INVESTIGATION OF BENDING EFFECT ON LONG PERIOD FIBER GRATINGS (LPFG) REFRACTIVE INDEX SENSITIVITY

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"Investigation of bending effect on LPFG refractive index sensitivity"** was prepared by Tan Poh Seong has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electronic Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ___________________________

Supervisor : Mr. Daniel Yong Yun Thung

Date : ___________________________

Specially dedicated to

my beloved grandmother, mother and father

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INVESTIGATION OF BENDING EFFECT ON LONG PERIOD FIBER GRATINGS (LPFG) REFRACTIVE INDEX SENSITIVITY

ABSTRACT

Improvement of refractive index sensitivity remained as high interest area for researchers working in fiber sensor including long period fiber gratings (LPFG). Various methods have developed to enhance the refractive index sensing like coating, etching, bending and etc. Recently bending method has successfully demonstrated by researcher through theory and simulated in different curves. However there is lack of experimental based data to demonstrate the effect of bending on LPFG refractive index sensitivity performance. During this project, investigation of bending effect on long period fiber gratings (LPFG) refractive index sensitivity was carried out to find the right method to form the bending on LPFG. From this study, practical results will able to show the right curve for bending LPFG and comparison of straight line LPFG was done to demonstrate the enhancement of refractive index sensitivity of bending LPFG. In addition, the number of gratings induced by arc-discharges on LPFG affected the refractive index sensitivity due to the length of LPFG under bending effect. It is concluded that the bending LPFG is more sensitive than LPFG in straight line.

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LIST OF SYMBOLS / ABBREVIATIONS

c_p	specific heat capacity, J/(kg·K)
h	height, m
K	thermal coefficient, W/cm K
Z	depth, cm
c	bending curvatures
L	grating length
d	diameter
l	length

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CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the development of fiber gratings already had significant impact in global telecommunications and optical fiber sensing. Basically, a long period fiber grating is built up by few hundred microns of fiber gratings along the optic fiber. Moreover, the fiber grating of LPFG whose grating period will be approximately 100μm to 1000μm.

So far there are two types of fiber gratings which are the Fiber Bragg Grating (FBG) and the Long Period Fiber Grating (LPFG) (Liu, 2001). The characteristic of Long period optical fiber grating (LPFG) not only more flexible as compared to fiber Bragg grating (FBG). LPFG also have low insertion loss and low back reflection (Ugale, 2013). In addition, it can offer the advantages of absolute measurement, all-fiber in-line, high sensitivity, small size. Moreover, easiness in adjusting the resonant wavelength within the spectrum of optical source and easiness in fabrication are also one of the advantages of LPFG sensor. LPFG composes of periodic structures and also enable the light coupling between the cores and cladding modes in fiber. However, the FBG is coupling between the contra propagating modes.

At 1966, Charles K. Kao demonstrated transmission of light through optical fiber, but the attenuation was 1000 dB/km compared to coaxial cable with attenuation of 5 dB/km. Optical fibers have wider bandwidth to provide higher bit rate(up to 40Gbps). Besides, optical fibers also have low attenuation (as low as

0.2dB/km) which the attenuation is almost constant at any signalling frequency within the specified bandwidth of fiber. Hence, its suitable using in optical communication networks to transmit the signals over long distances.

1.2 Problem Statements

Basically LPFG used to measure the refractive index sensitivity of the material surrounding the cladding surface. Since the refractive index of medium surrounding was very sensitive to LPFG. However, the sensitivity will get different if changing the weights at pulling tension. Hence, the weights with 14g, 20g, 22g was used as pulling tension during the fabrication process with the grating period of 650μm. Besides, the different grating period will perform the advance wavelength in fiber.

Optical fiber grating period is the most important part for bend sensing. The LPFG will have high sensitivity due to the changing the bending structures of the fiber. LPFG-based bending sensors were performed in the free style bending curvatures with diameter 9cm and petri dished with diameter 9.5cm. The refractive index of a bent fiber is not equal in all points of its cross section. LPFG-based fiber optic bending sensors function due to coupling-wavelength shift and new wavelength adjacent to initial mode. As compared with FBG bending sensor, the shift wavelength in FBG-based structures is used for measure the bending curvature. Hence, the fiber will be tested under the air, water and sucrose condition to verify that bending curvatures on the gratings which can give the better refractive index sensitivity.

1.3 Aims and Objectives

The aim in this project is to perform the refractive index sensitivity with different weight and bending curvature using long period fiber grating (LPFG).

In this project, the objective of this project is to study the fabrication method of Long Period Fiber Grating (LPFG). Moreover, the second objective is to observe fabrication of LPFG at long wavelength (1500-1600nm). The third objective is to compare the refractive index sensitivity performance using bending method and without bending.

CHAPTER 2

LITERATURE REVIEW

2.1 Fabrication of an Electric Arc Discharges LPFG

Two fabrication methods of LPFGs by electric arc discharges: which are micro-tapers method and the flattening method.

2.1.1 Fabrication of LPFG by Micro-taper Method

Nowadays, LPGs can be fabricated by many methods, for example, CO_2 laser irradiation, High Intensity Femtosecond Radiation and electrical discharges. However the fabrication of LPFG still relies on the periodic modulation of refractive index in the fiber.

To fabricate the optical fiber by electric arc method, a bare of optical fiber will placed between the electrodes and this purpose to perform grating period. The Fig 2.1 was shown the electric arc is controlled by the external motorized translation stages. Hence, once the first grating formation was completed, the motorized stage will move the electrodes to the next point for the formation of subsequent gratings along the fiber (Yong, 2015). Therefore, the fibers were able to move with accurate under a micro meter.

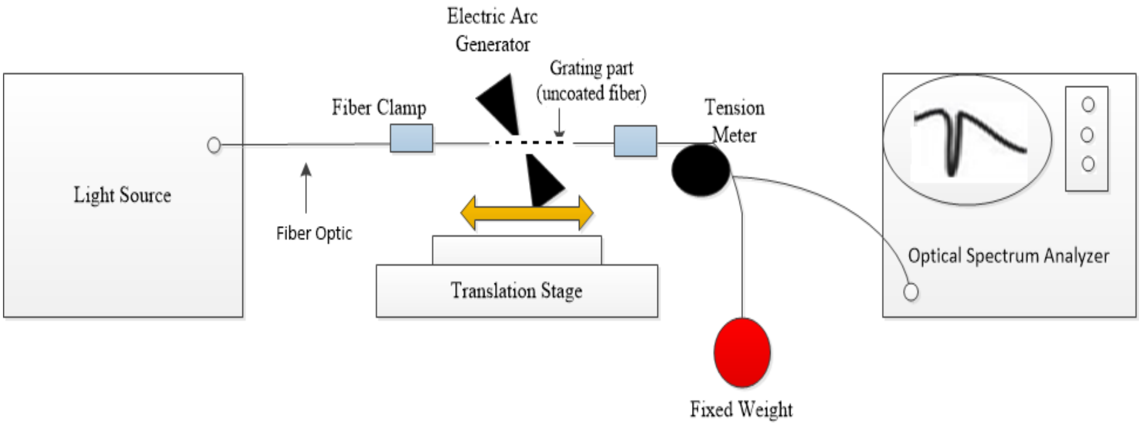


Figure 2.1-1: Experimental setup used for LPFG by the micro-taper method

By changing the fabrication parameter such as arc duration, current and pulling tension (Estudillo-Ayala, 2011), the spectrum of the grating will show the different result. A great grating period was selected due to the notch wavelength for the fabrication.

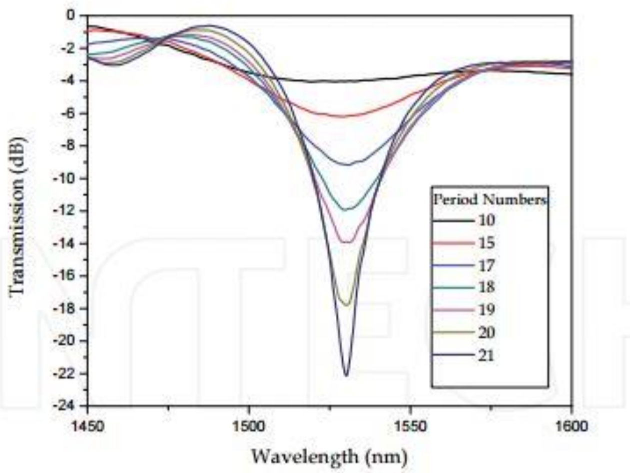


Figure 2.1-2: The number of grating period with transmission spectra (Estudillo-Ayala, 2011)

In Fig 2.1-3 show the experimental setup for change the diameter of curvature of the LPFGs. To measuring the output spectrum of the LPFG, turned the screw and the hose clip diameter was changes. However, In Fig 2.1-4 shown the attenuation peak was changes because of decreasing of the diameter of curvature of LPFG.

