the solid-state laser using a small laser crystal, the fiber amplifier consists of a few meters long fibers. Thus, the fiber amplifier has a wide surface area, which brings us a high heat radiation efficiency. The high heat radiation efficiency of the fiber laser, does not need water cooling, and a small and portable laser system can be demonstrated. The reason is that the atom levels of these earth elements have extremely useful energy levels, which allow for a cheaper diode laser pump source to be used, but still provide a high output of energy. For example, by doping fiber in Erbium, an energy level that can absorb photons with a wavelength of 980nm is decayed to a meta-stable equivalent of 1550nm.

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 compared to active techniques because of their advantages such as smaller in 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. [1]

2.2.1 Application

Q-Switcher lasers have a wide range of applications, including trace gas sensing, LIDAR (e.g. for range finding and autonomous driving), biomedical devices and nonlinear optics. They are also used in industries for cutting or drilling in hospitals for clinical applications such as tattoo or nevi removal. [2]

2.2.2 UNIVERSITI TEKNIKAL MALAYSIA MELAKA Advantages and Disadvantages

An advantages of fiber lasers over other lasers is that the laser light is generated and delivered by an inherently flexible medium that allow easier delivery to the focusing location and target. It can be important for laser cutting, welding and folding of metals and polymers. Another advantages is high output power compared to other types of lasers. Fiber lasers can have an active region and provide very high optical gain. Fiber laser is compared to other to solid-state or gas lasers of comparable power, because the fiber can be bent and coiled. Fiber lasers are reliable and exhibit high temperature and vibrational stability and extended lifetime. High peak power and nanosecond pulses improve marking and engraving. Other applications of fiber lasers include material processing, telecommunications, spectroscopy, medicine and directed energy weapons.

2.3 Erbium Doped Fiber Laser

The rare-earth ions Er^{3+} have a broad wavelength range of roughly 1.5µm, which is particularly advantageous for optical communication applications. Thus, during the twentieth century, erbium-doped fiber (EDF) was researched. In 1985, the first EDF was manufactured and reported [3]. All EDFLs can be pumped by tiny, efficient, and reasonably priced laser diodes operating at 980 or 1480 nm. They are compatible with a variety of 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 realized [4]. Additionally, the Er^{3+} ion is often utilized as an active element because it operates in the low-loss 1550 nm area, which is appropriate for communication applications. Erbium-doped fiber amplifiers (EDFA) and erbium-doped fiber lasers (EDFL) are utilized in EDF and function in a similar manner. By including a feedback mechanism into the setup, an EDFA device may be converted to an EDFL device. Due to the broad range of its fiber gain spectrum and the anomalous fiber dispersion at 1.55 μ m, the EDF is often utilized as a gain medium for ultra-short pulse production [5].

2.4 Q-Switching

According to El Sherif and King, the extractable energy from Q-switched fiber lasers is mostly determined by the amount of active ions in the gain medium and the lifespan of the metastable level. One way to get high peak power is to minimize the pulse width by using the pulse width's proportionality to the cavity length through a short length of highly doped fiber. However, a high active ion concentration may result in self-pulsation and dynamics effects, as well as ion clustering, hence reducing the laser's effectiveness through lifetime quenching of clustered ions. [6]

Another approach is to use a large-mode-area fiber as the gain medium to increase the extractable energy stored in the fiber. One method for increased pulse energy in a fiber laser, as used here, is to increase the mode area using a larger core diameter to generate millijoule pulses. However, it clearly cannot be increased indefinitely without compromising the modal quality of the output. Moreover, it is compared with the millijoules that are routinely obtained from the bulk laser system in which the mode sizes are much larger and less constrained.

Q-Switching, sometimes known as giant pulse information, is a technique by which a laser can be made to produce a pulsed output beam. The technique allows the production of light pulses with extremely high power (gigawatts), much higher than would be produced by the same laser if it were operating in CW mode. Compared to mode locking, another technique for pulse generation with lasers, Q-switching leads to much lower pulse repetition rates, much higher pulse energies and much longer pulse durations.

Q-Switching is accomplished by incorporating a variable attenuator into the optical resonator of the laser. When the attenuator is functioning, light that leaves the gain medium does not return and lasing cannot begin. The variable attenuator is commonly called a "Q-Switch" when used for this purpose. Initially, the laser medium is pumped while the Q-

Switch is set to prevent light feedback into the gain medium. Similar to mode locking, active and passive techniques are used for Q-Switching. Electro-optical and opto-acoustic (active Q-switching) switches and saturable absorbers (passive Q-switching) prevent feedback signal into the active media. [7]

2.4.1 Active Q-Switching

Active Q-Switching uses modulation devices that change the cavity losses by an external control signal. Active Q-Switches are divided into three categories; mechanical, electro-optical and acousto-optics. Mechanical Q-Switches have been developed based on the rotational, oscillatory or translational motion of optical components. The similarity between these techniques is that they inhibit laser action during the pump cycle by either blocking the light path, causing a mirror misalignment, or reducing the reflectivity of one of the resonator mirrors.

