UNIVERSITI PUTRA MALAYSIA

GENERATION OF A PASSIVE MODE-LOCKED FIBER LASER BY USING ISOGAIN ERBIUM DOPED FIBER AS A GAIN MEDIUM

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By

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Thesis Submitted to the Department of Physics, Universiti Putra Malaysia, in partial Fulfilment of the Requirements for the Degree of Bachelor of Science in Physics with Education (Honours)
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DEDICATION

This dissertation is dedicated to:

- My supervisor, Dr Amirah Bt Abd Latif, who was guiding and giving me a lot of information and advices about this project. She also being there for me even though she has a lot of work to do but she manage to make sure my final project can be well complete.
- My friends and family who have supported me throughout all the process in this final year project. I will always appreciate everything that they have done, especially Ms. Nurnazifah for always helping me by teaching how to use the devices, how to obtain the result and giving me a lot of information in this project.

Thank you.

ABSTRACT

GENERATION OF A PASSIVE MODE-LOCKED FIBER LASER BY USING ISOGAIN ERBIUM DOPED FIBER AS A GAIN MEDIUM

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This final year project report that demonstrates in detail the generation of passive mode-locked fiber laser by using IsoGain erbium doped fiber as a gain medium. This technique was chosen because this technique has advantages by using erbium doped fiber IsoGain as a medium gain which is gives high absorption fibers for L-band amplifiers and mini/micro C-band EDFAs. 3 meters long erbium-doped fiber IsoGain is used as a gain medium in this fiber laser. The nonlinear polarization rotation technique was applied in this passive mode-locked where the polarizer controller placed between the polarizer and coupler. The optical spectrum was used to measure the output pulses in terms of repetition rate, peak to peak time duration, output spectrum and stability. The passive mode-locked was achieved at the highest pump power of 273mW.

ABSTRAK

PENJANAAN LASER GENTIAN MOD PASIF YANG DIKUNCI DENGAN MENGGUNAKAN ISO GAIN SERAT ERBIUM DIDOP SEBAGAI MEDIUM GAIN

Oleh

NURFAIZATUL NIZA BINTI KHAIROL ANUAR

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Laporan projek tahun akhir ini menunjukkan secara terperinci penjanaan laser gentian mod pasif yang dikunci dengan menggunakan IsoGain didop sebagai gentian didop erbium Teknik ini dipilih kerana teknik ini mempunyai kelebihan dengan menggunakan IsoGain didop sebagai gentian didop erbium dimana ia memberi gentian serapan tinggi untuk penguat jalur L dan EDFA jalur C mini/mikro. 3-meter IsoGain gentian dop erbium digunakan sebagai medium gain dalam laser gentian ini. Teknik putaran tidak sejajar telah digunakan dalam gentian mod pasif yang dikunci ini di mana pengawal polarisasi diletakkan di antara polarizer dengan pengganding. Spektrum optik digunakan untuk mengukur denyutan yang dihasilkan dari segi kadar pengulangan, jangka waktu puncak ke puncak, pengeluaran spectrum dan kestabilan. Mod terkunci pasif dicapai pada kuasa pam yang tertinggi iaitu 273mW.

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APPROVAL

This thesis entitled "generation of a passive mode-locked fiber laser in a ring cavity" by Nurfaizatul niza binti khairol anuar (Matric No.: 196247), was submitted to the Department of Physics, Faculty of Science, Universiti Putra Malaysia and has been accepted as partial fulfillment of the requirement for the Degree of Bachelor of Science in Physics with Education (Honours)

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LIST OF ABBREVIATIONS

SESAMs	Semiconductor Saturable Absorber Mirrors
CNT	Carbon Nanotubes
CNT-SA	Carbon Nanotubes Saturable Absorber
EDFL	Erbium Doped Fiber Laser
CW	Continuous-wave
ML-FL	Mode-Locked Fiber Laser
NPR	Nonlinear Polarization Rotation
L-BAND	Long band
PC	Polarization Controller
OSA	Optical Spectrum Analyzer
OSC	Oscilloscope
OPM	Optical Power Meter
ASE	Amplifier Spontaneous Emission
C-BAND	Conventional band
WDM	Wavelength-Division Multiplexing
EDF	Erbium Doped Fiber
LD	Laser Diode
EDFAs	Erbium Doped Fibers
HC	High cut-off wavelength
HEDF	highly erbium-doped fiber
SAM	Self-amplitude modulation
SAs	saturable absorbers
EOM	electro-optic modulator
AOM	acoustic-optic modulator

EDZF	Erbium Doped Zirconia Fiber
EDFA	Erbium-Doped Fiber Amplifier
ISO	isolator
LED	light-emitting diode
LASER	Light Amplification by Stimulated Emission of Radiation
FWHM	Full Width at Half Maximum

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Fiber optic also known as optical fiber is a medium and technology for transmitting data in the form of light particles or photons that pulse through a glass or plastic strand. A fiber optic cable contain a few to several hundred of these glass fibers. There are contains three basic components in a single optical fiber. First component is the core which is the light transmission area of the fiber, either glass or plastic strand. The larger the core then the more light that will be transmitted into the fiber. Second component is surrounding the glass fiber core called cladding which is to provide a lower refractive index at the core interface and reflection within the core will occur so that light waves are transmitted through the fiber. Lastly is buffer coatings, usually there are multi-layers of plastics applied to maintain the fiber strength, absorb shock, protect the cladding and provide an extra fiber protection. These buffer coatings are available from 250 microns to 900 microns. The cladding is made of a material has a slightly lower index of refraction than the core. This difference causes total internal reflection to occur at the core-cladding boundary along the fiber. Total internal reflection occurs when the incident angle is greater than the critical angle and this phenomenon involves the reflection of all the incident light off the boundary. In an optical fiber, the light travels through the core by constantly reflecting from the cladding because the angle of the light is always greater than the critical angle. Usually fiber optic used in long distance and high performance data networking also in telecommunication services such as internet, television and telephones.

1.2 Mode-Locked Fiber Laser

Mode-locked is one of the technique to achieve ultrashort pulses from lasers with a very short duration, particularly within the picoseconds and femtoseconds regimes. The pulsed laser achieved by inducing all the oscillating multiple longitudinal modes and locked in phase with fixed mode spacing with each other. There are two types mode-locked, first is active mode-locking using optic modulator and second is passive mode-locking using saturable absorber as the modulator. An optical modulator is a device that used for manipulating a property of light. Optical modulators are used in very different application areas, such as in optical fiber communications, displays, for active Q-witching or mode locking of lasers, and in optical metrology. A saturable absorber is an optical component with a certain optical absorption loss, which is reduced at high optical intensities.

1.3 Problem Statement

One of the example of the saturable absorber that are very commonly used is semiconductor saturable absorber mirrors (SESAMs) but this device brings a lot of disvantages. The disadvantages of using SESAMs is high cost and time consuming of fabrication process. To overcome this disadvantage, IsoGain erbium doped fiber has been applied as a gain medium in this fiber laser. IsoGain erbium doped fiber has advantages, which is high cut-off wavelength (HC) variants optimized for high pump power Erbium Doped Fibers (EDFAs) and high absorption fibers for L-band amplifiers and mini/micro C-band EDFA.

1.4 Objectives

The project objectives are as follows:

i. To analyze the performance of the generation of a passive mode-locked fiber by using IsoGain erbium doped fiber as a gain medium.

ii. To improve performance of passive mode-locked technique.

1.5 Thesis arrangement

This thesis is divided into five chapters. The first chapter explains about the background of the study that related to optical fiber and working principle. The objectives for this research project also mentioned in this chapter. Chapter 2 explain about the literature review and some previous study that related to this research project. The working principle of passively mode-locked is mentioned in this chapter. Chapter 3 explain about methodology of this research, which is explanation about the technique and steps how to achieve pulses. In chapter 4, the results and discussion from this project are mentioned in this chapter. Lastly, Chapter 5 concluded this research and suggestion for the further studies also mentioned in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 IsoGain Erbium Doped Fiber

The HEDF manufactured by Fibercore Limited Company is the I-25 product in the IsoGain™ range. The fiber with numerical aperture of 0.25 has cut-off wavelength from 870 nm to 970 nm and has mode field diameters of 3.3 µm at 980 nm and 5.4 µm at 1550 nm. Its absorption coefficient at 980 nm can attain 27 dB/m which is much higher than the value (about 3 dB/m) of ordinary EDF. This high absorption means high gain, which is beneficial to increase output power and decrease the cavity length. Meanwhile, a length of LEDF with 4 dB/m absorption coefficient at 980 nm is introduced in the ring cavity. (Cheng et al, 2014). IsoGainTM EDF has a numerical aperture (NA) of 0.25, a cut-off frequency of 910 nm and absorption of 10 dB/m at 979 nm. While DHB 1500TM has a NA of 0.23, cut-off frequency of 930 nm and an absorption of 4.3 dB/m at 979 nm. (Anthony et al, 2013). Baharom (2019) mention that the gain medium (2.8 m EDF, IsoGain I-25(980/125) has peak core absorption of 35–45 dB/m at 1531 nm wavelength. In addition to that, it also has a core diameter of 4 µm, a cladding diameter of 125 µm and numerical aperture (NA) of 0.23–0.26.

2.2 Pulsed Laser

The pulsed laser technique was applied to remelt the deposited Cr3C2-NiCr coatings. (Chong et al, 2021). Pulsed lasers are the lasers that emit a light in the form of optical pulses not in continuous mode. Coupling the high peak power with overlapping pulses, pulsed laser not only produces a good melting ratio but also brings about a high cooling rate and a low heat input than that of the continuous wave laser. (Hamidi et al,2010). A pulsed laser produces a series of pulses at a certain pulse width and frequency until it stop. A pulsed laser allows the user control the duration of beam an intensity, but emitted in pulses rather than one continuous beam. Q-switch and mode-locked are the methods to achieve the pulsed laser. An attenuator or compressor can be insert in between of the oscillator and amplifier in order to improving the performance and the quality of pulses output from the laser.

2.3 Mode-locked

Mode-locked is one of the technique to achieve the pulsed laser with a very short duration, within the picoseconds and femtoseconds. Graphite nano-particles and even charcoal powder shave been reported to be usable as saturable absorber for laser mode locking (Yamashita et al, 2014). Mode locked technique works by including all the oscillating multiple of longitudinal modes to be locked in phase with a fixed mode spacing with each other. In harmonically mode-locked fiber lasers, in the presence of relatively high pumping power, the single pulse circulating in the cavity can be split into several pulses. (Sotor et al, 2012). In mode-locked fiber lasers with high pump power, multiple pulses tend to be generated due to nonlinearity induced wave breaking. (Huang & xiao, 2020).

2.3.1 Active Mode-Locked

Gao (2020) mention that the actively mode-locked fiber lasers have the advantages of high pulse repetition rate, symmetrical shape and tunable central wavelength. Moreover, it is easy to realize high-order tunable mode-locked and to produce optical pulse without frequency chirp approximating transformation limitation, achieving high conversion efficiency and high repetition rate (GHz) and considering their harmonic frequency characteristics, actively mode-locked fiber lasers surely become one of the suitable light source. Active mode-lock is achieved with an acousto-optic or optic modulator involving the periodic modulation of the resonator losses. In active mode locking, an external signal is applied to an optical loss modulator typically using the acousto-optic or electro-optic effect. Here, the pulse is formed shortly after the trigger signal arrives. Such an electronically driven loss modulation requires exact synchronism of an external modulator with the resonator round trip, which is not easily achieved. Also, the pulse duration is limited to the electronic speed of the external modulator, which is usually in a range of 1–100 ps, adding more complexity to the system. (Sadeq et al, 2018).

