Faculty of Electrical and Electronic Engineering Technology

DEVELOPMENT OF Q-SWITCHER FIBER LASER USING TANTALUM ALUMINUM CARBIDE THIN FILM AS SATURABLE ABSORBER

MUHAMMAD SYAZWAN AL-HAFIZ BIN ROSLAN

Bachelor of Electronics Engineering Technology with Honours

2021

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MUHAMMAD SYAZWAN AL-HAFIZ BIN ROSLAN

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

Faculty of Electrical and Electronic Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI TEKNOLOGI KEJUTERAAN ELEKTRIK DAN ELEKTRONIK

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : DEVELOPMENT OF Q-SWITCHER FIBER LASER USING TANTALUM ALUMINIUM CARBIDE THIN FILM AS SATURABLE ABSORBER

Sesi Pengajian : 2021/2022

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DR AMINAH BINTI AHMAD
Pensyarah
Jabatan Teknologi Kejuruteraan Elektronik Dan Komputer
Fakulti Teknologi Kejuruteraan Elektrik Dan Elektronik
Universiti Teknikal Malaysia Melaka

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Supervisor Name : DR AMINAH BINTI AHMAD

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DEDICATION

To my beloved mother, Mrs. Khairul Fadzilah Binti Mohamed Yusof, and father, Mr. Roslan Bin Hashim, siblings, housemate, friends and others who always support and encourage me through my education journey.

And

To my supervisor Dr. Aminah Binti Ahmad and laboratory staff
Mr. Muhammad Farid Bin Rusdi

Thank you for everything.

ABSTRACT

Fiber lasers have gotten a lot of attention in recent years as a potential substitute for highcost bulk solid-state lasers. Remote sensing, laser range finding, communication, labelling, micro-machining, biomedical imaging, and medical surgery are just a few of the fields where these lasers could be helpful. Fiber lasers might also create short and ultrashort pulses at kHz and MHz repetition rates, respectively, in Q-switched or mode-locked modes. Because of its high peak power and nanosecond pulse duration, Q-switching fiber lasers are commonly employed for tattoo removal and 3D optical data storage. We show a small, all-fiber Qswitched Erbium-doped fiber laser with a saturable absorber made of tantalum aluminium carbide thin film (SA). However, SA is necessary to create Q-switched in active Q-switched semiconductors. This technique is no longer being researched because of its short operating wavelength and high manufacturing cost. Furthermore, the SA recovery time is longer than the cavity round trip time in passive Qswitched systems since the pulse duration is reliant on the time to deplete the gain once the SA saturates. As the gain medium for the laser cavity, erbium-doped fiber was used. The discovery suggests that tantalum aluminium carbide could be an effective SA for Q-switched lasers operating in the 1.55-14m range. EDF, SMF fiber, splicer, LD, WDM, Isolator, OSA, 90/10 coupler, fiber connection, and excel software were among the materials and equipment used.

ABSTRAK

Laser gentian telah mendapat banyak perhatian dalam beberapa tahun terakhir sebagai pengganti berpotensi untuk laser keadaan pepejal pukal kos tinggi. Penginderaan jauh, penemuan jarak jauh laser, komunikasi, pelabelan, pemesinan mikro, pencitraan bioperubatan, dan pembedahan perubatan hanyalah beberapa bidang di mana laser ini dapat membantu. Laser serat juga dapat membuat denyutan pendek dan ultrashort pada kadar pengulangan kHz dan MHz, masing-masing, dalam mod Q-switched atau mode-lock. Kerana daya puncaknya yang tinggi dan jangka masa nadi nanodetik, laser gentian Qswitching biasanya digunakan untuk penyingkiran tatu dan penyimpanan data optik 3D. Kami menunjukkan laser serat Q-switched Erbium kecil serat dengan penyerap tepu yang diperbuat daripada filem nipis aluminium karbida tantalum (SA). Walau bagaimanapun, SA adalah perlu untuk membuat Q-switched dalam Q-switched semiconductors aktif. Teknik ini tidak lagi diteliti kerana panjang gelombang operasi yang pendek dan kos pembuatan yang tinggi. Tambahan pula, masa pemulihan SA lebih panjang daripada waktu pusingan rongga dalam sistem berpindah Q pasif kerana jangka masa nadi bergantung pada masa untuk mengurangkan keuntungan setelah SA jenuh. Sebagai medium penguatan untuk rongga laser, serat erbium-doped digunakan. Penemuan menunjukkan bahawa tantalum aluminium karbida boleh menjadi SA yang berkesan untuk laser yang diubah Q yang beroperasi dalam jarak 1,55-14 m. EDF, fiber SMF, splicer, LD, WDM, Isolator, OSA, 90/10 coupler, sambungan gentian, dan perisian excel adalah antara bahan dan peralatan yang digunakan.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Beneficent and the Most Merciful.