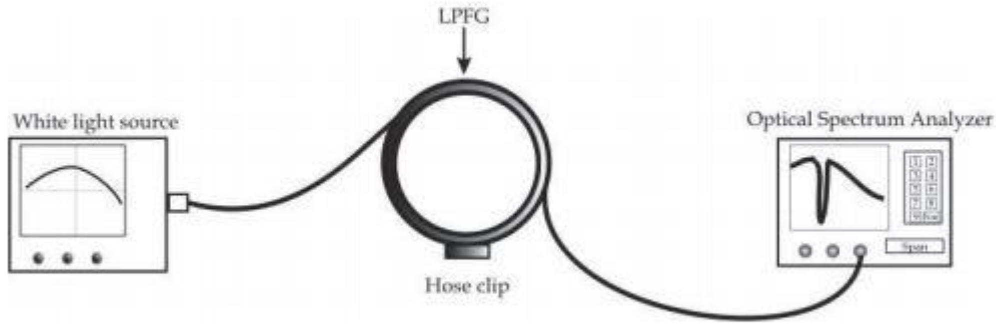


Figure 2.1-3: Experimental setup for sensing diameter of curvature (Estudillo-Ayala, 2011)

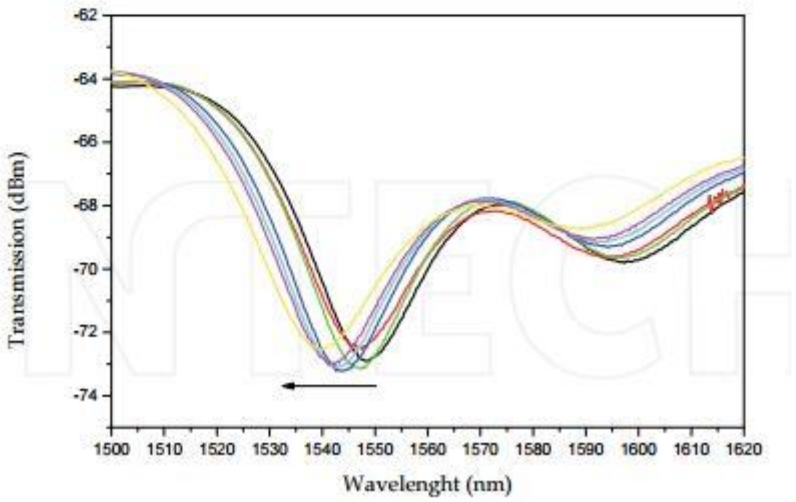


Figure 2.1-4: Displacement to left the attenuation peak when decrement the diameter of curvature (Estudillo-Ayala, 2011)

2.1.2 Fabrication of LPFG by the Fattening Method

The flattening method that's used to fabricate the LPFG consists in enlarging the optical fiber diameter. After applying the electrical discharges in one point, the fiber was displayed by the fusion machine where the process will repeated in order to enlarge the optical fiber diameter until filtering functions was observed. As Fig 2.1-5 shown that the transmission loss band by the flattened method.

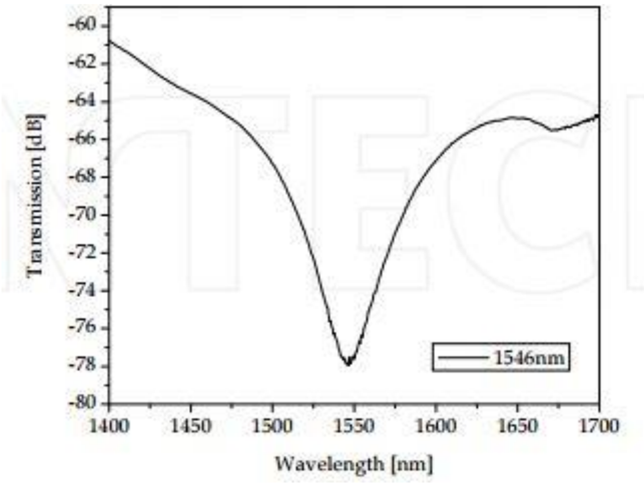


Figure 2.1-5: Loss band of a fattened long period grating near 1550 nm

After selected the relevant optical type program and re-modify some parameter such as arc power, arc duration, pre-fusion and z-push distance. Fig 2.1-6 shows the time delay of the standard discharged method. The electric arc discharge was continues with fusion machine process where the hot push delay heats the fiber to reach the softening point until a desired diameter was observed.

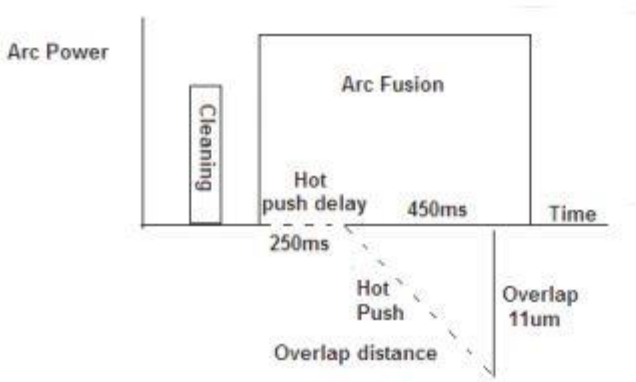


Figure 2.1-6: Time delay of the standard discharged method

2.2 Fabrication of LPFG by CO_2 Laser irradiation

Long-period fiber gratings (LPFGs) are quite popular in nowadays. Fig 2.2-1 and Fig 2.2-2 shows the schematic setup of the CO_2 laser based LPFG fabrication system and photograph of the CO_2 laser base LPFG fabrication system. However, the CO_2 laser is controlled by the computer through the laser controller to produce a desired power and also to induce refractive index changes inside an optical fiber.

With using a computer to control the optical fiber with its buffer stripped where was placed on a three dimensional (3D) motorized stage, the purpose of this is to let the fiber can moved to the center of the laser beam.

During fabrication, use the optical power meter and a tuneable laser to monitor the transmission spectrum. Set the step of tuneable laser to 1510 to 1640 nm and transmitted power after grating so that the LPFG spectrum able to recorded the data.

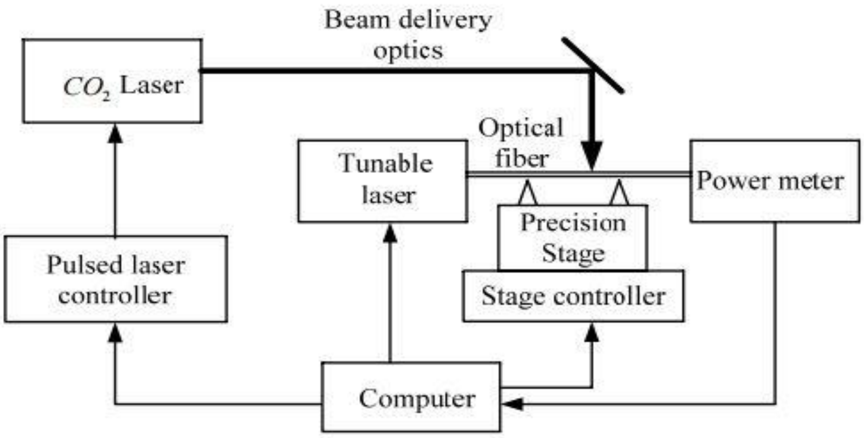


Figure 2.2-1: Schematic setup of the CO_2 laser based LPFG fabrication system

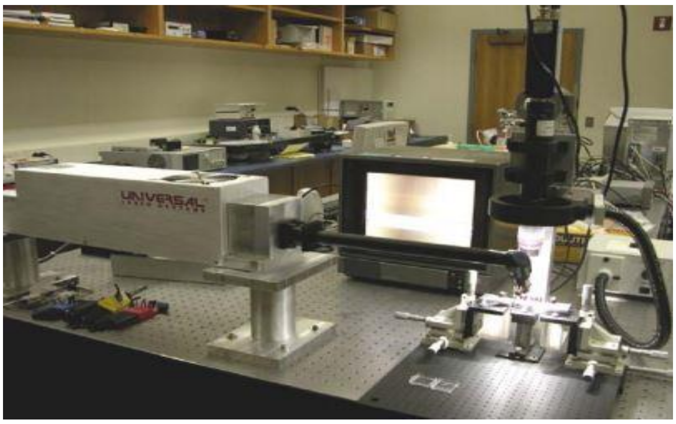


Figure 2.2-2: Photograph of LPFG fabrication system

2.3 Fabricated of LPFG by Femtosecond Laser

In the single mode fiber, a non-H2_loaded standard single mode fiber (SSMF) has been used in order to fabricate the LPFG by using femtosecond laser pulses with set regenerative amplified as pulse width (200fs), repetition rate (250 kHz), wavelength (800 nm) and the maximum energy of single pulse (4uJ) (Kondo, 2011). Fig 2.3-1 shows the experimental setup for LPFG fabrication technique. Put the beam into a microscopy and using microscope look into the fiber core where the numerical aperture (N.A.) is 0.4 (Wei, Yuan, and Yu Jie Du, 2014). After the polymer coating was removed, then the fiber was placed on computer controller which the XYZ stage can only adjusted from 0.32mm/s to 32 mm/s (Yu, 2011). However, the fiber was irradiated point by point so it can easily achieve the LPFG with different periods.