When maximum energy has been stored in the active medium towards the end of the pump pulse, a high Q-condition is established and a Q-Switch pulse is emitted from the laser. Among the techniques is a spinning reflector technique that involves simply rotating one of the two resonant cavity reflectors so that parallelism of the reflectors occurs for only a brief instant in time. [8]

The main advantages of this technique are that it can be inscribed in almost any host material independent of its doping. Furthermore, it is a flexible 3-dimensional fabrication method that allows. For example, creating both a waveguide and Bragg granting in a single processing step enable a truly monolithic laser design.

2.4.2 Passive Q-Switching

Passively Q-switched fiber lasers have a wide attraction in recent years due to their advantages of being compact, cost effective and easy to setup.[9] In a passive approach, the Q-Switching process is automatically obtained using a saturable absorber. This saturable absorber replaces the active modulator in the laser cavity. The switching process is caused by the optical nonlinearity of the saturable absorber. Passively Q-switching can occur with SAs, and it produce high power optical pulses depending on the laser cavity condition. [10]

2.5 Mode-Locked

Mode-locked laser technology is one of the most efficient means that generate ultrafast optical pulses.[11] Author mention that much attention has been focused on modelocked erbium-doped fiber lasers (EDFLs) for their intensive telecommunication, imaging spectroscopy and medicine.[12]

do

2.6 Graphene

In 2004, Geim and Novoselov developed one-layer graphene. Researchers created graphene with a few layers and single layer graphene using the graphite scotch-tape approach and discovered that no substance exists in a free state.[13]. The process is referred to as graphite mechanical exfoliation. The process is referred to as graphite mechanical exfoliation. The process is referred to as graphite mechanical exfoliation. The technique of large-scale graphene manufacturing is called liquid phase exfoliation (LPE), in which graphite flakes are disseminated in solvent and then ultrasonified and centrifuged to form a distributed solution of microscopic graphene flakes arranged in a few layers or single layers.[14]. However, the most promising technology for graphene synthesis is chemical vapour deposition (CVD).[15]. Graphene has become a rising star due to its unique and valuable electrical properties.

Despite this, owing to the huge demand for graphene due to its unique properties, graphene research has reached a saturation point today. There are several experiments that use graphene as a material, not only in photonics, but in a variety of other domains as well. Due to increased demand in the industry, graphene has grown more costly.[16]. Additionally, graphene has a deficiency. It has a band gap of zero and a low absorption coefficient. This will diminish their capacity to adjust light.[17].



CHAPTER 3

METHODOLOGY

3.1 Introduction

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This chapter will discuss about the methodology that is being used to complete and working well for this project. There are countless methods from this field that have taken as references for others to take advantages and will improve in upcoming studies. In order to complete this project, it divides into two part of method. The first part is specific for build up the laser cavity and for the second part is specially focused on fabricating the thin film of MoAlB. These two methods need to integrate together, thus the process of developing the project is getting easier.

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3.2 Flowchart

Figure 3.1 below is the figure of flowchart for developing a pulsed laser from MoAlB film.



Figure 3.1: Methodology Flowchart

The flowchart's explanation is as follows:

- Assemble the laser ring cavity by splicing all components together until a CW laser is produced.
- 2. Fabrication of MoAlB in thin film form.
- Sandwich the thin film between two fiber ferrules and insert it into the cavity of the laser ring.
- 4. Establishment of pulsed laser in Q-switched mode.
- Record the measurement from Optical Spectrum Analyzer, Oscilloscope, Optical Power Meter and Radio Frequency Spectrum Analyzer.

3.3 Laser Configuration

The laser configuration refers to the laser setup cavity in this experiment. This laser configuration is required to operate the laser.



Figure 3.2: Ring Laser Cavity Configuration

The ring cavity lasers used in this experiment are shown in Figure 3.2. As mentioned in Chapter 2, the laser's fundamental requirements include a laser diode, wavelength division, multiplexer, gain medium, isolator, fiber connection, and coupler.

3.3.1 Block Diagram

To explain more about the laser's information, the process inside the ring cavity must run through all of the components. The block diagram of the ring cavity is shown in Figure 3.3 below.