2.3.2 Passive Mode-locked

Passively mode-locked fiber laser has advantages in the stability, robustness, cost efficiency and ultrashort pulses durations. Passive mode-locked can generate more shorter pulses in the femtosecond with using a saturable absorber that can modulate the resonator losses faster than an electric modulator. Sadeq et al (2018) mentioned that passive mode-locked is based on a saturable absorber, which is used to obtain a self-amplitude modulation (SAM) of the light inside the laser cavity. The benefit of passive technique is its simplicity, fast response, easiness to implement, and superior performance compared to actively mode-locking technique. Low-cost and reliable passive mode-locked, mainly exploited in ultrashort pulse laser sources, enables generation of the pulses with a pulse duration much shorter than the modulator switching time. Stoliarov et al (2021) mentioned amongst passive mode-lockers, saturable absorbers (SAs) are excellent due to their simplicity, compactness and reliability. With a passive mode-locking 2-µm Tm-laser based on the SAs, which can yield picosecond and femtosecond pulses having been successfully demonstrated.

2.4 Q-switch

Q-switch is a technique that used for obtain the energetic short light pulses from a laser by adjusting the loss of intracavity and thus the Q factor of the laser resonator. To realize pulsed emission in fiber lasers, Q-switching is one of the preferred technology to generate short and high-energy pulses which are widely employed in optical communications, industrial processing, sensing, medicine and spectroscopy. (Wen et al, 2021).

2.4.1 Active Q-switch

An active Q-switch technique is method that used based on modulator by using acousto-optic or electro-optic. The active Q-switched laser is generally realized by using bulk elements of electro-optic modulator (EOM) or acoustic-optic modulator (AOM), which impede the fiber laser's original advantage of compactness and suffer from high cost. Fu et al (2015) mentioned the use of actively Q-switched technology in pulsed laser operation can provide higher energy pulses and stability. The wide pulse fiber laser with low repetition rate increases the peak power of a single pulse and reduces the pulse repetition frequency when the average power is constant (Pan et al, 2021).

2.4.2 Passive Q-switch

Passively Q-switch is a technique where the optic modulator is replaced with a saturable absorber. (Ahmad et al, 2021) mention the passive Q-switching offers a simpler design that does not require the use of bulky optical modulators that increase the system complexity and thus diminishing its flexibility. In the passive Q-switching technique, the loss modulation mechanism is achieved by incorporating a nonlinear optical material having an intensity-dependent transmission property, generally termed as saturable absorbers. (Ahmad et al, 2021). Passively Q-switching has been recognized to be a compact, low-cost, and efficient method to achieve ultra-short laser pulse compared with the actively Q-switching using electro-optical or acousto-optical modulators. (Hu et al, 2021).

2.5 Nonlinear Polarizer Rotation technique

The mode-locked EDZF laser is presented using one of the passive mode-locked techniques called the nonlinear polarization rotation (NPR). The principle of the NPR technique relies on the Kerr effect in a length of optical fiber in conjunction with polarizers to introduce artificial saturable absorber action and achieve pulse shortening. (Hamzah, et al. 2012). NPR can be achieved when incident of a linearly polarized light on a piece of weakly two different refractive indices fiber such as EDFL, and it will generally become elliptically polarized in this fiber. Hamzah et al (2012) mention that NPR can be achieved when a linearly polarized light is incident on a piece of weakly birefringent fiber such as EDZF, and the polarization on the light will generally become elliptically polarized in this fiber. Tu et al (2007) mention that Passively mode-locked fiber lasers have been demonstrated using nonlinear polarization rotation (NPR) technique and NPR is an effective method to generate mode-locked ultrashort pulses. Nonlinear polarisation rotation can be disturbing in systems with fibre amplifiers, but it is also commonly employed for passive fiber laser mode locking. Polarisation controller or waveplates that can be adjusted to provide maximum transmission (lowest loss) at the polarizer for the highest possible optical intensity. As the Kerr effect and this absorber is very fast, and same goes with the polarization controllers, its intensity strength is adjustable. It shows that with nonlinear polarization rotation makes the mode-lock fiber laser becomes a good technique.

2.6 Erbium Doped Fiber Amplifier

Erbium-Doped Fiber Amplifier (EDFA) is a device that amplifies the signal of optical fiber within the C-band (1530-1560) nm and L-band (1570-1610) nm where the loss of telecom optical fibers becomes lowest within the entire optical telecommunication wavelength bands. Doped fiber amplifier is refer to the process of using chemical elements which is erbium in order to facilitate results through the manipulation of electrons. Erbium-Doped Fiber Amplifier (EDFA) used to increase the intensity of optical signals, as a booster inline and pre-amplifier in an optical transmission line. Erbium-Doped Fiber Amplifier provides in-line amplification of signal without involve any conversion of signal to electrical signal before the amplification and the amplification is independent of data rate. EDFA also provides a high power transfer from pump to the signal power. EDFA can amplify multiple signal of optical simultaneously and can be easily combine with Wavelength-Division Multiplexing (WDM) is one of the most important characteristics of the Erbium Doped-Fiber Amplifier. EDFA mostly used to balance the loss of optical fiber in a long-distance optical communication.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter starts by introducing a brief review on a passively mode-locked technique in a ring cavity configuration. This approach allows for a deeper understanding of the methodology that used in the research project. The methodology for this project includes preparation of fiber optics linkage, characterization of mode-locked fiber laser and preparation of carbon nanotubes film as a saturable absorber for passively mode-locked fiber laser in a ring cavity configuration. The experimental setup is explained from the schematic diagram shown in this chapter, which includes the devices that are used in this research work to analyze the data.

3.2 Flowchart

Figure 3.1 presents the flowchart of the process generating passively mode-locked fiber laser by using IsoGain Erbium Doped Fiber as a gain medium until measurement used to analyze the data. Firstly, the preparation of optical fiber linkage had to be done. This is the important process to prepare the cavity which is a ring cavity for the production of passively mode-locked fiber laser. The method that is used to connect two fibers is the fusion splicing method. After the preparation of the cavity, the characterization of the laser diode pump was performed. This step is important to obtain the output of light intensity from the laser diode pump when the current is being supplied to it. The next step is to generate the amplified spontaneous emission of erbium-doped fiber that can be characterized by the light emission observed from the Optical Spectrum Analyzer (OSA). Next, the Preparation of Laser Cavity for Passive Mode-locked fiber laser by using IsoGain Erbium Doped Fiber as a gain medium. The result is obtained by using an optical spectrum analyzer, oscilloscope and optical power meter.

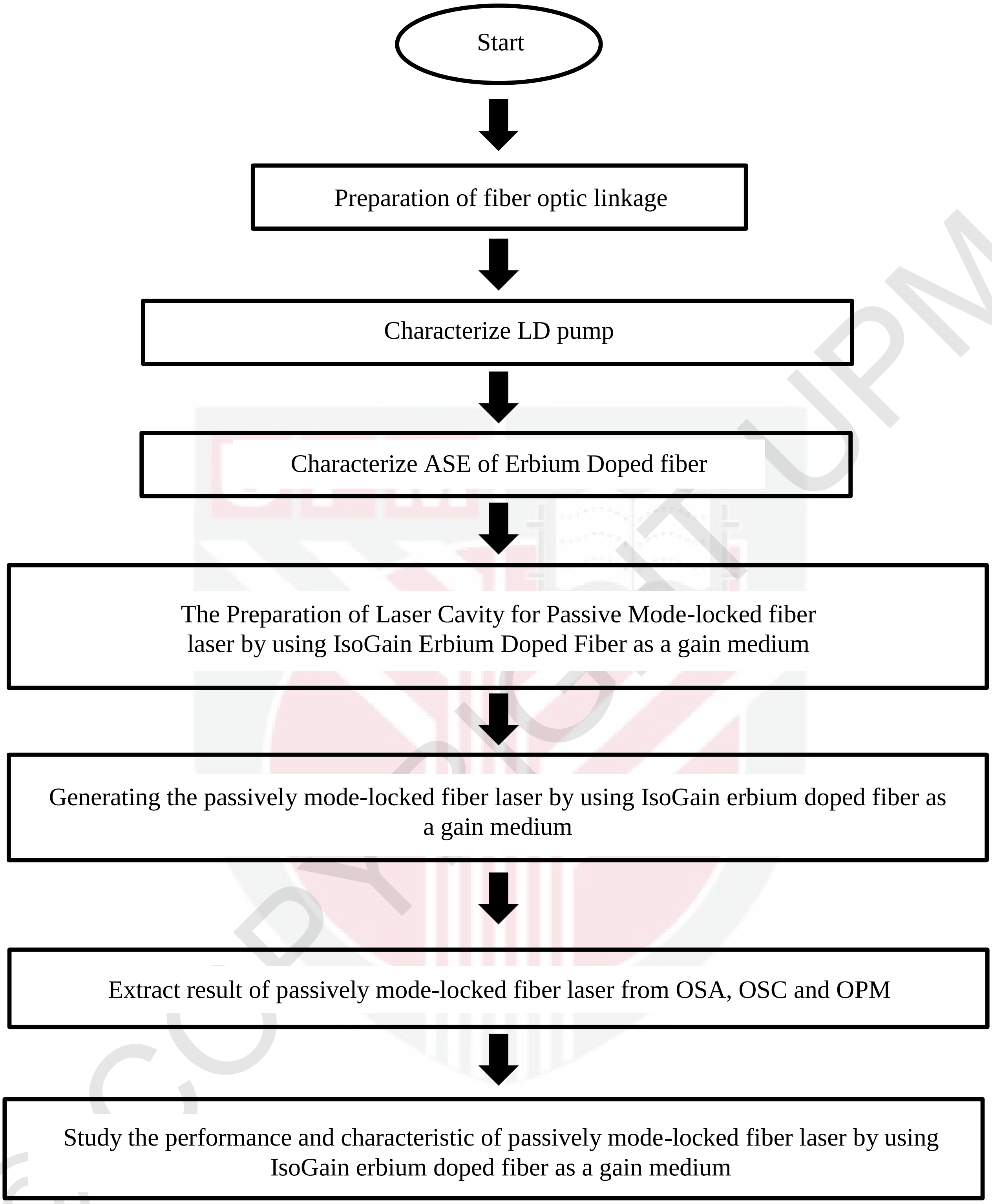

Figure 3.1: Process of generating Passive Mode-locked fiber laser by using IsoGain erbium doped fiber as a gain medium

3.3 Process of Optical Fiber Linkage

The first step to prepare the optical fiber laser is to do the fusion splicing. Fusion splicing is the technique or process of fusing or welding two fibers together by an electric arc. This technique is used to form long optical links for a better long-distance optical signal transmission. Fusion splicing is also a technique that the transmission loss is really small compared to the mechanical method. An optical fusion splicer is basically a machine that combines two end fibers together by a high-intensity ark to heat and melt the fiber, before both of the ends are combined. The optical fiber must be stripped and cleaved beforehand by using an optical fiber stripper and cleaver before the process of fusion splicing starts. Other equipment and materials such as alcohol, ruler, marker pen and Kimwipes tissues are also used in this fusion splicing process.

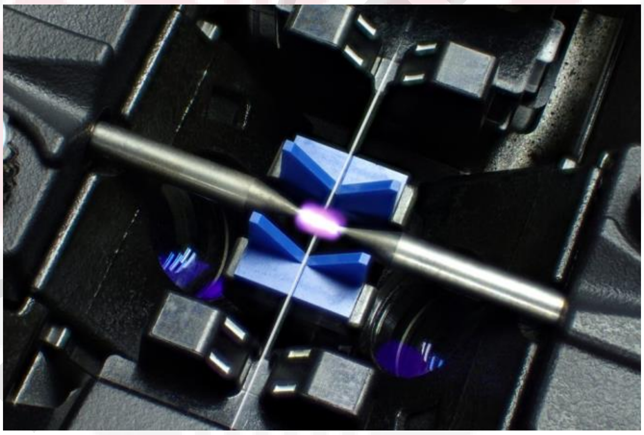

Figure 3.2 Diagram of Electric Arc

3.3.1 Strippng

Stripping is a process where the protective polymer coating around the optical fiber is removed by using the stripper as the preparation for the fusion splicing. The stripping process must be done at both ends of fibers before starting the optical splicing process. After all the protective polymers are removed, the fibers must be cleaned by using alcohol and wiped it using Kimwipes tissues.