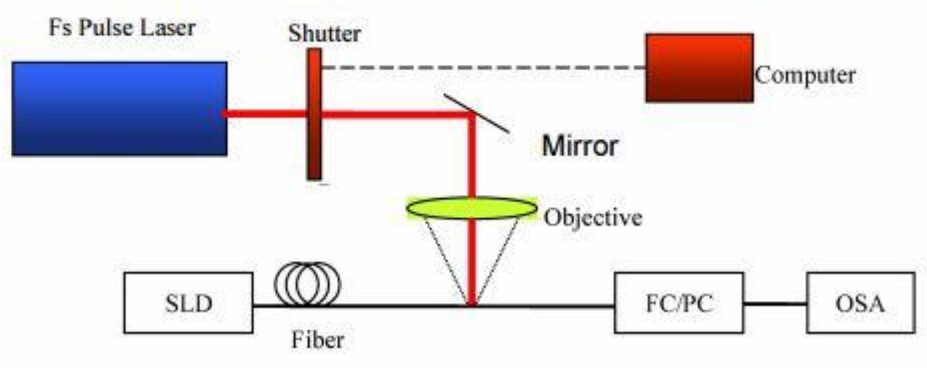


Figure 2.3-1: The experimental setup for LPFG fabrication technique by Femtosecond Laser (Kondo, 2011)

Fig 2.3-2 shows the transmission spectrum with grating period. Hence, the transmission losses was 22.3 dB, 20.8 dB and 16.9 dB at 1401 nm, 1380 nm, and 1310 nm respectively. The thermal expansion of polymer was 5.6x 10-5 mm/K, while the thermal expansion coefficient of Aluminium was 2.3x 10-5 mm/K. To enhance the temperature sensitivity of LPFG, the LPFG need to encapsulate in the Aluminium slabs with V-groove.

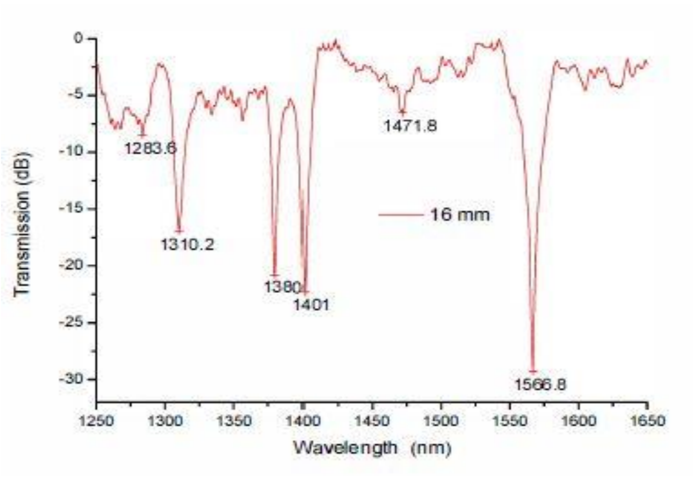


Figure 2.3-2: The transmission spectrum of LPFG with grating period of 400 um and length of 16 mm

Use the digital oven to controlled the temperature in the range of –l0 ℃ to 25 ℃ where the fiber was put into digital oven. Moreover, an extra launch was added into the fiber. However, when the temperature rises, the wavelength will shift with linearly to longer wavelengths. This is effect due to the refractive index of the material and deformation of the fiber. The result shows that temperature sensitivities which observe 23 pm/ ℃ for encapsulated LPFG and 12 pm/ ℃ for the bare LPFG.

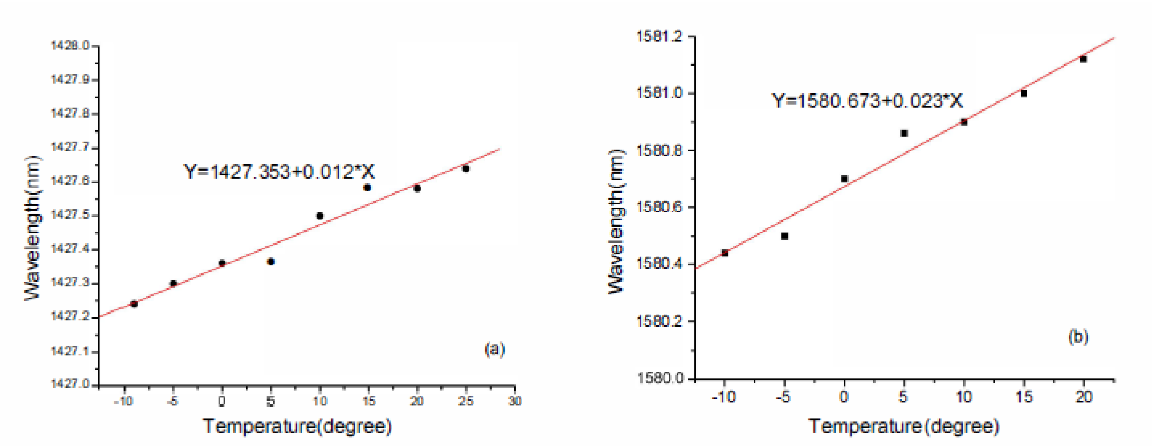


Figure 2.3-3: Temperature dependence of dip wavelength shift of LPFG in air. (a). The temperature sensitivity of LPFG without encapsulation was measured to be 12 pm/ ℃. (b).The temperature sensitivity of LPFG encapsulated was measured to be 23 pm/ ℃

2.4 Fabricated of LPFG by Low Pressure Mercury Lamp

In this low pressure mercury lamp method, it requires a mechanical fine positioning system so it can save the cost of LPG. The purpose of this method is to study the increasing of the grating length to reduce the exposure time. Moreover, the wavelength of a low-pressure mercury lamp emits is about 254nm and the exposure time was 18 h for grating period of 212 µm. The hydrogen loading is exposed to the emission of the lamp through an amplitude mask (Mizunami, 2014). To increasing the photo sensitivity, hydrogen loading was performed at pressure of 120atm for a period of 3 weeks. The grating period was 212 µm and the length was 30mm. However, the fiber was send to annealed room which temperature was 150 ℃ for 1 day. After annealing was performed, use the electric oven to measure the temperature sensitivity of the fiber. Fig 2.4-2 shows the peaks after annealing was performed.

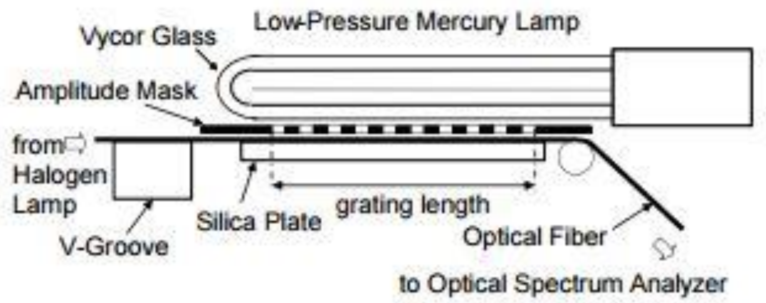


Figure 2.4-1: The experimental setup for fabrication LPFGs by mercury-lamp exposure (Mizunami, 2014)

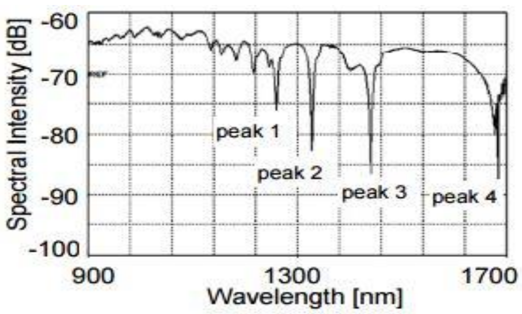


Figure 2.4-2: Transmission spectrum of an LPG with a grating period of 212 µm and a grating length of 30 mm, exposure time was 18 h. (Mizunami, 2014)

If the grating length was faster than the 20mm at exposure time of 3 h which the exposure time was getting smaller after they achieved the maximum loss. From the Fig 2.4-3 shows that the growth characteristics of resonance peaks of LPGs with a grating period of 212 µm. The reduction of exposure time will be quite useful because it will contribute to sensing applications. In addition, since the grating period of 212 µm so the sensing applications was suitable to uses because is near to the dispersion turning point. When near the dispersion turning point the increasing of temperature and strain sensitivity will increased. Thus, since the grating period of 460µm was not sensitive to temperature and strain so it can be used in telecommunication applications. Therefore, this technique is used for the telecommunication applications as it can provide a longer grating period.

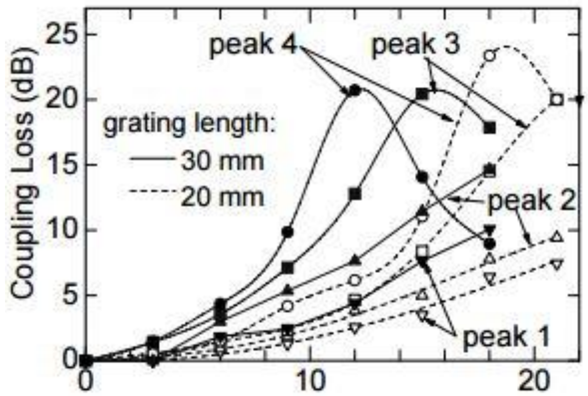


Figure 2.4-3: Growth characteristics of resonance peaks of LPGs with a grating period of 212µm.