First and foremost, all praised to Allah with the Most Kindness for giving me chance to finish and completed this Bachelor Degree Project. I would like to express my gratitude to my supervisor, Dr. Aminah Ahmad and co-supervisor, Mr. Muhammad Farid Rusdi for their precious guidance, words of wisdom and patient throughout this project.

I am also grateful to the Universiti Teknikal Malaysia Melaka (UTeM) and the laboratory personnel for their assistance in providing locations that allowed me to complete the study. Not to mention my coworkers for their readiness to share their opinions and ideas about the project.

My gratitude is extended to my parents and family members for their support and prayers during my studies. Mrs. Khairul Fadzilah Mohamed Yusof deserves special recognition for her dedication and understanding. And thank you, Mr. Roslan Hashim, for being my support during the most challenging times.

Finally, I'd like to show my thankfulness to all of the faculty members at the Faculty of Electronic and Computer Engineering (FKEKK), as well as those persons who are not included here, for their cooperation and assistance.

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°C	-	Celcius
°F	-	Fahrenheit

LIST OF ABBREVIATIONS

CW	-	Continuos-wave
Ta_2AlC	-	Tantalum Aluminum Carbide
SA	-	Saturable Absorber
EDFL	-	Erbium-Doped Fiber Laser
EDF	-	Erbium-Doped Fiber
kHz	-	Kilo-hertz
WDM	-	Wavelength division multiplexing
nm	-	Nanometre
DWDM	-	Dense Wavelength Division Multiplexing
OSA	-	Optical Spectrum Analyzer
LIDAR	-	Light Detection and Ranging
OC	-	Output Coupler
HR	-	High Reflecting
NDLM	-	Non-linear Optical Loop Mirror
NALM	-	Non-linear Amplifying Loop Mirror
NPR	-	Non-linear Polarization Rotation
CuO	-	Copper Oxide
TiO_2	-	Titanium Dioxide
PVA	-	Polyvinyl Alcohol
RO	-	Reverse Osmosis
DI	-	Dionized
g	-	Gram
rpm	-	Revolution per Minutes
ml	-	Milimetre
V	-	Voltage
RF	-	Radio Frequency
µs	-	Micro second
mW	-	Miliwatt
SNR	-	Signal to Noise Ratio

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CHAPTER 1

INTRODUCTION

1.1 Background of project

The fiber laser has a long history. The fiber laser took nearly two decades to develop after Elias Snitzer's creation in 1963, with the first commercial devices appearing in the late 1980s. These lasers produced a few tens of milliwatts and employed single-mode diode pumping. Its significant increases drew attention, as did the prospect of single-mode continuous-wave (CW) lasing for various rare-earth ion transitions that were impossible with the more common crystal-laser type. The erbium-doped optic laser with a wavelength of 1550 nm is the most well-known use of fiber laser technology.

Several recent research has concentrated on using active or passive Q-switching or mode-locked lasers to make pulse lasers for various manufacturing and communication applications. Within the cavity, a power-managed modulator has been used as an active method. Saturable absorber by passive mode-locking uses to provide a mode-locked or Q-switch pulse. A light-absorbing device known as a saturable absorber emits high-intensity light while absorbing low-intensity light. In other terms, when height increases, the degree of absorption of saturable absorber drops. Semiconductor materials can also be used to create saturable absorbers. The semiconductor materials bandgap should equal the operational bandwidth.

Tantalum Aluminium Carbide is a good choice for a saturable absorber because of its saturable absorber, quick relaxation time, and wideband accessibility. Aluminum Carbide Tantalum Ta2AlC is a ternary layered MAX phase compound of the generic form Mn+1AXn, with n=1, 2, or 3 and M being a transition metal, A being an element such as aluminium or silicon, and X being either carbon or nitrogen. MAX phase compounds are precursors for creating MXenes, which are innovative 2D materials with qualities that mix metal and ceramic features. Exfoliation or etching is used to selectively remove the A layer from the bulk three-dimensional MAX phase compound, resulting in layers separated by other ions (known as intercalation), which improves their characteristics. American Elements produces a wide range of MAX phase and MXene materials with very high purity (>e;99.999 percent).