Figure 3.3: Stripper

3.3.2 Cleaving

Cleaving is a process to cut or break the optical fiber by using the cleaver. The surface of the end of the optical fiber must be perfectly flat or perpendicular to the axis to produce better splicing of the optical fiber. After the cleaving process, the optical fiber can be checked using the splicer to check either the surface is flat enough to continue the splicing process.

Figure 3.4: Cleaver

3.3.3 Splicing

The optical splicing process is a method where two fiber optics are connected by melting or fusing both ends of the optical fiber. The splicing process begins with the steps of fiber preparation which is stripping and cleaving. The two fiber optic are placed at the holder in the fiber optic splicer. After the two fibers are tightly held by the splicer holder, a large spark is emitted from the optical fusion splicer which melts the two ends of the optical fiber without causing the fiber's cladding and molten glass core to mix. Then, the optical fiber that already melted is joined together to form the final fusion spliced optical fiber. Lastly, the optical splicer will show the amount of the splice loss and the successfully splicing will show usually a loss of 0.1 dB or less on the screen.

Figure 3.5: Splicing the fiber optic

3.4 Optical Devices Used In the Experiment

This subtopic explains the function of each device used in the experiment such as laser diode, wavelength division multiplexer (WDM), optical isolator (ISO) and the output coupler.

3.4.1 Laser Diode

A laser diode is a semiconductor device similar to a light-emitting diode (LED). This device used the electrical power to generate light using a complicated p-n junction as a gain medium to emit coherent light which all the waves are generated at the same frequency and phase. Coherent light is produced by the laser diode using a process termed as "Light Amplification by Stimulated Emission of Radiation" (LASER).

3.4.2 Wavelength Division Multiplexer

Wavelength division multiplexer (WDM) is a device that multiplexes multiple optical carrier signals on a single fiber optic by using different colors of laser light to carry different signals. WDM uses a single fiber optic in order to transmit multiple optical signals. In the WDM system, there are multiplexers and demultiplexers. A multiplexer at the transmitter will take the signal and combine it together, while the demultiplexer will split apart the signal at the receiver. This technology is usually found in fiber optic communication.

3.4.3 Optical Isolator

Optical isolator is a device that allows the optical signal to travel in the only one direction and will block the reflections of signal that would travel in the backward direction. This is because it will affect the stability of frequency in the laser source and the oscillation in the operation of the optical amplifier.

3.4.4 Polarization Controller

Polarization controller is an optical device that allows one to change the polarization state of light controller. The polarization controller uses the birefringence that caused by bending (coiling) a fiber by wrap the fiber about two or three spools in order to create the independent wave plates where adjust the polarization of the transmitted light in a single-mode fiber. One can transform a given input state polarization at a fixed wavelength into any output state of polarization by adjust the orientation of all three coils.

Figure 3.6: Polarization controller

3.4.5 Photodetector

A photodetector also known as photosensors is a device that is used for the detection of light in the optical system. Photodetector will deliver an electronic output signal in terms of voltage or electric current which is proportional to the incident optical power. This device has a good and high sensitivity at its operating wavelength and also having a short-time response to obtain a high capacity bandwidth.

3.4.6 Optical Power Meter

An optical power meter is a device where the power is measured in an optical signal. This device is used for testing the average power in a fiber optical system. This device also helps to obtain the power loss in optical signals while passing through the optical media. This OPM is also used in continuity testing which is measured by placing a calibrated light source at one end of the fiber and the optical power meter is connected at the other end. An optical power meter allows the measurement of power that only with relatively low bandwidth and only the average of power will be displayed when a pulse train with a high pulse repetition rate is being measured.

Figure 3.7: Optical Power Meter

3.4.7 Fiber optical couplers

A fiber optic coupler is a device that can transfer the optical signal from one fiber into two or more fibers and also can combine the optical signal from two or more fibers into a single fiber. There are two categories of optical fiber couplers which are active and passive. Active coupler refers to splitting or combining the signal electrically, by first converting the light into an electrical source and finally change it back into the optical light source via an electrical-to-optical conversion. Meanwhile, a passive coupler refers to the distribution of the optical signal without involves the conversion of the optical signal to the electrical signal. One of the techniques most commonly used for splitting input power for signals or wavelengths into two or more outputs in an optical fiber coupler is Biconical Taper Coupler or Fused Coupler. This device is created by the process of fusing or melting two fibers, twisting and tapering so that their core will be very close to each other. In this research project, 1×2 fused couplers are used to split the light with one input or two outputs.

3.5 Characterization of Laser Diode Pump

A laser diode uses a p-n junction for producing coherent radiation with along same frequency and phase. The p-n junction used to allows the electric current in a forward bias condition whereas it blocks the electric current in a reverse bias condition. The threshold value is when the laser diode starts to emit stimulated radiation at a certain value of the current supply. The threshold value is an important characteristic of a laser diode because it can be used to approximate the minimum value to start a light emission from the laser diode. The laser diode doesn't operate until a minimum power is applied. If the light is below its energy, then the emission is weaker than the threshold compared to the full energy. The information of the laser diode can be achieved by investigating the output of the power against the current curve.

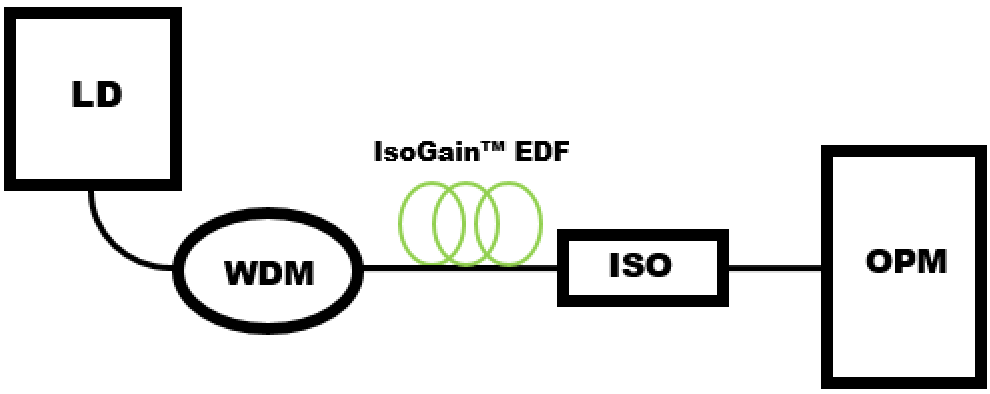

Figure 3.8: Laser diode pump characterization setup

3.6 Characterization of Amplified Spontaneous Emission

Amplifier spontaneous emission (ASE) light source is one of the types of optical light sources. ASE is the process where the emission is produced by amplified spontaneous emission. When the optical gain is electrically pumped, the light will be emitted spontaneously. They consist of the laser diode wavelength division multiplexes, erbium-doped fiber, isolator and optical spectrum analyzer in this system.

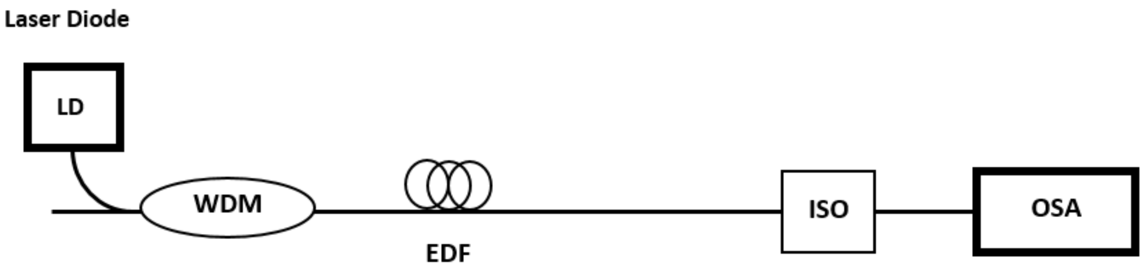

Figure 3.9: Experimental set up to characterize ASE.

3.7 The Preparation of Laser Cavity for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium

This experimental set-up for this research project is an optical fiber laser cavity which is designed in a ring cavity configuration. In the figure 3.7 below, a passively mode-locked fiber laser in the experimental setup is shown accordingly. An IsoGain Erbium-Doped Fiber (EDF) is used in this laser cavity as the gain medium where a 980 nm laser diode will be pump into the system and then connected through a fused Wavelength Division Multiplexer (WDM). A laser diode is electrically pumped in the range of 53 mW to 295.5 mW to the cavity. Next is an isolator that is used for the prevention of unidirectional light during the operation that will be passed through by a laser. In this laser cavity, a fused 90:10 coupler is used as an output coupler. The 95 percent is used to pass through along the ring laser cavity to maintain the pulses and the remaining which is 5 percent will be divided into 2 devices which are Output Spectrum Analyzer (OSA) and the autocorrelator output devices for measuring the pulses.

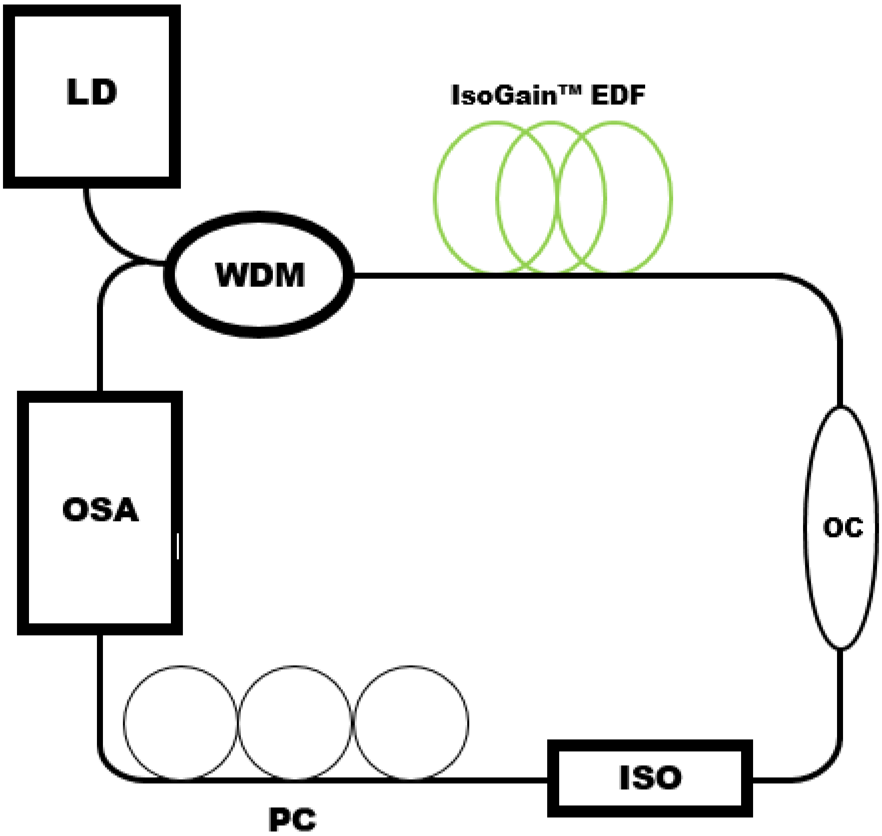

Figure 3.10: Experimental set up for Passively Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium

3.9 Analysis Characteristics of Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium

There are two types of devices used to analyze the characteristic of the Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium laser which are optical spectrum analyzer (OSA) and oscilloscope (OSC). The typical characteristic of Mode-locked pulses are pulse repetition rate and the optical spectrum was considered for further analysis.

3.9.1 Optical Spectrum Analyzer

The optical spectrum analyzer is used for the measurement of optical spectra and displays the power distribution of the optical source over a specified wavelength span. Optical Spectrum Analyzer (OSA) will display the optical spectra in the form of a diagram in which the power density (dBm) is plotted as a function of wavelength (nm).