2.5 Bending Sensors of LPFG and FBG

Bending sensors are very useful in many fields because it able use to sense structural shape and deformation. FBGs typically own a sub-micron period length and LPFGs which contain a period of 100–1000µm. So the optical fiber grating is the most important part for bend sensing. LPFG was performed bending curvatures in the range smaller than10m^{-1}. However, FBG were performed bending curvatures in a wide range 25m^{-1}.

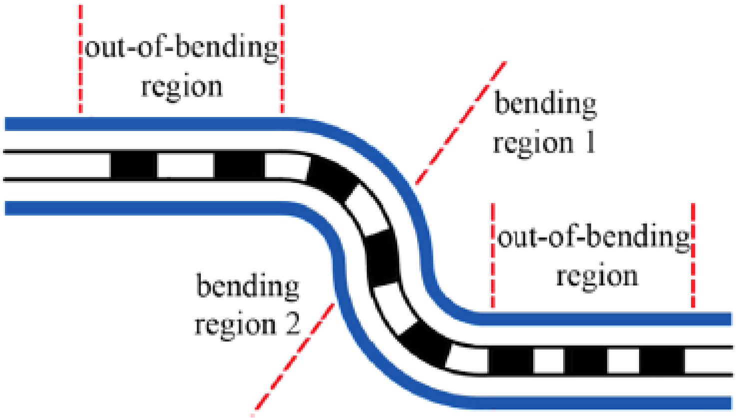


Figure 2.5-1: The structure bending in a LPFG-based bending sensor (Taghipour, 2014).

LPFG-based bending sensors function due to coupling-wavelength shift and new wavelength adjacent to initial mode (Taghipour, 2014). As compared with FBG bending sensor, the shift wavelength in FBG-based structures is used for measure the bending curvature. Hence, in the theoretical state that bending able to affect the effective refractive index of core and variation of gratings.

Some parameter of a SMF-28 fiber have been considered in the simulations which the core and cladding radius was of 4.1μm and 62.5μm, and the refractive index of 1.44922 and 1.444024 while the periodicity of LPFG, index modulation, and total length of LPFG have been assumed as 560μm, 0.00026 and 25mm. By using the Finite Element numerical method to simulation based on the bending range $K=0\text{-}26m^{-1}$. In the Fig 2.16 shows that intensity profiles of LP_{01}, LP_{04} and LP_{13} and the x-axis slices of the intensity profiles with different bending curvatures of 0, 4, 10, 15, 20 and $26m^{-1}$, λ= 1550nm. Moreover, the intensity profiles in the x-axis slices need to illustrated for more clarification.

In addition, the different between the cladding modes and core regions of effective refractive index as illustrated for LP01, LP04, and LP13, even modes show in Fig 2.5-2. This is because the core mode does not affected too much in the bending curvatures.

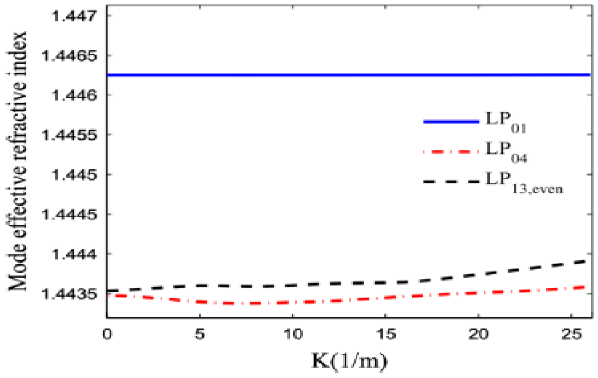


Figure 2.5-2: At the different bending curvatures, to obtain the effective refractive indexes of LP01, LP04, andLP13, even modes

2.6 LPFG Sensitivity Modified by Bending

Long-period gratings (LPGs) are fiber devices based on periodical modulation of refractive index of fiber core. Basically sensing applications of LPGs will able to detect the refractive index, temperature, strain and pressure measurements.

First, the LPGs were manufactured by UV-exposure of germanium-doped Corning SMF28 single-mode optical fiber. After that, the LPGs were fabricated by UV irradiation of 4 cm-long fiber section with laser and then pass to chromium amplitude mask with a period of 226.8 μm. Moreover, when done with the LPG manufacturing process it will turn to wet etching up to DTP (dispersion turning point).

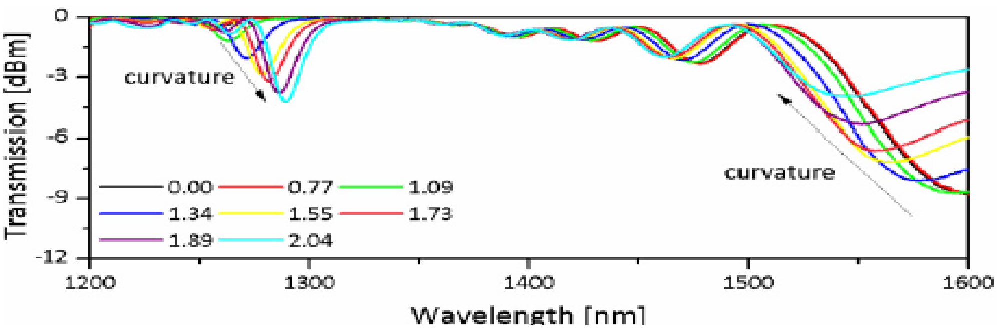


Figure 2.6-1: Effect of bending given in m-1 LPG transmission spectrum (M. Szymańska, 2014)

The effect of bending on the LPG transmission spectrum when the sample is surrounded by air (*RI*=1) is shown in Fig 2.6-1. Bending sensitivity depends on the elasto-optic properties of the core and cladding as well as on mode order. The appearing resonance is an effect of coupling of a core mode to an asymmetrical cladding mode. When the LPG is bent, the resonances coming from coupling of the symmetrical cladding modes experience a shift in wavelength to reduce their depth and their attenuation band broadens.

However the effect of bending on temperature and on RI sensitivity of the LPGs highly is depends on DTP conditions achieved by post-fabrication wet etching. Furthermore, the LPGs working at different DTP conditions will show different sensing properties. These conditions can be also influenced by LPG bending and thus a change in RI and Temperature sensitivity is obtained. The reason of the RI sensitivity modification after bending has been also explained by a change in the incident angle at the cladding-external medium interface. When the fiber is bent the incident angle, related to the considered cladding mode, increases and approaches the critical angle. This effect increases the penetration depth of the evanescent wave related to the coupled mode and, in turn, increases the amount of optical radiation that interacts with the external medium. Fig 2.6-2 shows the notch which test in different refractive index.

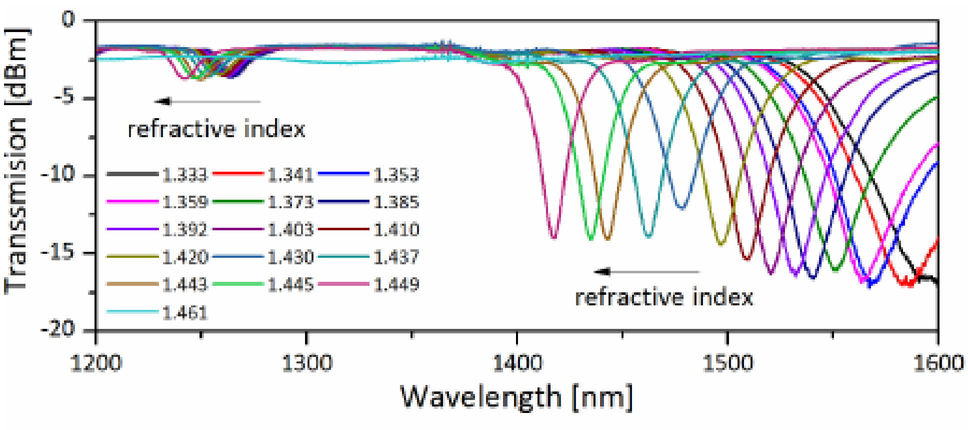


Figure 2.6-2: Evolution of LPG response with different refractive index. (M. Szymańska, 2014)

2.7 Summary

Name of method	Features
Fabrication of an electric arc discharges LPFG	**Advantages:** Can be used in any commercial fusion splicer. An easy and fast as sensors, equalizers in any optical fiber **Disadvantages:** Unrepeatability of fabricated filters, attenuation has higher loss
Fabrication of LPFG by the micro-taper method	**Advantages:** Good sensitivity, compact and low cost **Disadvantages:** Low repeatability and high loss
Fabrication of LPFG by the fattening method	**Advantages:** Provide good sensitivity **Disadvantages:** Low repeatability of the physical of the fabricated filters
Fabrication of LPFG by CO_2 laser irradiation	**Advantages:** Simple and flexible to use **Disadvantages:** Refractive index changes hardly to survive in high temperatures
Fabricated of LPFG by Femtosecond Laser	**Advantages:** Temperature sensitivity of encapsulated LPFG was 2 times than that of bare LPFG **Disadvantages:** Environmental impact
Fabricated of LPFG by Low Pressure Mercury Lamp	**Advantages:** Provide longer grating length **Disadvantages:** High cost and inconvenient for warming up to start the lamp

2.8 Application of LPFG

Long period fiber grating (LPFG) is now developing and very useful in communication system. Recently, the demand of optical fiber has extreme grown greatly. LPFG could be useful in a variety of application.