1.2 Problem Statement

The optical output power of continuous wave (CW) is limited by the most significant attainable pump power. The peak output power of a Q-switched fiber laser can be increased by compressing the available energy into a single, short optical pulse or a periodic sequence of optical pulses. By swiftly switching the cavity loss, Q-switching allows the creation of an optical pulse with a repetition rate in the kHz range and a pulse width ranging from microseconds to nanoseconds. Fiber lasers with a high peak power are better than CW fiber lasers for a lot of applications, including remote sensing, medicine, range discovery, and industrial processing. Because Q-switching does not create ultra-short pulses like mode-locked lasers, it has few benefit, including being less expensive, easier to construct, and more successful at collecting energy from the upper laser energy. The different length of EDF effect the lasing characteristic. High cost of material normally used for SA and the different SA will affect the effectiveness of the laser operation.

Active or passive methods can be used to create a Q-switched fiber laser. An electro-optic or acoustical optic modulation technique can be used to accomplish active Q-switching in the cavity. Furthermore, passive Q-switching with a saturable absorber (SA) is a great way to external Q-switching is no longer necessary, making cavity design easier. devices. Saturable absorbers (SA) such as transition metal-doped crystals and semiconductor materials have been used to generate Q-switched fiber lasers, notably operating in the 1550 nm range. Carbon nanotubes and graphene are frequently utilised as saturable absorbers in today's Q-switched fiber lasers. This is due to its inherent characteristics, with a wide working bandwidth, excellent optical fiber compatibility, quick recovery time, and less saturation intensity. Besides that, SA based on semiconductor and crystal cannot be employed for all fiber optic structures. Furthermore, the bandgap fluctuates depending on the circumstances. The limited research into Q-switching laser sources based on low-bandgap components is still ongoing. In this work, the laser cavity will be created using Erbium Doped Fiber Laser (EDFL as the gain medium, and evidence of Tantalum Aluminum Carbide's (Ta_2AlC) promise as an effective SA for Q-switched lasers operating at 1550 nm will be provided.

1.3 Project Objective

The objective of this project are :

a) To study the lasing characteristic of erbium doped fiber.

b) To investigate the characteristic of Ta_2AIC as saturable absorber.

c) To demonstrate Q-switched EDF laser using Ta_2AIC thin film as saturable absorber in the 1.55 µm region.

1.4 Scope of Project

This project's scope is to study, understand and develop the Q-switched fiber lasers with a wavelength of 1550 nm are being produced. Q-switch laser use repeated Q-switching to generate regular pulse trains. The pulse repetition rate is usually between 1 and 100 kHz. Passively Q-switching has achieved pulse durations as short as one millisecond and repetition rates high as a few megahertz. So, passively Q-switching, where the losses are regulated automatically by a saturable absorber. The pulse energy and duration are fixed, and pump power variation only affects the repetition rate, so the saturable absorber material was utilized. Tantalum Aluminium Carbide (Ta_2AlC) was chosen as the material to prove the possibility of an effective saturable absorber due to its low band gap as determined by the periodic table:

1.5 Thesis organization

Introduction, Literature Review, Methodology, Result, and Conclusion are the five chapters that comprise the thesis. The project's concept is briefly introduced in Chapter 1. Then, it provides the project's background, problem statement, project objectives, and project scope. Following that, Chapter 2 covered the literature review and theoretical work completed in the recent article. Chapter 3 provides an overview of the project's methodology. It includes all of the methods discussed in the previous article, such as the design algorithm, research, and laboratory activities. The preliminary results are explained in Chapter 4, and the final chapter, Chapter 5, concludes the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The fiber laser has nearly as extensive a history as the laser itself. The fiber laser took almost two decades to develop after its creation in 1963 by Elias Snitzer, with the first commercial devices appearing in the late 1980s. These lasers used single-mode diode pumping and emitted a few tens of milliwatts. They drew attention because of their enormous gains and the possibility of single-mode continuous-wave (CW) lasing for several rare-earth ion transitions that were impossible with the more common crystal-laser variant. Erbium-doped fiber amplifiers with a wavelength of 1550 nm are the most well-known use in technology laser source. Many laser applications, meanwhile its require watts of optical power rather than milliwatts. In 1990, a 4-W erbium-doped fiber laser was announced, marking the first step toward the watt-level fiber-laser output. This breakthrough paved the way for ten-watt and more effective single-mode fiber lasers, the first accurate high-power fiber lasers, to be developed for micromachining and other applications. Because of its potential uses in wavelength-division-multiplexing (WDM) communication, microwave production, high-resolution spectroscopy, fiberoptic sensing, and other fields, all multiwavelength fiber lasers have recently gained a lot of attention.[1]. With the rapid advancement of fiber laser technology, many telecommunications and other fields saw the promise of incorporating fiber laser technology into their applications. Q-switching and mode-locking are two techniques for producing ultra-short optical pulses in a fiber laser in an all-optical non-linear approach [2].