3.9.2 Pulse repetition rate

The pulse repetition rate refers to the number of pulse activity that occurs per second and occurs when the number of pulses or frequency is operated by the laser every second in pulsed mode. The pulse repetition rate of Mode-locked was measured in Megahertz range.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will be discuss the results that obtained for the characterization of laser diode pump power and the output performance of the Passive Mode-locked pulsed output with a 3 meters long erbium-doped fiber IsoGain as the gain medium in this fiber laser. The 980 nm pump laser diode initially adjusted at 30mA in order to produce threshold condition for the Passive Mode-locked to be generated. In addition, the pulse output of the Passive Mode-locked was obtained in order to obtain the pulse repetition rates, peak-to-peak time duration, pulse width at pump power of 273 mW. The output spectra and stability of the pulses of the Passive Mode-locked pulse generated in a fiber laser taken at different pump power of 79 mW, 110 mW, 143 mW, 176 mW, 208 mW, 241 mW, and 273 mW.

4.2 Characterization Laser Diode Pump

One of the most important characteristic in this research is the laser diode, where the amount of light emit as the current will injected into the device. The characterization of the laser diode is observe by output power versus current curve in Figure 4.1. From the graph, the laser pump injected at current is 30 mA.

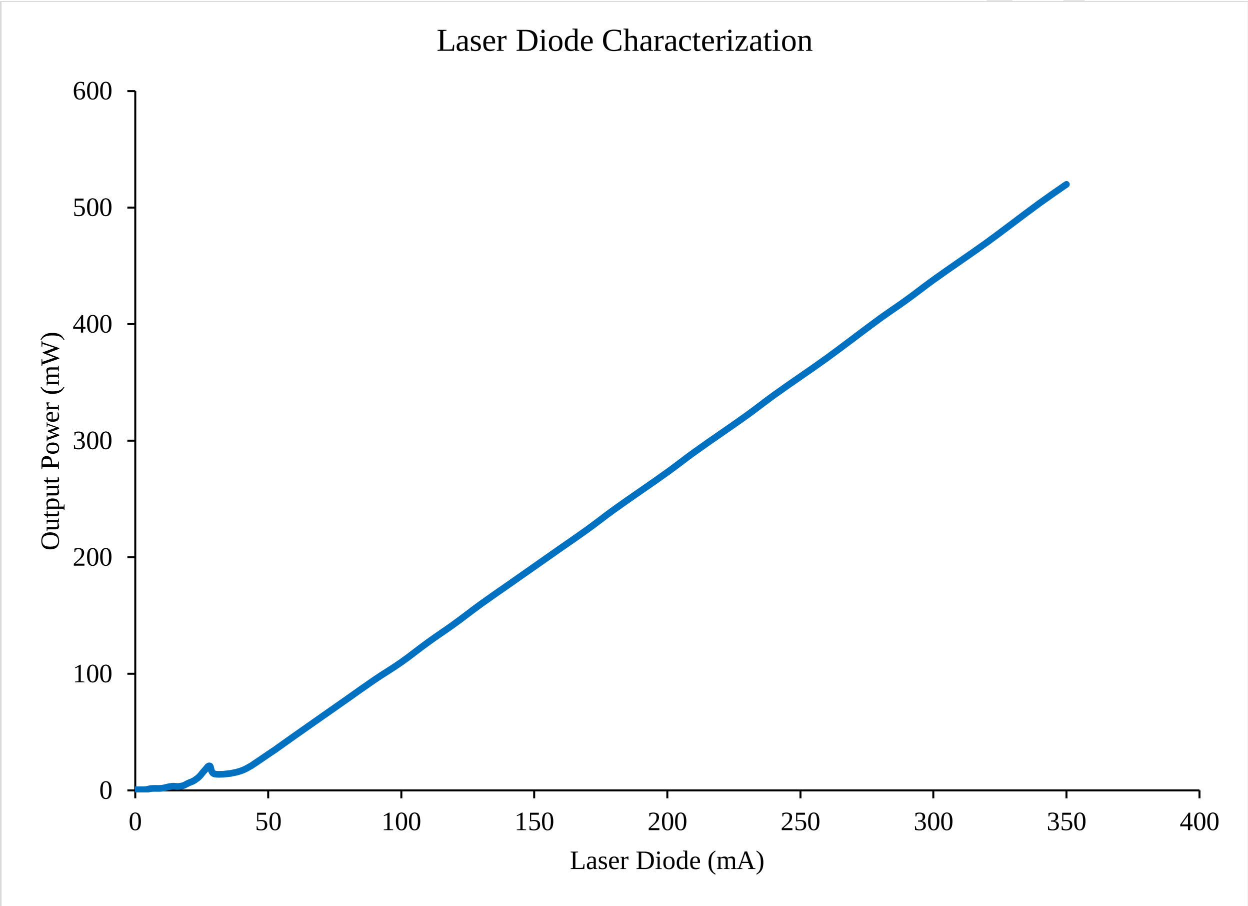

Figure 4.1: Characterization of Laser Diode

4.3 Output performance Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium

In this section, the operation of Passive Mode-locked Fiber Laser will be discuss the operation of pulsed Passive Mode-locked output including the pulse repetition rates, peak-to-peak time duration, pulse width at pump power of 200mA, the output spectra and stability of the pulses of the passive mode-locked pulse generated in a fiber laser taken at different pump power of 79 mW, 110 mW, 143 mW, 176 mW, 208 mW, 241 mW, and 273 mW. All the output performance measured by using the Optical Spectrum Analyzer (OSA) and the Oscilloscope. In the cavity of the Passive Mode-locked design, which was include 3m of erbium-doped fiber IsoGain was pumped with laser at 980 nm wavelength with different of pump power.

4.3.1 Output pulsed Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium in ring cavity at pump power of 200mA.

Figure 4.2 and 4.3 shows the output pulse of passive mode-locked obtained at pump power of 273 mW. Based on the output pulse, the repetition rate obtained is 1.06 MHz and the peak-to-peak calculated is 924 ns. FWHM calculated from any random single pulse is 0.11 ns.

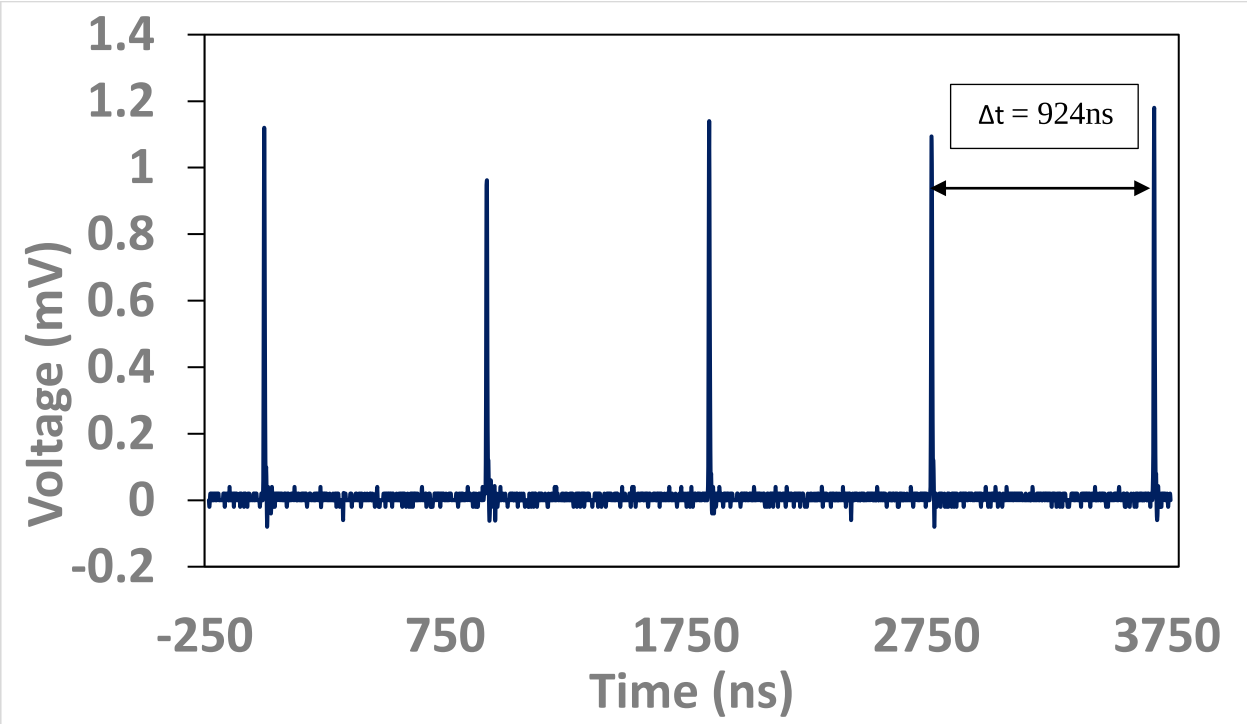

Figure 4.2: Repetition rate for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at the pump power of 273 mW.

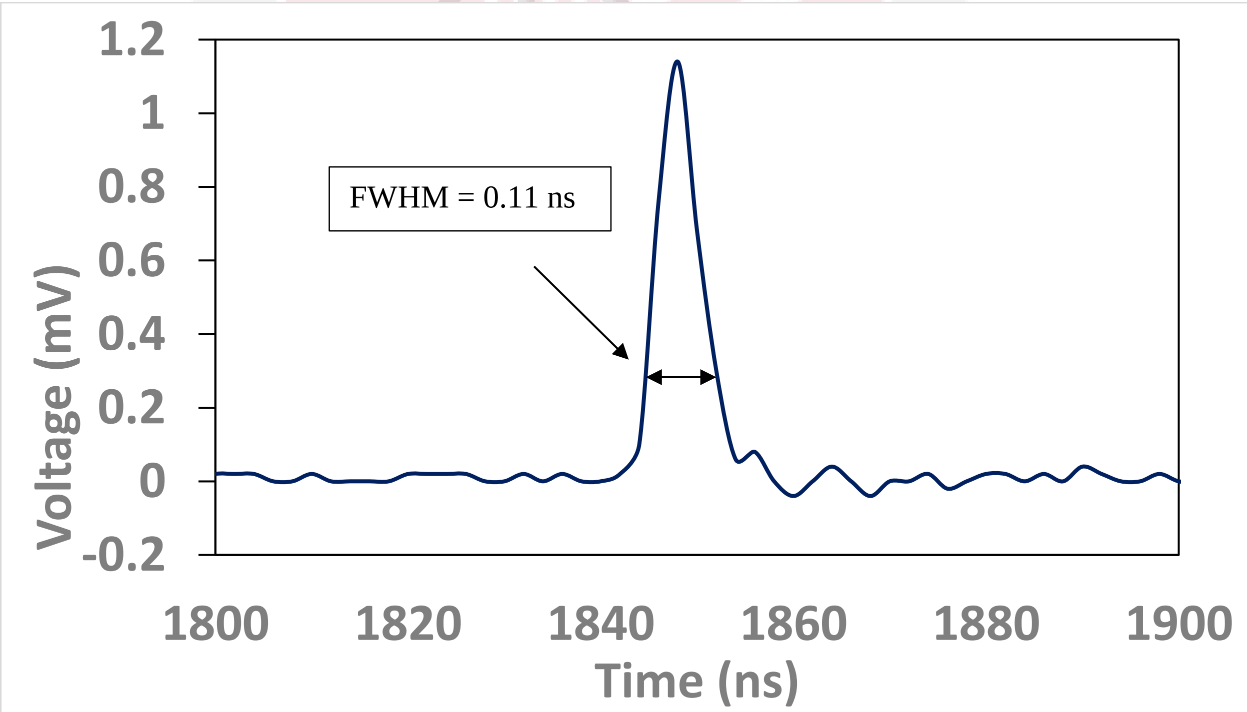

Figure 4.3: FWHM for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 273 mW

4.3.2 Optical spectra for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at different pump power using optical spectrum analyzer.

The optical spectra generated from Passive Mode-Locked Fiber Laser, which taken by using OSA to analysis the spectrum. When the pump power of the laser diode was increased, the output spectra generated from Passive Mode-Locked observed become more stable as a significant amount of population inversion was obtained during the increment of the pumping power.