First, telecommunication applications are widespread in global, and it will ranging from global networks to desktop computer. Fiber optics is the one of the cables which is most suitable for the telecommunications over long distances. This is because of the high bandwidth possible with a single fiber strand. Fibers are lighter as compare with the copper wire, so fibers can easily route and also more easily transported to the cable site. In addition, fiber cables have a security advantages because it was hard to tap.

Some application has been used which the LPFG also suitable for chemical sensing such as environment measurements or gas concentration because of the high sensitivity of cladding modes to surrounding refractive index values.

Another important application for optical fiber is used for stress, bending, torsion and temperature sensing. This is because the all glass structure that consists in the optical fiber that could help these devices survived in high temperature (1200 ℃) and corrosion condition.

Moreover, optical fiber is use in biomedical industry. Recently, fiber optic systems are suitable used in biomedical which the devices are used for transmission of digital diagnostic images.

Long-period fiber gratings (LPFGs) have played a quite important position in optical communication systems so optical fiber is very common used for transmission of data. Companies can use the optical fiber for delivery of digital video and data services with easily. Besides, some multinational firms also use the optical fiber to transfer data and some important information to around the world or transfer data to the desktop terminals which will gives the systems became more secure.

Therefore, the high bandwidth was provided by fiber in order to transmitting the broadband signals became perfectly, such as high-definition television (HDTV) telecasts.

In addition, LPFG also can play a role in intelligent transportation systems, like smart highways with automated tollbooths, intelligent traffic and changeable message signs. With having this kind of technology, the jam of transportation on the traffic can be solved.

CHAPTER 3

METHODOLOGY

3.1 Instrument and tools

Table 3.1-1: Instrument and tools list has been used in the project

No.	***Stages of process***	***Instrument and tools***
1	Cleaning process	SMF-28 fiber
		Stripper
		Glass cutter
		Tissue
		Cleaner for glass cutter
		Alcohol
		Connectors
2	Fabrication process	Optical Spectrum Analyser (OSA)
		Laser source
		Software (LabView & Thorlabs APT users)
		Power source & function generator
		Weight
		Electrodes arching
		Translation stage
		Bosch with 30kW, 12 V

3	Testing process	Optical Spectrum Analyser (OSA)
		Laser source
		SMF-28 fiber with grating (fabricated)
		Petri dish
		Stickers
		Bending ruler
		Water
		Sucrose with 60%, 65%, 70%
		Fusion splicer
		Connectors
		Marker pens
		Plastic sheet

3.2 Fabrication Process

There have two types of fiber which is SMF-28 and SM-750. But both type of fiber given different wavelength. The wavelength of the SMF-28 was used in around 1500-1600 nm and the parameter period set as 650μm used it for the long period fiber grating purpose. Besides, the wavelength of the SM-750 was used in 800-1000nm and the parameter period set as 350μm used it for the short period fiber grating. However, in the project 1 SMF-28 has been selected to be fabricated.

In this project we had chosen the electric arching discharges method to fabricate the fiber. Firstly, the SMF-28 was made by silica structure so must use the fiber cleaver to remove the polymer coating at top and bottom of fiber. Then clean up the top and the bottom where the poly coating has been removed by the alcohol. This is because to prevent the dust or some not removed coating inside the fiber. After cleaning, put the both ends of the fiber into bare fiber adapter. Meanwhile, the center of fiber needs to remove the polymer coating in order to get the fabrication purpose and clean up by alcohol. Then connect the fiber with spectrum analyzer and laser, and put the fiber in between electric arcing. The purpose of translation stages is to move the position of the electrodes during the fabrication. Set the wavelength 650 μm period and discharge at every 1 seconds to form tapers at arcing point. And record the data every 10 times grating. Therefore, the target is to achieve to get the notch wavelength for the fabrication. Experimental setup used for fabrication LPFG by the electric arcing discharges method as shown at below:

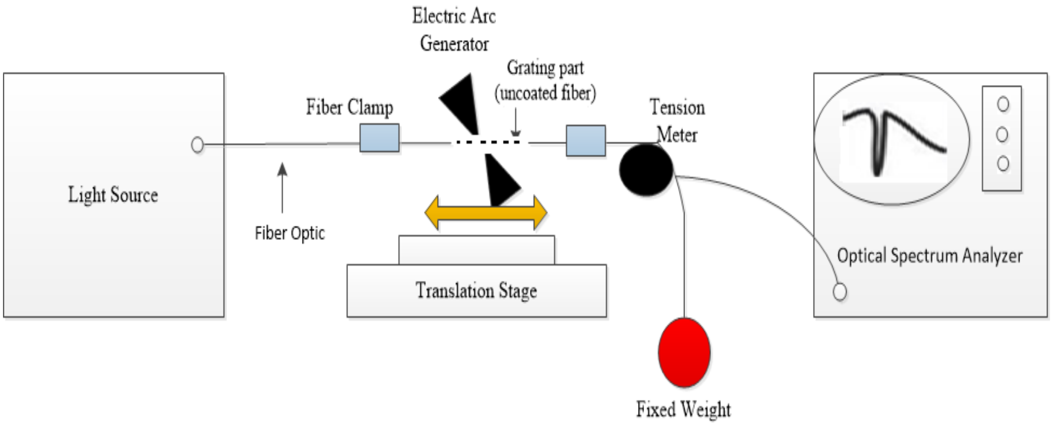


Figure 3.2-1: Experimental Setup of LPFG fabricated by electric arc

3.2.1 Testing Process

Firstly, the fiber will be tested in the straight line. This is done by connecting the fiber connectors to the light source and the spectrum analyzer. After that, the fiber will put in the straight line under the air condition. Hence, the graph was observed in spectrum analyzer. Besides that, the fiber was remained the same position and put it on the stickers where the stickers has already cover a supported stand and then filled with water and sucrose in the grating part of the fiber in order to observe the graph compare with the air condition.

Two bending methods of LPFGs have been used: which are bending the fiber in petri dish and bending the fiber with free styles.

3.2.1.1 1st method- testing the Fiber in bending Structures (Petri Dish)

After the fabrication process, the fibers were being test in bending structures which the fiber would bend in petri dish under the air, water and sucrose condition. The fiber was bending in 9.5cm diameter of petri dish, put the grating part which was uncoated part of fiber on the center bottom of petri dish. Moreover, the fiber was stickers on the both side of the petri dish in order to ensure that the fiber wills not easily being moved. Therefore, the graph was observed after switch on the light source and the OSA. However, after finish the bending test then put some water and sucrose on the grating part of the bending fiber with repeat the same procedure as below:

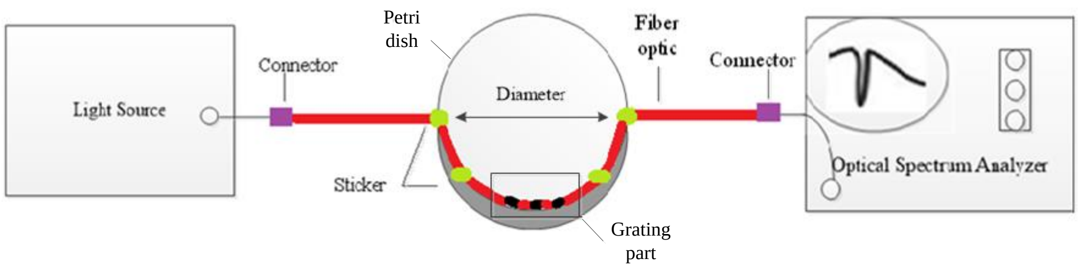


Figure 3.2-2: Experimental Setup for bending structure in petri dish

3.2.1.2 2nd method- Testing the Fiber in Plastic Sheet with Free Style Bending

Another method to bending the fiber is testing it with manually bending which the fiber would bend in petri dish under the air, water and sucrose condition. With using the plastic sheet as bending structure base in order to bent the fiber on the plastic sheet.

During the testing process, left side of fiber will fix by stickers because this purpose is to lock the fiber so that fiber will not easily being moved and the most important thing is to ensure that the grating part would stay in the center. Besides, adjust the right side of the fiber with free style bending way to get the notch. After best notch has been observed, then use sticker to fix the right side of fiber and measure the diameter of bending structure. Next, use marker pen to mark structures deformation of fiber in order to repeat the same fiber for few times and also may use it for others fiber test in the same bending way. In addition, after finish the bending test then put some water and sucrose on the grating part of the bending fiber with repeat the same procedure. Figure show that the step how to bend the fiber.