Figure 3.3: Block Diagram of Ring Cavity

According to Figure 3.3's block design, the laser diode will pump at 980nm via the wavelength-division multiplexer (WDM). Following that, the 980nm wavelength was transmitted over the Erbium Doped Fiber (EDF) gain medium. At EDF, the gain medium absorbed the 980nm laser wavelength and emitted the 1550 Amplitude Stimulated Emission (ASE) to the isolator. The ASE laser travelled via the isolator and an optical coupler. At the optical coupler, the laser splits into two parts, with 90% of the laser returning to WDM and 10% being output. This operation took just a few minutes, and hence the laser generated is a continuous-wave (CW) laser. Following that in Figure 3.4 below shown the saturable

absorber is put into the ring cavity of the fiber connection to create the pulsed laser. The laser that is created will be analyzed using an Optical Spectrum Analyzer (OSA) to determine if it is a Q-switched laser.



3.3.2 Flowchart of the Ring Cavity



Based on figure 3.4, it shows the overall flow to set up the cavity laser.

Figure 3.5: Flowchart for Laser Configuration.

It began with the characterization of a laser diode. The technique of laser diode characterization 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 980nm. It was because, in order to generate a laser with a wavelength of

1550nm, it required a pump laser diode with a wavelength of 980nm. Following that, the process of WDM characterization begins. The laser diodes pigtail was connected to a 980nm 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, which are often created using an EDF gain medium. A 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 minimizing 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 and formed the laser output. The remaining 90% of laser energy was returned to the 1550nm laser wire through WDM.

The output 10% fiber ferrule 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 analyzer 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 synthesized is Molybdenum Aluminum Boride (MoAlB). Optimize the insertion of SA if a pulse fiber laser was not created. The optical spectrum analyzer, oscilloscope, radio frequency (RF) spectrum analyzer, and optical power meter were used to measure the pulse laser's performance.

3.4 SA Fabrication

3.4.1 Preparation of Molybdenum Aluminium Boride (MoAlB) SA

The MoAlB-PVA film was formed using casting method. The thin film was created by dissolving MoAlB powder into PVA solution. Figure 3.5 show the casting method used to fabricate the MoAlB thin film.



Firstly, PVA was chosen as the host polymer owing to its non-toxic nature and ability to connect with other metal. The 1g of PVA powder and 120ml de-ionized water with the aid of magnetic stirrer at room temperature. Stirring was continued until the PVA powder was completely disseminated and the PVA solution become homogenous. To reiterate, when doing this method, the user should wear suitable safety equipment such as eyeglasses, gloves and lab coat to prevent any unintended chemical reactions.

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

In this case, the preparation has some difficulties when the MoAlB

3.4.2 Summary

As summary for this chapter, the various concentrations of MoAlB were analyzed 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.

E	MoAlB Powder	PVA Solution	Thickness
	(g)	(ml)	
	0.015	40ml	Too thin
de	0.030	40ml	Thin
٢,	0.045	40ml	Too thick

Table 3.1: Comparision between the concentration of MoAlB

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter will summarize the experiment's results and discuss them. The films of MoAlB have been successfully fabricated. By sandwiching of those films, between fiber ferrules, Q-Switching laser has formed. The analysis of Q-Switched lasers has recorded and analysed utilised MoAlB films as SA. The result will be discussed in terms of MoAlB's laser performance. In performance of laser, the Q-Switched laser has managed to develop by using MoAlB film. The analysis of output power, repetition rate, pulse width and frequency spectrum of laser will be discussed.

4.2 Laser Performance

When any SA is sandwiched between two fiber ferrules, a Q-switched laser may be formed. The film being analysed is Molydenum Aluminum Boride (MoAlB), and the findings are detailed in the following subtopics.

4.2.1 Output spectrum of Q-switched laser

The optical spectrum analyzer is used to determine the spectrum of the Q-switched laser (OSA). The cavity was first investigated without consolidating the SA, which implies that 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 4.1: Optical spectrum of Q-switched laser.

It shows the output spectrum of the Q-switching pulse in EDFL at the threshold pump power, which has a wavelength of 1559.10 nm as its centre. When the pump power was increased to 110.66 mW, the Q-switching pulse train functioning remained steady.

4.2.2 Repetition Rate and Pulse Width of the Q-switched laser

The repetition rate and pulse width of the Q-Switched laser were measured from initial formation of pulsed laser until it was destroyed. The data was gathered by using an oscilloscope and a MoAlB thin film.

As the pulsed laser has 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 pulse width decreased from 20.3µs to 7.425µs. Additionally, the plotted graph in Figure 4.2 demonstrated the typical signature of Q-switching laser operation where, the repetition rate and pulse width are dependent to input power.



Figure 4.2: Repetition rate and pulse width of pulsed fiber with MoAlB as saturable absorber against pump power.