In figure 4.2.3, the output spectra obtained has a wavelength range of approximately 1545 nm to 1570 nm at pump power of 79 mW. In figure 4.3.4, the output spectra obtained has a wavelength range of approximately 1545 nm to 1570 nm at pump power of 110 mW. . In figure 4.4.5, the output spectra obtained has a wavelength range of approximately 1549 nm to 1569 nm at pump power of 143 mA. In figure 4.5.6, the output spectra obtained has a wavelength range of approximately 1549 nm to 1569 nm at pump power of 176 mW. In figure 4.6.7, the output spectra obtained has a wavelength range of approximately 1549 nm to 1569 nm at pump power of 208 mW. In figure 4.7.8, the output spectra obtained has a wavelength range of approximately 1549 nm to 1569 nm at pump power of 241 mW. In figure 4.8.9, the output spectra obtained has a wavelength range of approximately 1549 nm to 1569 nm at pump power of 273 mW.

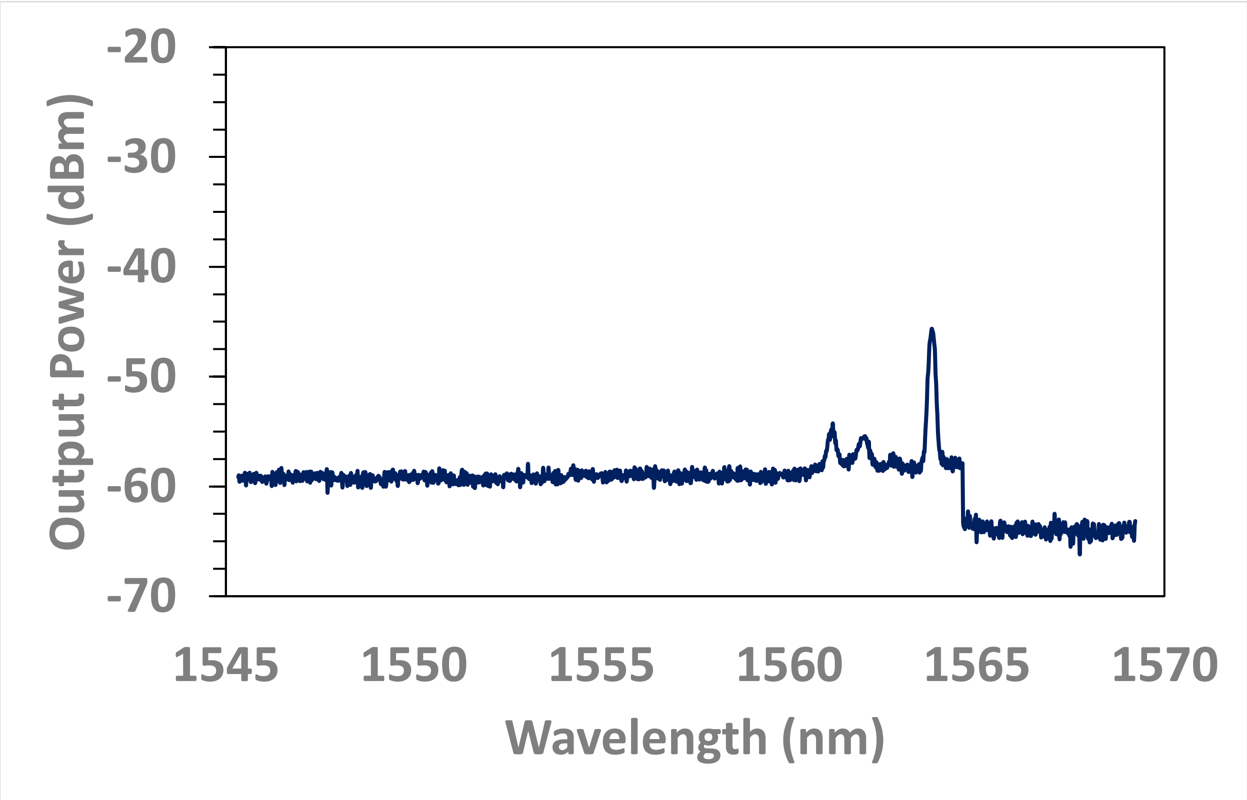

Figure 4.4: Output spectra for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 79 mW.

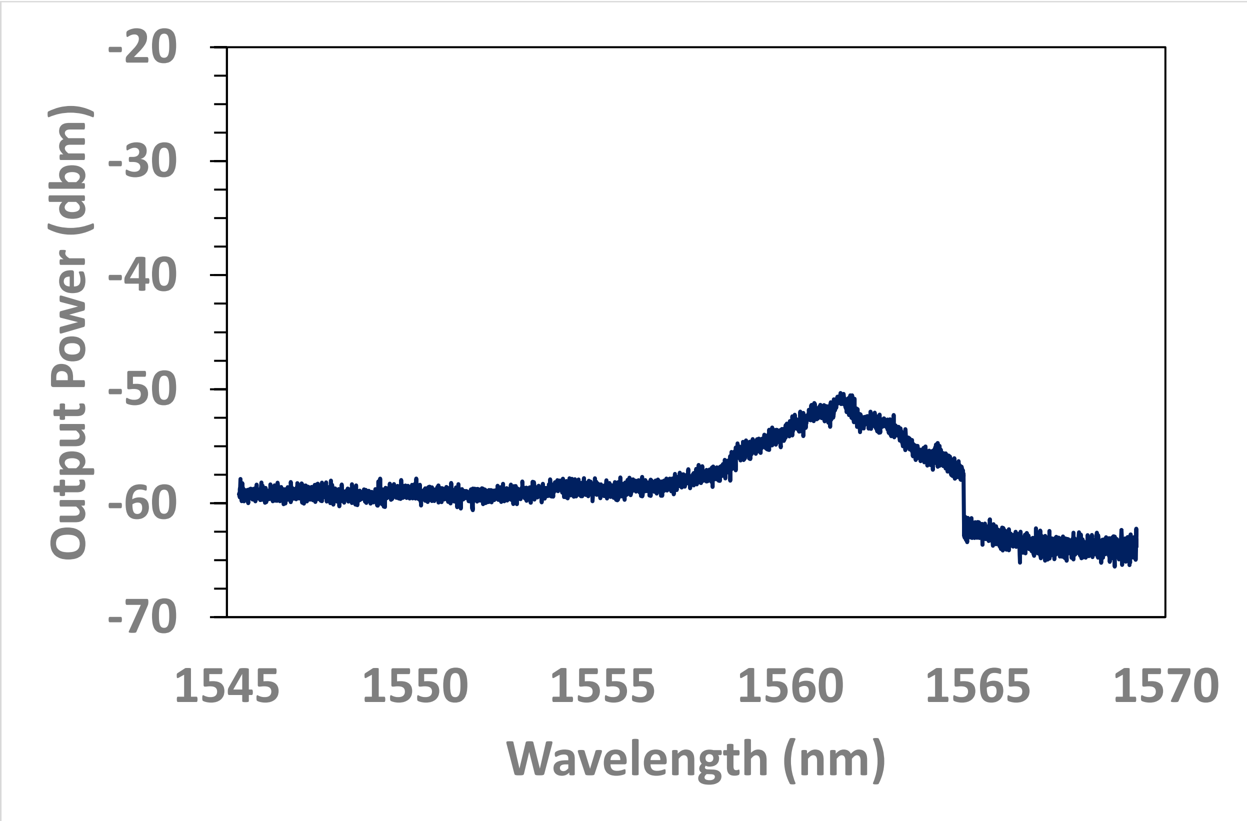

Figure 4.5: Output spectra for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power 0f 110 mW.

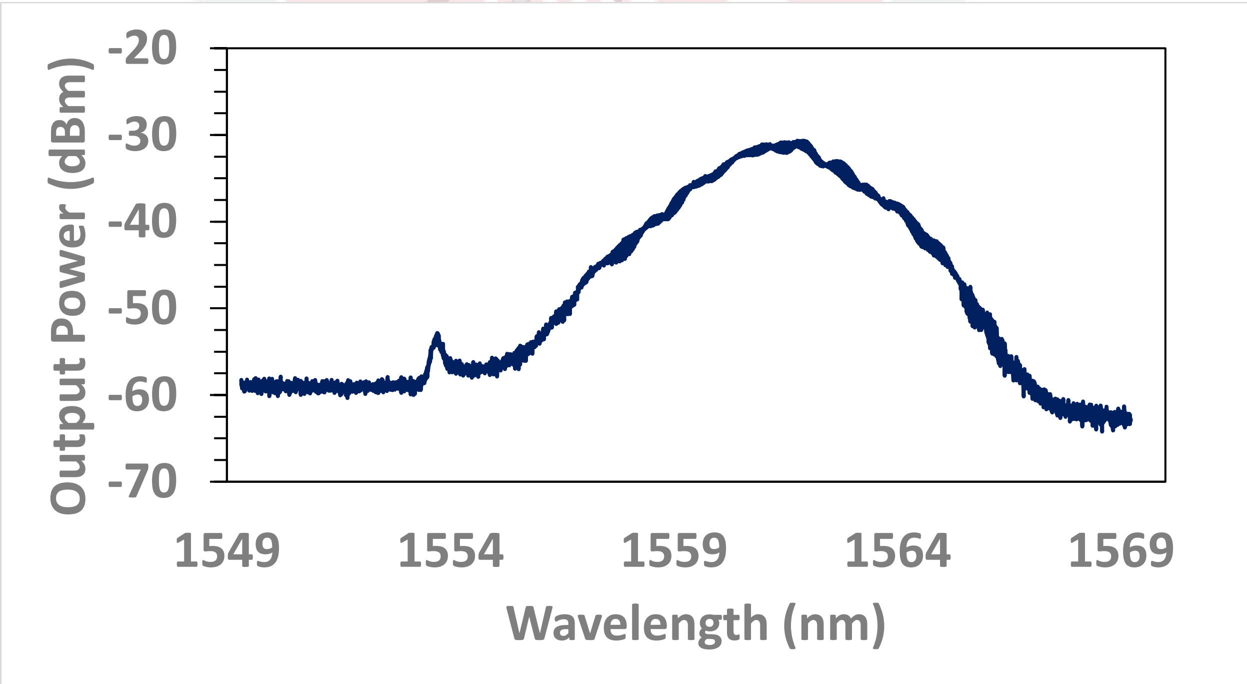

Figure 4.6: Output spectra for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 143 mW.

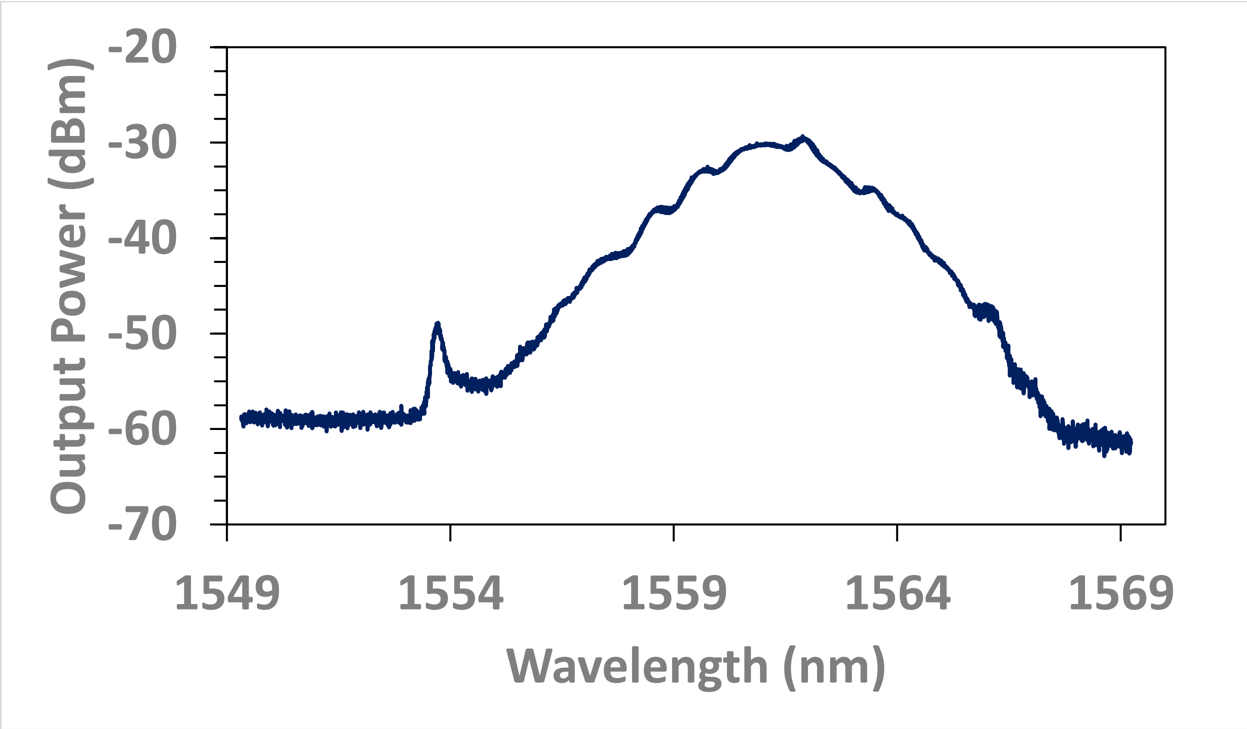

Figure 4.7: Output spectra for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 176 mW.