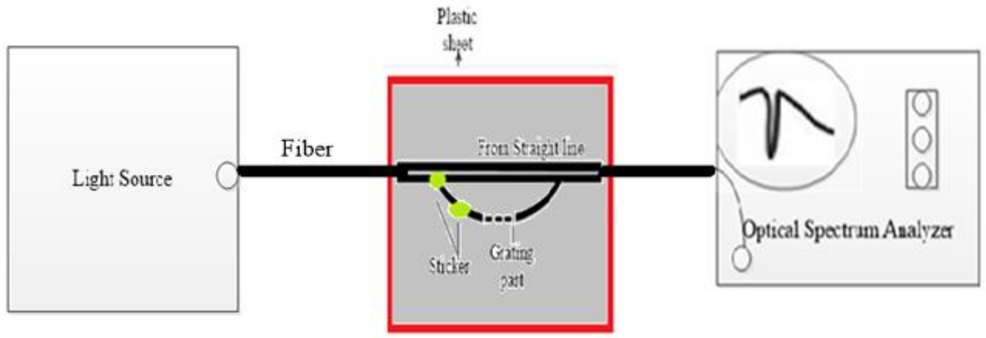


Figure 3.2-3: Experimental Setup for bending structure in plastic sheet

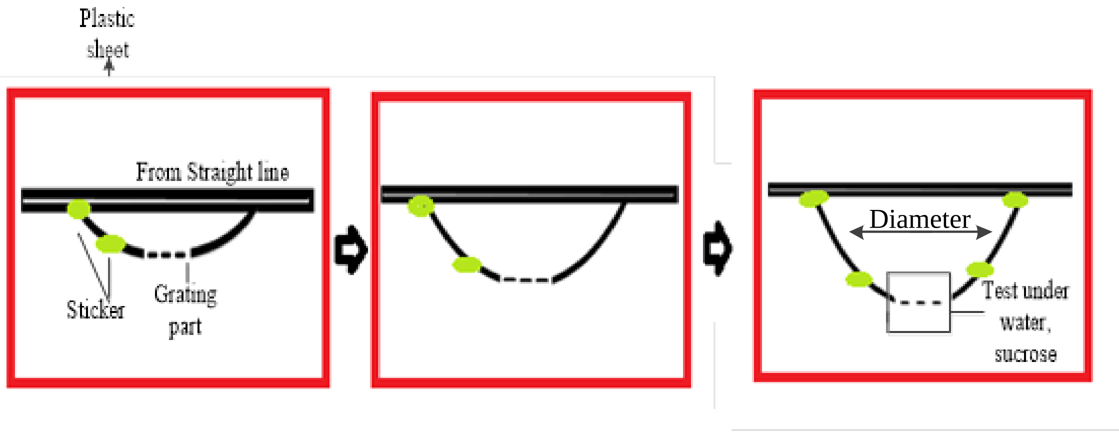
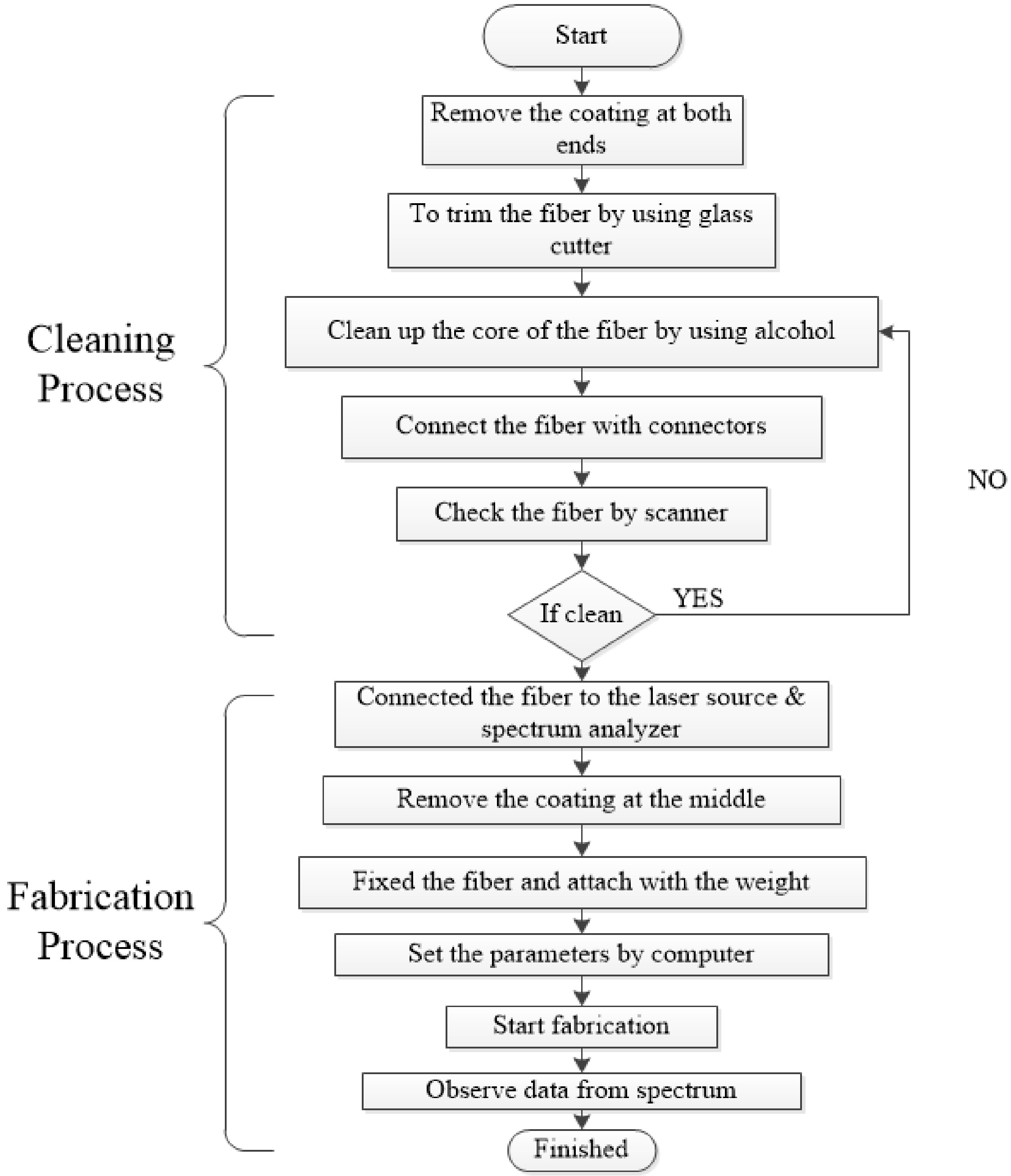


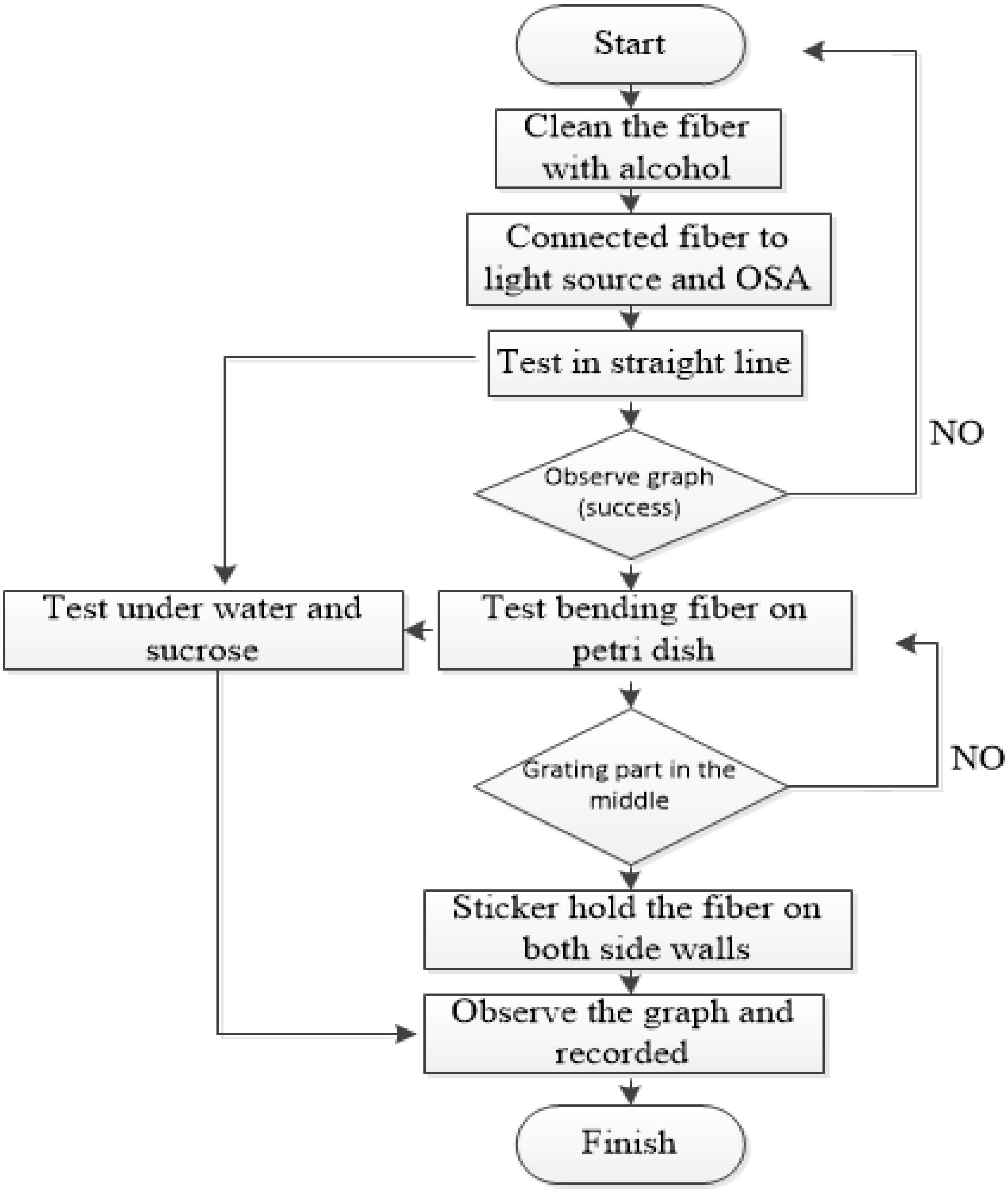
Figure 3.2-4: The experiment setup for the free style bending step. The notch was obtained in the right side picture so use that structure to test under water and sucrose condition