2.2 Fiber laser

Over the last ten years, fiber laser technology has advanced dramatically. The most advanced fiber laser has used Erbium-doped fiber (EDF) as the gain medium[3]. Fiber laser technology has produced a variety of new applications, including laser-based communication and measurement systems. In both optical communication and sensing applications, the single wavelength, single polarisation fiber laser is preferable. Soon after the laser's creation in 1960, the potential of using an optical carrier wave for telecommunication arose. When using a fiber laser, the use and design of the laser are much more versatile. Heat dissipation is more efficient when the surface-to-volume ratio of fiber is larger. With wavelength division multiplexing (WDM) technology, fiber also offers a considerable benefit in terms of carrying a big amount of data. As a result, the technology can carry data at rates of up to terabits per second. A single commercial optical fiber can carry more than 100 channels. [4].

Furthermore, Erbium-doped fiber (EDF) is employed as a gain medium in this study because it can efficiently amplify light in the 1550 nm wavelength range, which is where telecom fibers have the lowest loss [5]. Fiber lasers have been a popular topic for the past decade, attracting a lot of technical attention thanks to their numerous benefits. They outperform traditional bulk lasers in resilience, simplicity, superior heat dissipation, reliability, and zero maintenance [6]. Ultrafast optical technology deals with the generation, manipulation, amplification, and applications of ultrashort optical pulses with a peak power substantially higher than their average power. The additional requirement well covers most ultrafast laser work in the current literature that the pulses be derived in some way from a mode-locked laser [7].

2.2.1 Erbium-doped fiber (EDF)

Erbium-Doped Fiber (EDF) is a type of optical fiber with a large gain bandwidth centred at 1550 nm that is extensively used as an amplifier in today's optical communication systems. The EDF can amplify data channels simultaneously with the fastest data speeds in dense wavelength division multiplexing (DWDM) with low noise [8]. Furthermore, many academics are interested in EDF lasers (EDFLs) because of their optical communication and fiber sensing applications. As a result, multiplexing techniques involving merging numerous communications channels have been used to improve data transmission in optical fibers and meet the bandwidth need of future networks [9]. Q-switched erbium-doped fiber lasers (EDFL) have attracted intensive attention for their wide applications in fields such as communications, reflectometry, fiber optical sensing, etc. Compared to actively Q-switched fiber lasers, passively Q-switched ones have the advantages of compactness and simplicity of design. Many kinds of saturable absorbers (SA) have been used to achieve passive Q-switching of the EDFLs, such as the transition metal-doped crystals that include Co^{+2}: ZnSe, Co^{+2}: ZnS, Cr^{+2}: ZnSe, Co^{+2}: $MgAl_2\ O_4$, and the semiconductor quantum-well structures that comprise InGaAs–InP, AlGaInAs, etc. [10]. In this study, two varieties of EDF (EDF 1 and EDF 2) were utilised, each with a distinct absorption coefficient of 5.09 dB/m and 7.28 dB/m. Table 2.1 lists the various parameters of the two EDFs. The setup for characterization of the Erbium-doped fiber amplifier (EDFA) shown in figure 2.1. The pump laser is attached to a wavelength division multiplexing (WDM) system to generate 1550 nm, which is in the C or L band region, which is suitable for EDF absorption. The isolator is attached to the EDF's output, which is the component of optical that ensures one-way direction in the fiber cavity. The ASE spectrum's noise peak induced by oscillation reflection can be reduced by using an isolator. The spectrum of the output signal was measured using an optical spectrum