Faculty of Electrical and Electronic Engineering Technology

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

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Bachelor of Electronics Engineering Technology with Honours

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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 Q-switching 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.

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	-	Optical Spectrum Analyzer
PVA	-	Polyvinyl Alcohol
RF	-	Radio Frequency
SA	-	Saturable Absorber
SE	-	Slope Efficiency
SESAM	-	Semiconductor Saturable Absorber
SNR	-	Signal-To-Ratio
WDM	-	Wavelength Division Multiplexer
ZrB_2	-	Zirconium Diboride

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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, ZrB_2), 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.

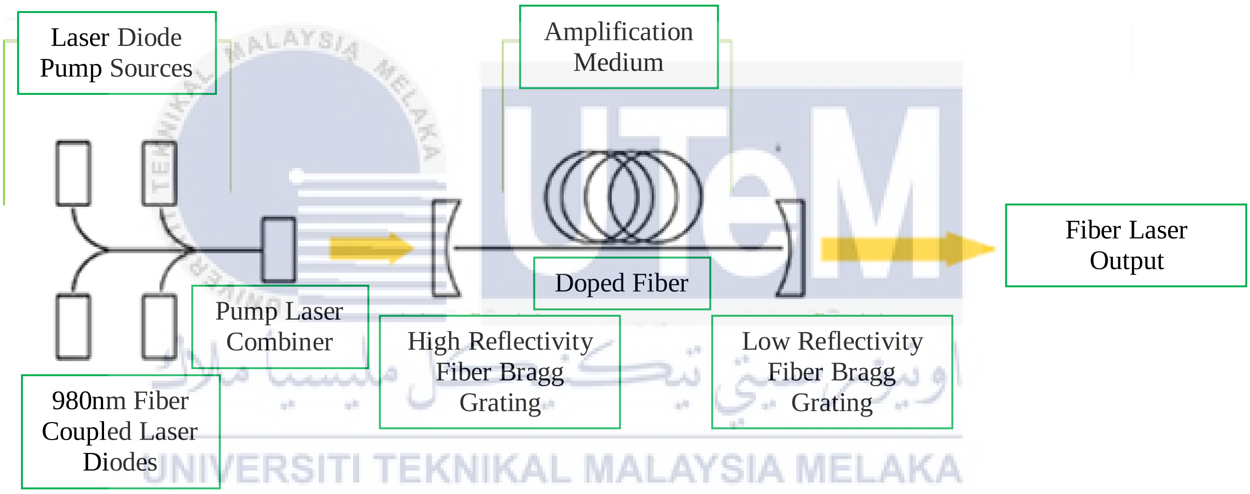

Figure 1.1: Fiber Laser Block Diagram

1.2 Problem Statement

Numerous other materials have been studied as saturable absorber (SA), including semiconductor saturable absorbers (SESAM), carbon nanotubes (CNT), and two-dimensional 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

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 Q-switching, 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,