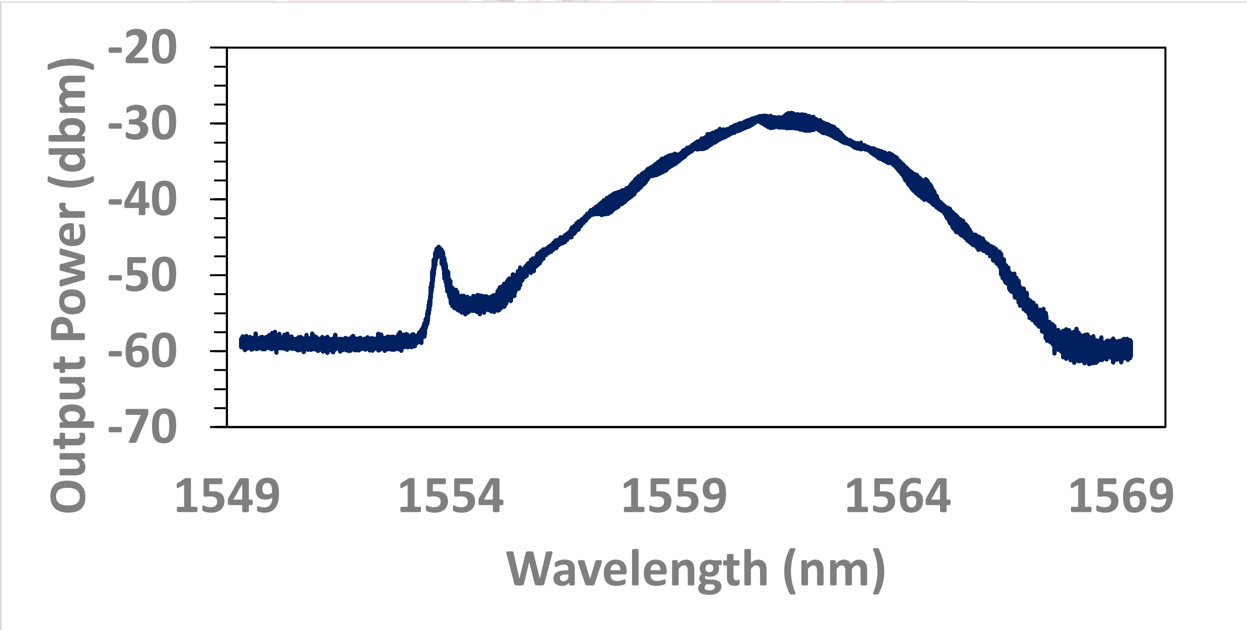

Figure 4.8: Output spectra for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 208 mW.

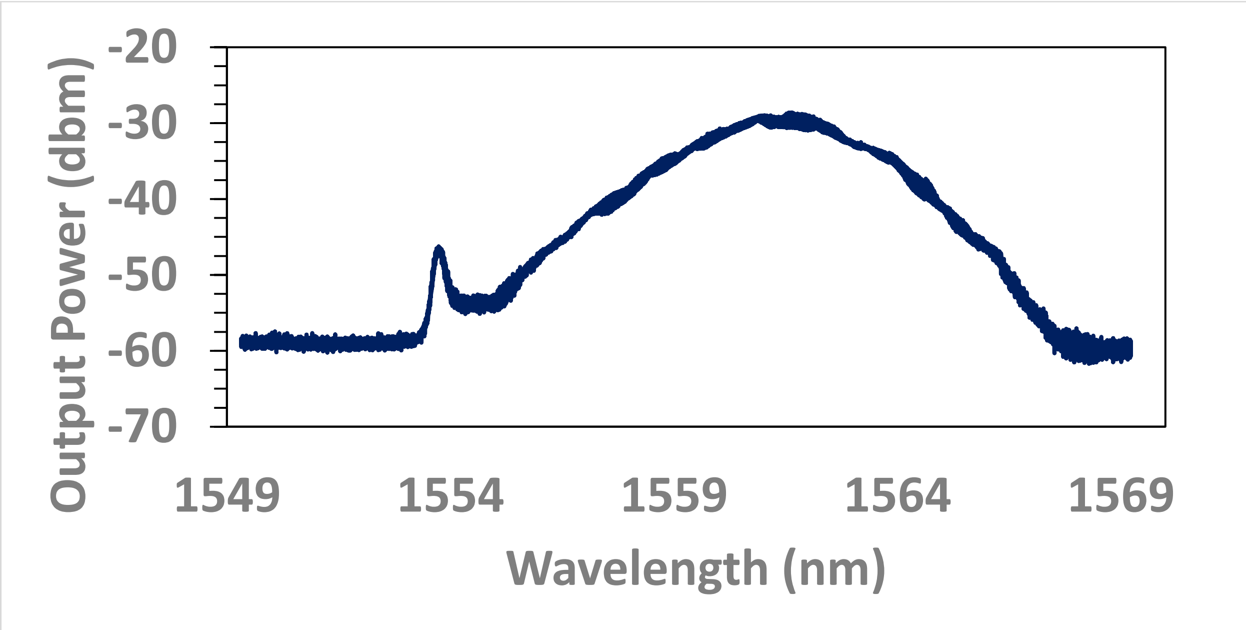

Figure 4.9: Output spectra for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 241 mW.

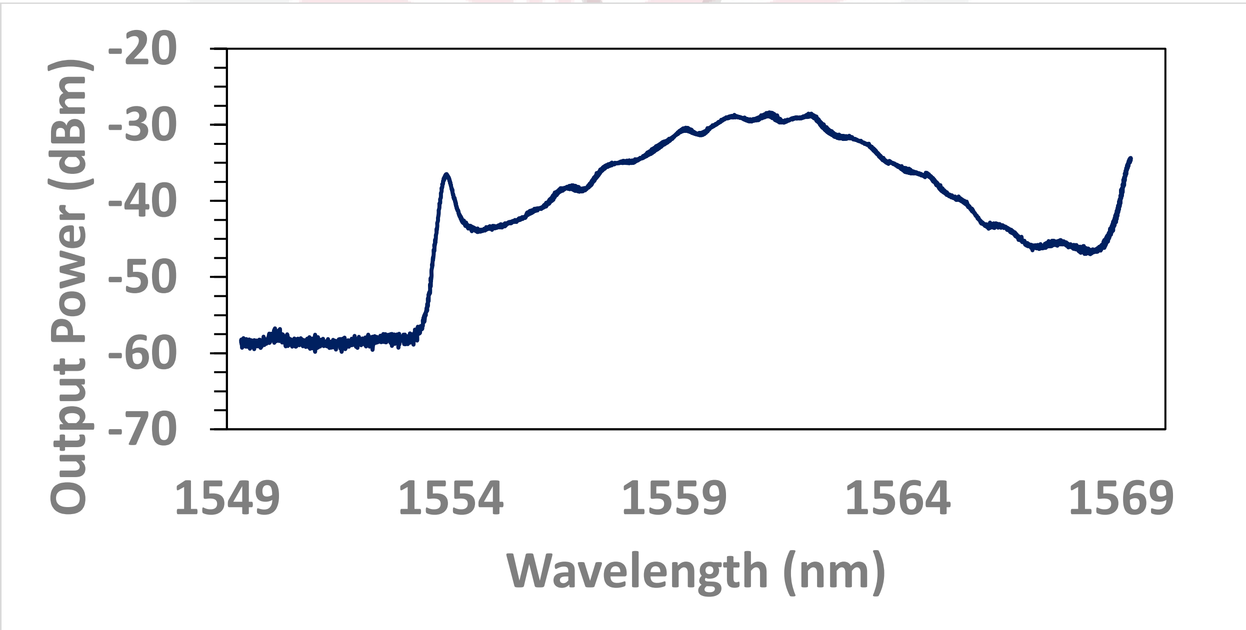

Figure 4.10: Output spectra for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 273 mW.

4.3.3 Stability measurement for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium with different power pump.

In figure 4.2.10 to 4.2.15, shows the output spectra for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium taken at 5 minutes interval for readings of continuous operation with pump power of 79 mW, 110 mW, 143 mW, 176 mW, 208 mW, 241 mW and 273 mW. Based on the output stability was obtained, the output spectra start become stable when the pump power at 143 mW until 273 mW. The central wavelength in the range 1545 nm to 1570 nm only for each pump power. By the stability performance that observed, it shows that the spectral evolution towards time graphs that the optical spectrum is stable for each pump power.

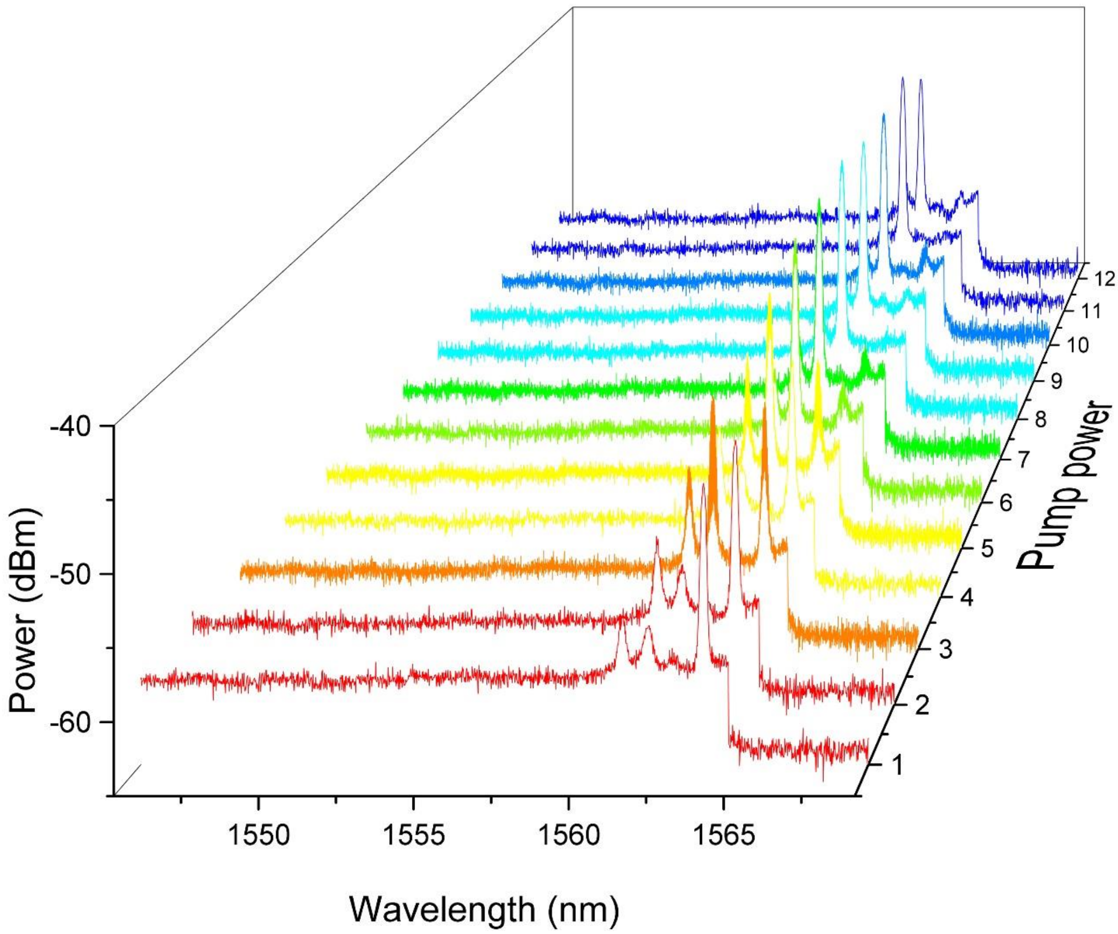

Figure 4.11: Spectrum evolution for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 79 mW.