3.3 Flow Chart- Fabrication Process

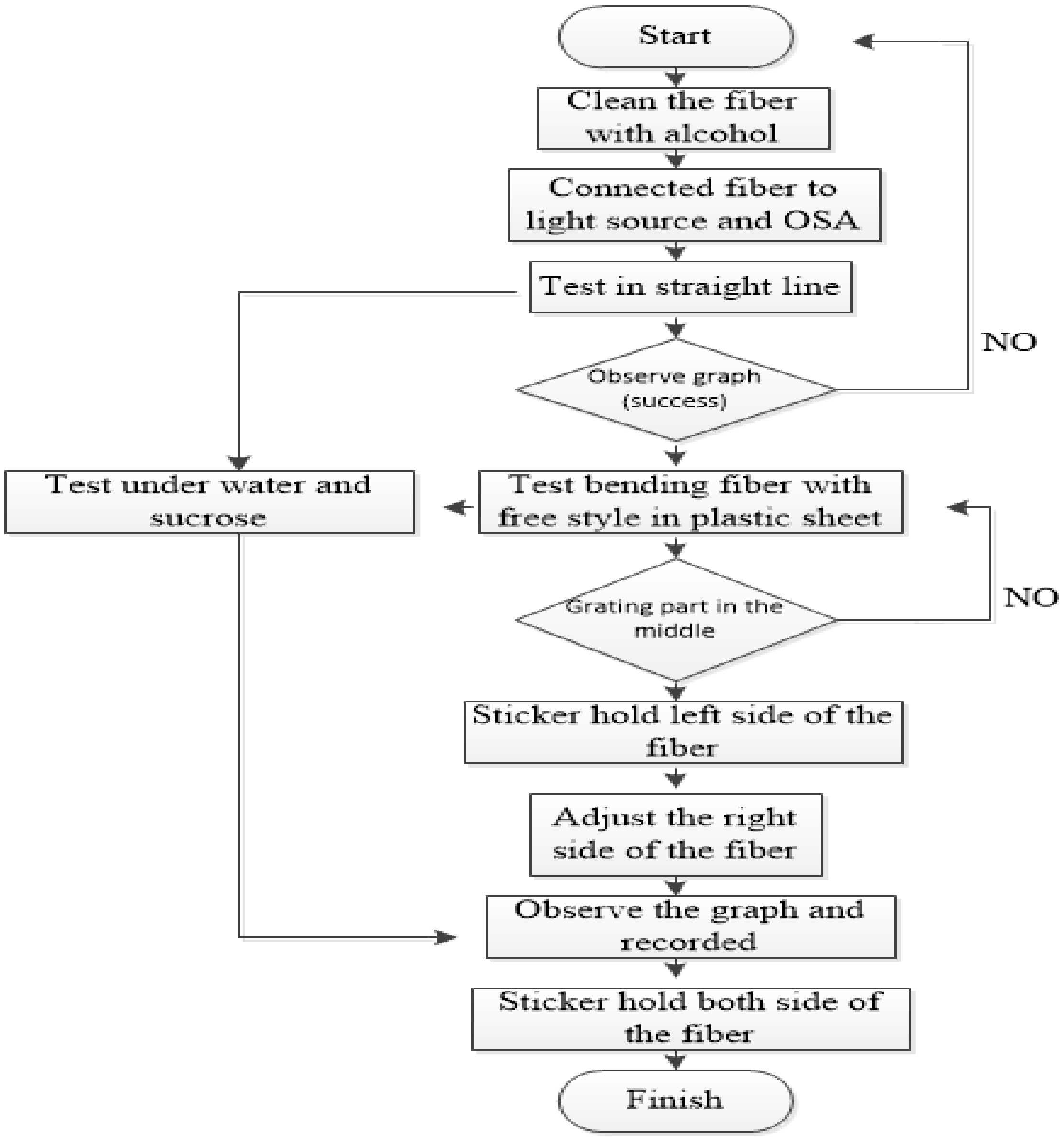


3.3.1 Flow Chart- Testing Process

3.3.1.1 1st method- Testing the Fiber in Petri Dish



3.3.1.2 2nd method- Testing Fiber in Plastic Sheet with Free Style



CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Fabrication Process

4.1.1 22g with 650 µm Grating Period

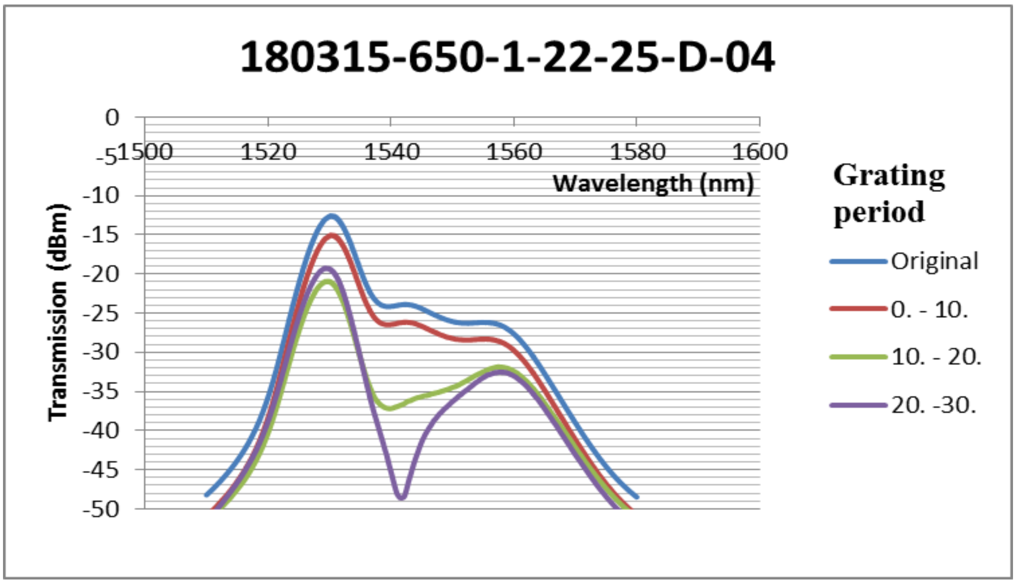


Figure 4.1-1: Fiber with 22g and 650 µm

The Fig 4.1-1 shows the fiber that already completed fabricated. The meaning of 180315-650-1-22-25-D-04 is on 18-march-2015 with wavelength 650 µm, 1 second, weight is 22g, the notch of grating period is 25 which store at D and fourth fiber has been completed fabricated on that date. Every trace was recorded after 10 times of grating period.

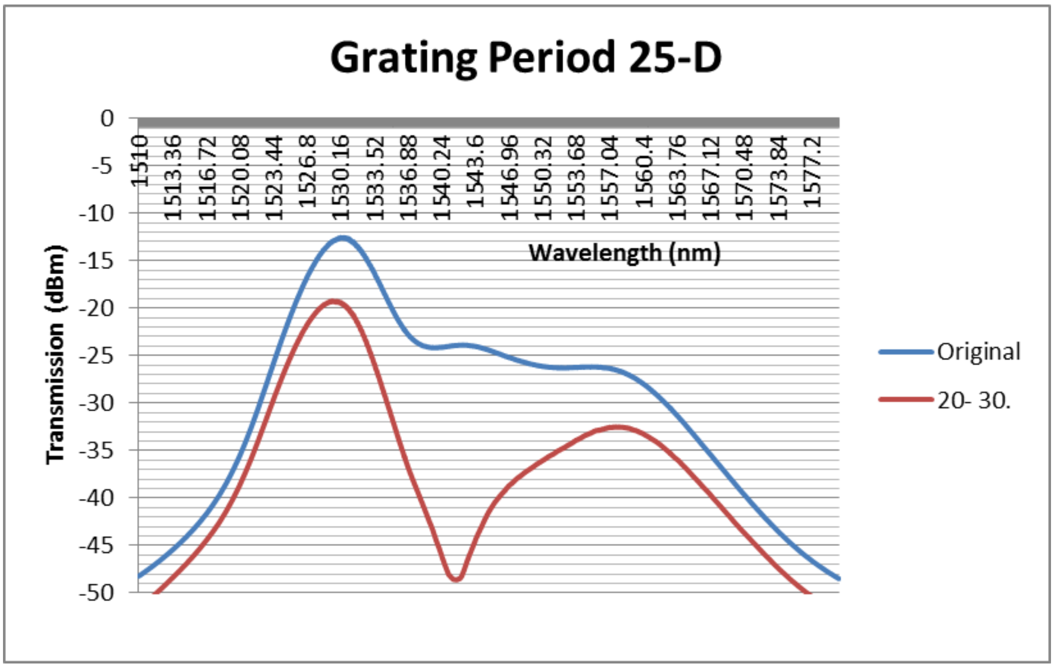


Figure 4.1-2: Comparison between original points with the notch

This Fig 4.1-2 shows the same fiber with the figure 15. But in this graph only show the original and the significant notch which gives 25 grating period. Thus, this fiber is suitable to use for any applications.