4.2.3 Output Power and Pulse Energy

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 slope efficiency (SE) of the Q-switching laser. The greater the SE value, the better the laser's performance. The relationship between output power and pulse energy and pump power is shown in Figure 4.3 for a Q-switched laser generated using MoAlB-based SA. It is obvious from the figure that when 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. Additionally, the highest pulse energy was determined to be 41.18 nJ when the pump was operating at full pumping power.



Figure 4.3: Output power and pulse energy of Q-switched laser when using MoAlB

saturable absorber.

4.2.4 Oscilloscope Train for Q-switched Pulse Laser

A 300 MHz digital oscilloscope was used to capture the characteristics of a Qswitched 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 shown in three different pump power to make sure, there are changing in the shape of traces.

Figure 4.4 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 as soon as the pump power reached 95 mW. The repetition rate was 43.67 kHz at the highest pump power of 110.66 mW.

The same figure 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 μ s at the initial pump power, which corresponds to a repetition rate of 22.73 kHz. Additionally,

the pulse width was 20.3 μ s. When the pump power was set to 95 mW, the time interval between two pulses was 29.2 μ s with a pulse width of 10.47 μ s. The data indicates that it is comparable in terms of repetition rate, which is 34.25 kHz on average. Additionally, the figure indicates that the time interval between two pulses while the pump's power is at its maximum is 23 μ s, which corresponds to the pump's repetition rate of 43.67 kHz. The pulse width of the trace was determined to be 7.43 μ s. 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. It was discovered that the damaged threshold for MoaAlB thin film as a saturable absorber was 110.66 mW. To demonstrate that it was responsible for the creation of the Q-switching laser, the film was removed from the cavity configuration.





Figure 4.4: Pulse train for MoAlB as saturable absorber under different pump power.

4.2.5 Radio Frequency (RF) Spectrum for Q-Switched Laser

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

The stability of the pulse generated from SA can be verified via RF spectrum analysis. The RF spectrum was acquired at a pump power of 110.66 mW and a frequency of 350 kHz, as seen in Figure. 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 4.5. Additionally, the fundamental frequency has an SNR of 30 dB, indicating that the Q-switched laser production is stable.



Figure 4.5: RF spectrum of MoAlB Q-switched laser with a span 350 kHz.

4.2.6 Summary

As summary for this chapter, the pulsed laser have been analysed and the SA has managed to develop a Q-switching pulse laser. The laser performance has been discussed in this chapter precisely. The MoAlB saturable absorber succeed to form a pulsing laser. The repetition rate and pulse width of the lasers has been discussed comprehensively. The shape pulsing with difference pump power also discussed in this chapter. Stability of the lasers has achieved and being discussed in this chapter. The output power and pulse energy of the laser has been recorded and calculated accurately using optical power meter. The table below show the comparison of SA by using other material.

SA	Max pump power (mW)	Repition 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	[18]
CNT	209.6	70.4	4.5	81.3	5.7	1563.1	[19]
BP	170	44.33	7.04	134	5.94	1552.9	[20]
MoS_2	170	38.43 🧹	5.02	141.3	5.43	1551.4	[20]
Ti ₃ AlC ₂	94	112 🔾	3.93	75 S.	8.4	1560.2	[21]
Na ₂ CO ₃	162	94.7	1.2	31	2.9	1560	[22]
MoAlB	U110.66 R	SI43.67EKN	7.43	1A41.22 SIA	1.8	1559.10	This work

Table 4.1: Comparison of MoAlB-SA with other SAs as a Q-switcher.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

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

The SA used in this work are fabricated and prepared from the rare earth material. The rare earth material from group lanthanide series are utilized as a base-material for 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 Q-switching pulse fiber laser. Fabrication of MoAlB based passive SA was demonstrated in Chapter 3. The MoAlB-PVA of SA have managed to develop the Q-switching pulse laser.

5.2 Future Works

MoAlB indeed a promising material to be used in generating pulsed laser. Therefore, based on this research, a further research should be carried out to enhance the laser performance. Among the parameters that influence the laser performance, the bandgap of material is the most important criteria. Lower bandgap material is more desirable as it provides broad spectrum absorption. As far as we know, graphene has a zero bandgap and since MoAlB has a large bandgap but with large exciton energy, combining both material as passive SA could help in providing 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 ultrashort pulses are important for many applications, MoAlB based passive SA could be integrated in mode-locked laser as its modulation depth is relatively high. Commercialization of the suggested Q-switched laser in the telecommunications and medical fields is possible.



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APPENDICES

Appendix A

Molybdenum Aluminium Boride (MoAlB) Data Sheet



Product Datasheet

Molybdenum Aluminum Boride

Product code: MO-ALB-02-P



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A Certificate of Analysis and Materials Safety Data Sheet (SDS) in accordance with EN 10204 are supplied with every shipment.

Note

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Appendix B

Molybdenum Aluminium Boride (MoAlB) Thin Film