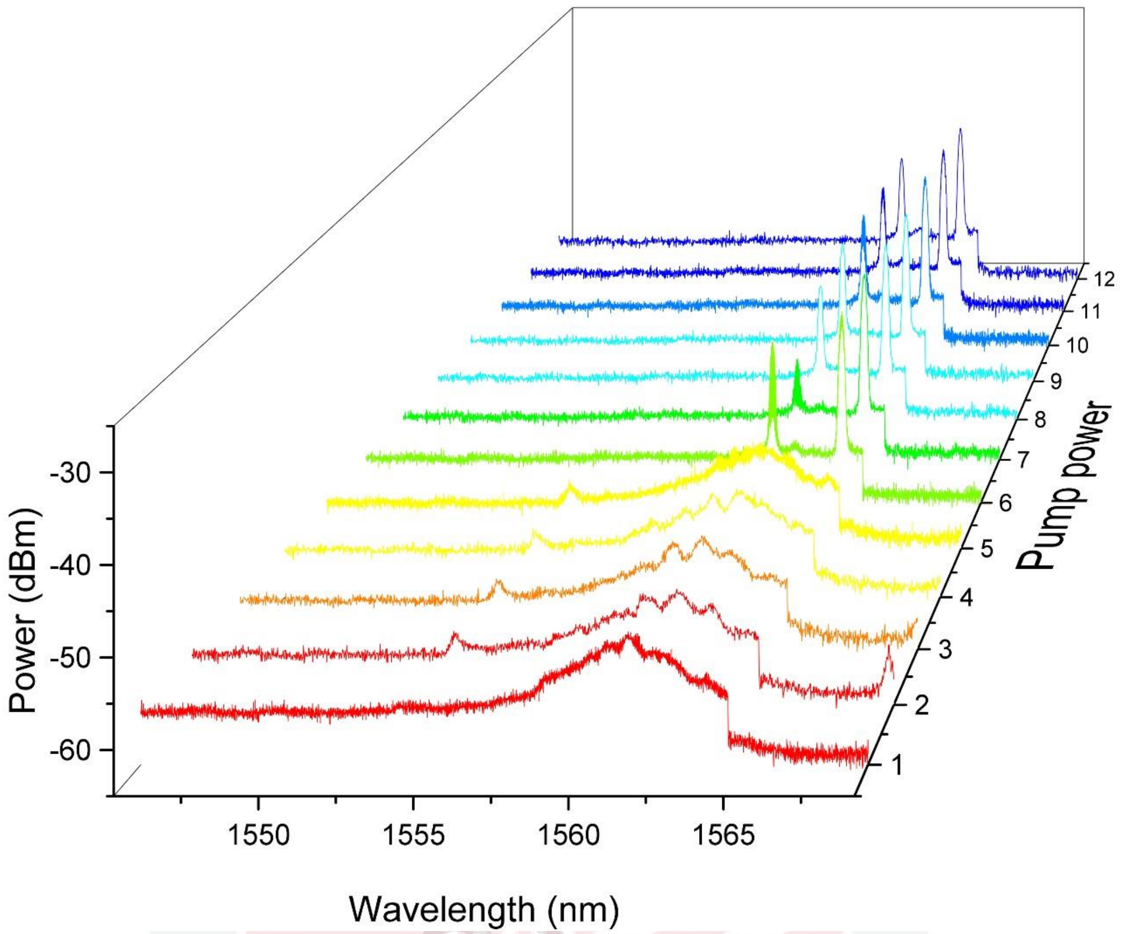

Figure 4.12: Spectrum evolution for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 110 mW.

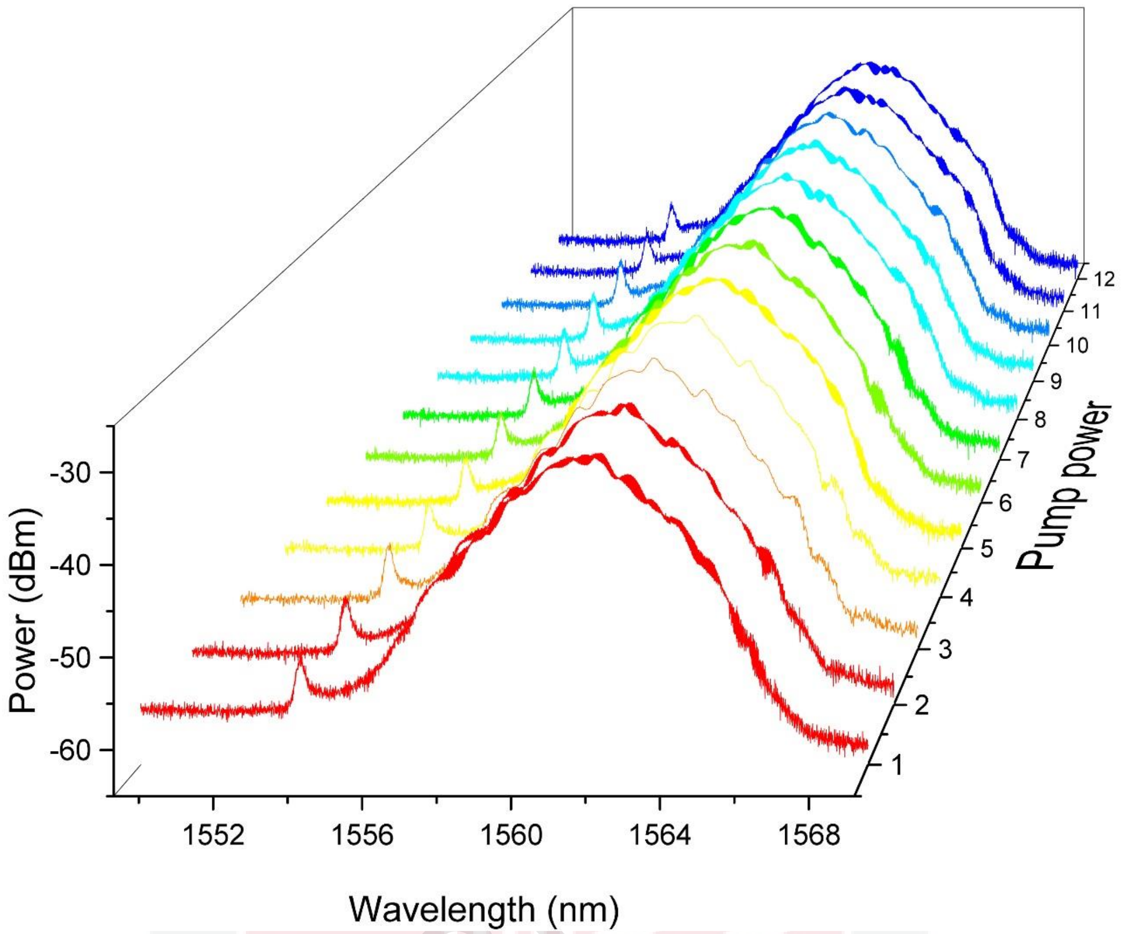

Figure 4.13: Spectrum evolution for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 143 mW.

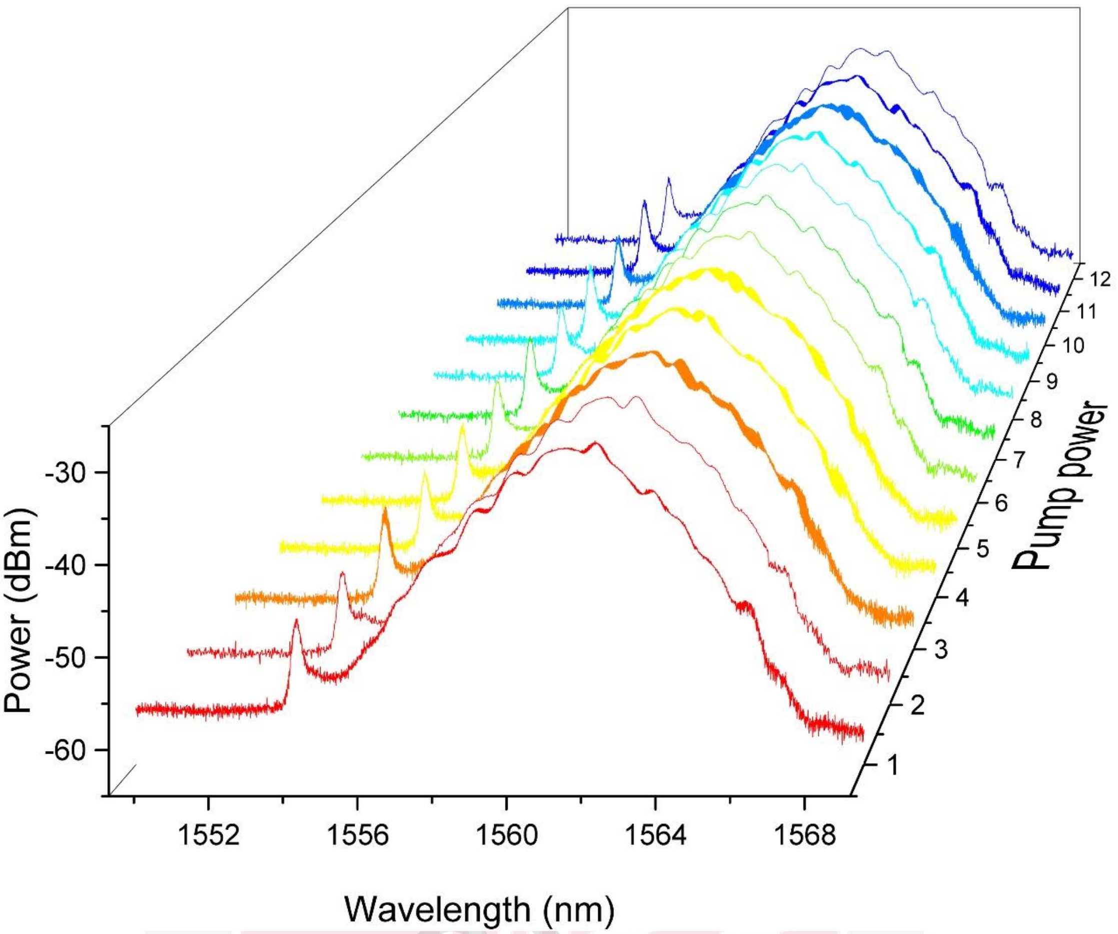

Figure 4.14: Spectrum evolution for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 176 mW.

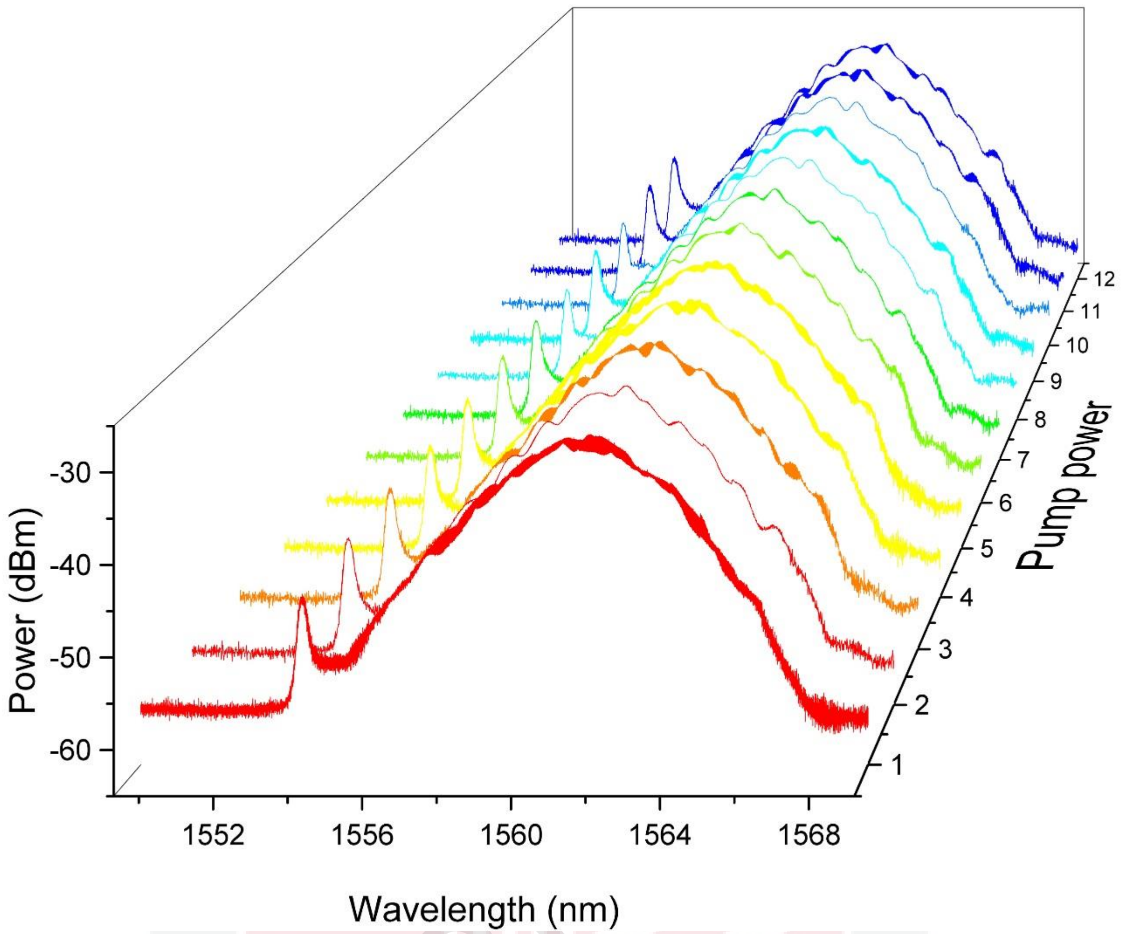

Figure 4.15: Spectrum evolution for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 208 mW.

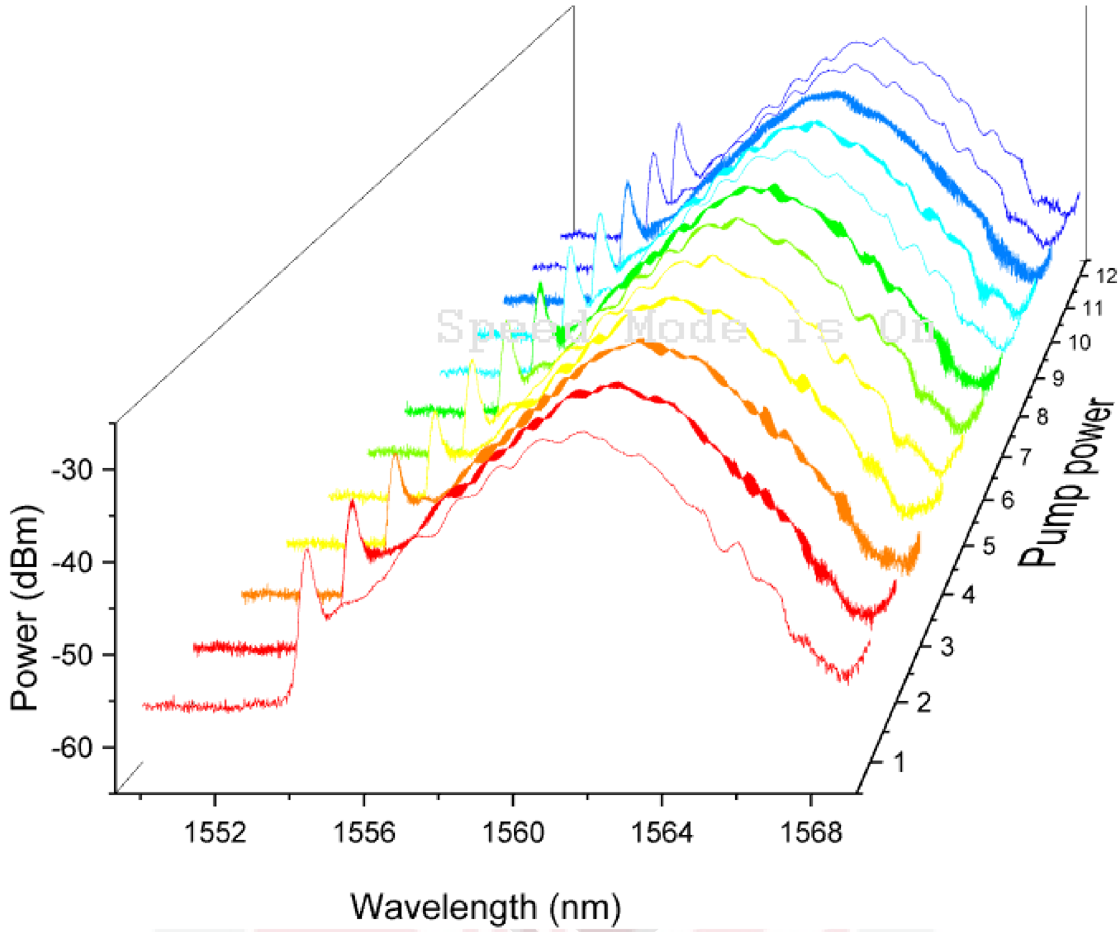

Figure 4.16: Spectrum evolution for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 241 mW.

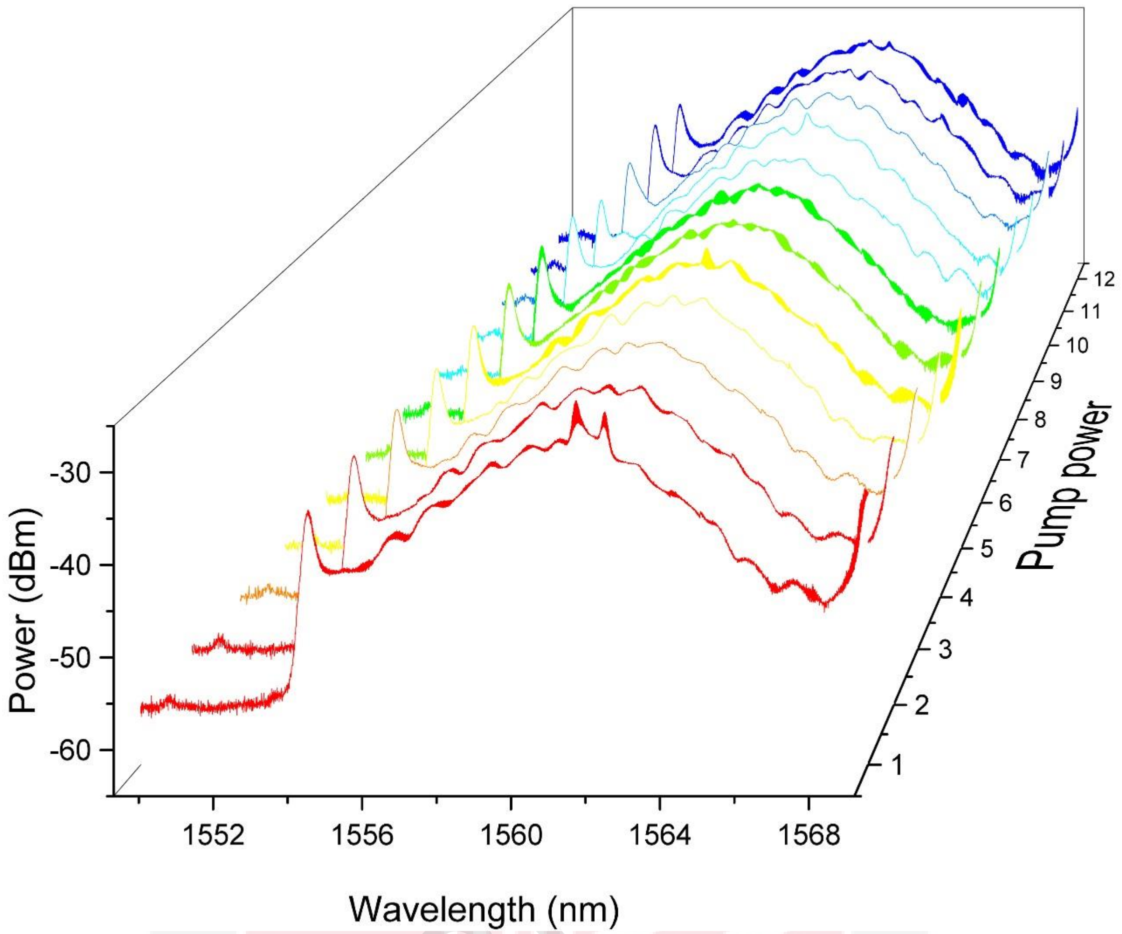

Figure 4.17: Spectrum evolution for Passive Mode-locked Fiber Laser by using IsoGain Erbium Doped Fiber as a gain medium at pump power of 273 mW.

CHAPTER 5

CONCLUSIONS

In this final chapter, we will make a conclusion and summarize the demonstrated generation of a passive mode-locked fiber laser by using IsoGain erbium doped fiber as a gain medium as well asdiscussing the future work of the research.

5.1 Conclusion

A generation of a passive mode-locked fiber laser by using IsoGain erbium doped fiber as a gain medium is succesfully demonstrated using a 3 m long IsoGain erbium doped fiber as the gain medium in this fiber laser. Our study concludes that passive mode-locked pulsed fiber laser output shows high potential in variety of applications especially in the optical transmission system as the pulses travel in the C-band region from 1525 to 1565 nm. Thus, it is supported the region of the optical communication systems technology. There are two method to achieved pulsed laser which is, Q-switch and mode-lock. In this project, a passive mode-locked fiber laser has been chosen because this technique gives significant advantages in terms of simplicity, fast response, easiness to implement, and superior performance compared to actively mode-locking technique.

In this final year project also successfully demonstrated the passive mode-locked by using IsoGain erbium doped fiber as a gain medium. IsoGain erbium doped fiber has been employed into the erbium doped fiber in this passive mode-locked. Where the IsoGain erbium doped fiber provides many advantages in terms of high efficiency core composition, high cut-off wavelength variants optimized for high pump power EDFAs, high absorption fibers for L-band amplifiers and mini/ micro C-band EDFAs, wide range of absorption values for EDFA design optimization and it is supported by Fibercore's GainMaster™ simulation software. The 10% of the output pulse was collected from the output coupler for analysis and the remaining

90% of the output pulsed is remain looping inside the cavity.

In this study, few characteristics of passive mode-lock fiber laser output were demonstrated and discussed including the optical spectrum, the pulse repetition rates, peak-to-peak time duration, pulse width and the stability performance. From this study, the pulse repetition rate obtain was 1.08 MHz and the FWHM calculated from any random single pulse is 0.11 ns.

5.2 Recommendation for Future Work

Generation of a passive mode-locked fiber laser by using IsoGain erbium doped fiber as a gain medium has been done in this research project. However, this study can be further explored by increase the performance of the passive mode-lock technique. The performance of the passive mode-lock fiber laser can be improved in terms of their stability of the performance.

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