Table 4.1-1: Comparison between the grating period of the original and the notch

Grating period	***Wavelength (nm)***	***Transmission (dBm)***	***Difference between the grating period of notch and original.***
Original	1541.56	-23.922	**-48.574-(-23.922)** **= -24.609dBm**
Notch	1541.56	-48.574	

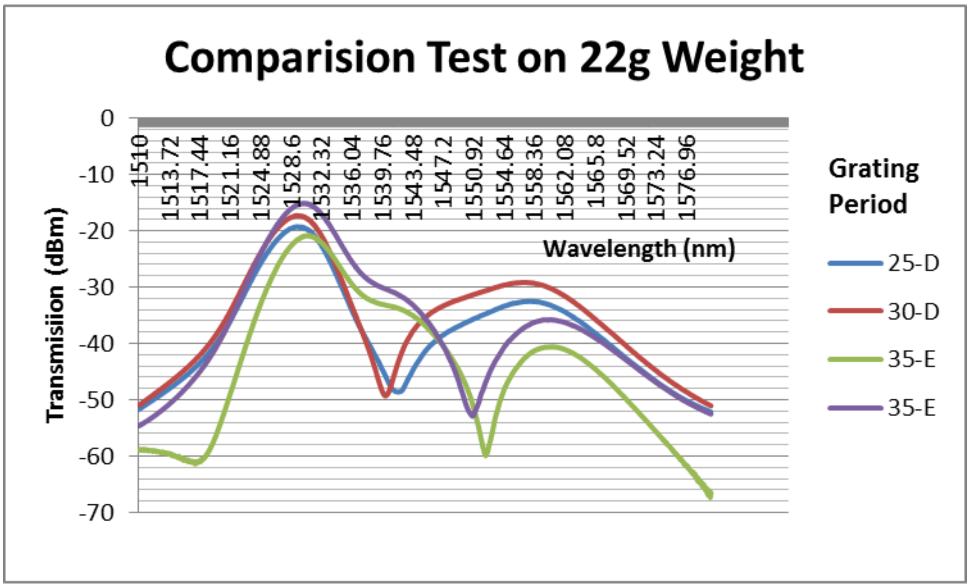


Figure 4.1-3: Combination the notch with different fiber. Weight is 22g

The Fig 4.1-3 shows that combination of the notch has been plot in this graph with different fiber. In this weight with 22 g, most of the notch will appear within -45dBm till -60dBm attenuation. But all the notch wills gives the different value even all the parameter was same. There have some reason which may affect the grating. Temperature is the one of the issue will cause the grating period, this is because the sensitivity of the fiber to the temperature. Therefore, during fabrication with air-condition, the graph will drop faster as compare with normal temperature.

The weight also may affect the number of grating. The weight will to create a constant axial tension along the optic fiber and allow the deformation of the cladding. With having dust or coating on the fiber may cause the power drop faster. This is because during fabrication electric arcing will burn together the coating and the graph will drop directly.

During fabrication, if people talking in front of the electric arc also will affect the number of grating. This is because the vibration and the temperature are not same and cause the graph drop faster. Every times before fabricate our first fiber, we need to let the machine to warn up first. This may due to the heater of the electric arcing; after the machine has been used for few times then can provide a stable graph.

4.1.2 14g with 650 µm Grating Period

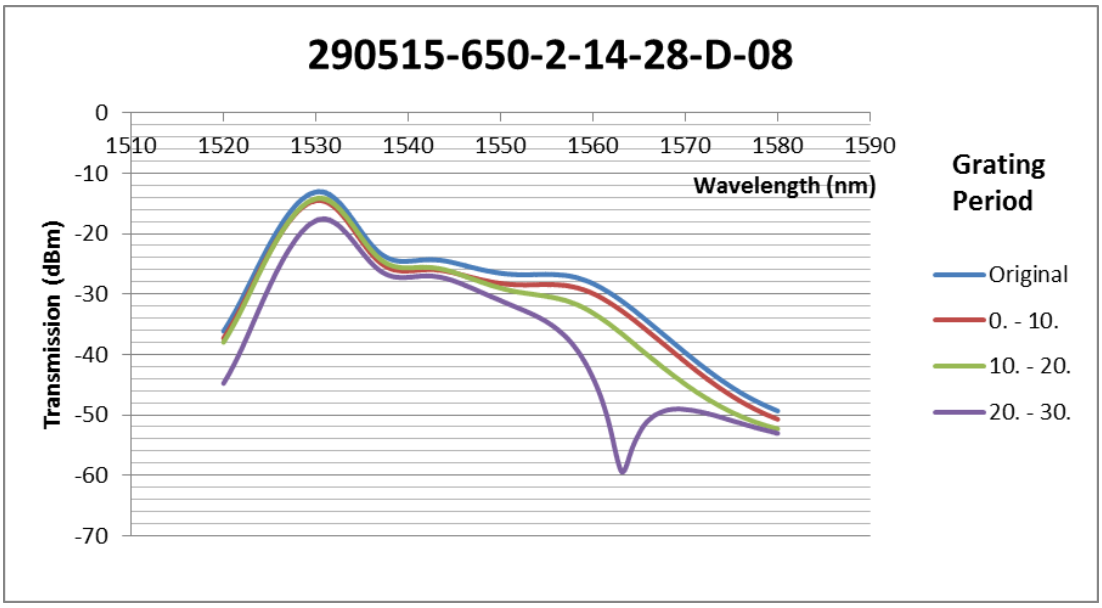


Figure 4.1-4: Fiber with 14g and 650 µm

The Fig 4.1-4 shows the fiber that already completed fabricated. The meaning of 290515-650-2-14-25-D-08 is on 29-May-2015 with wavelength 650 µm, 2 second, weight is 14g, the notch of grating period is 25 which store at D and eight fiber has been completed fabricated on that date. Every trace was recorded after 10 times of grating period.

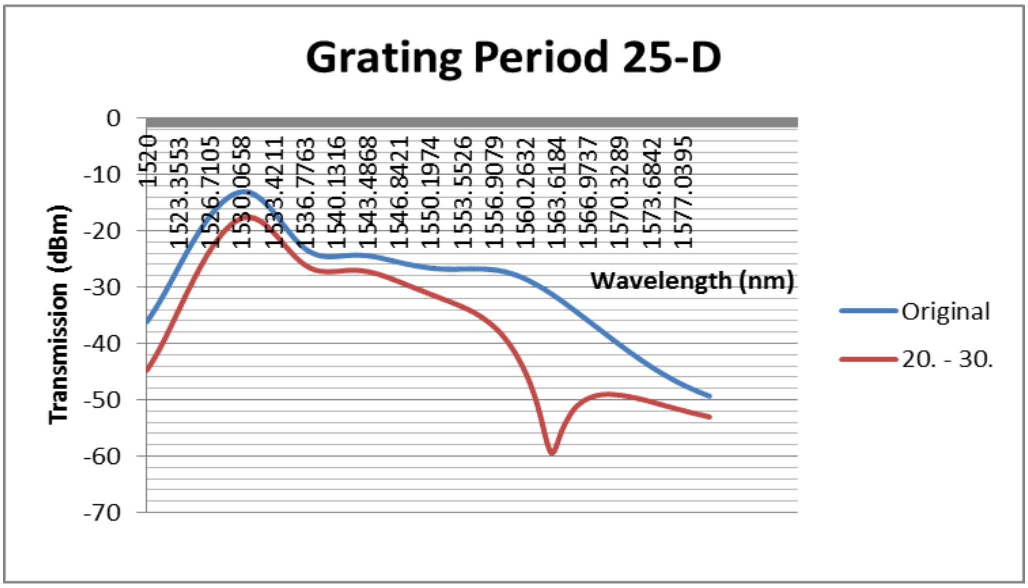


Figure 4.1-5: Comparison between the original points with the notch

This Fig 4.1-4 shows the same fiber with the Fig 4.5. But in this graph only show the original and the significant notch which gives 25 grating period. Thus, this fiber is suitable to use for any applications.

Table 4.1-2: Comparison between the grating period of the original and the notch

Grating period	***Wavelength (nm)***	***Transmission (dBm)***	***Difference between the grating period of notch and original.***
Original	1563.224	-31.267	**-59.483-(-31.267)** **= -28.216dBm**
Notch	1563.244	-59.483	

4.2 The Step of Bending Structures Deformation

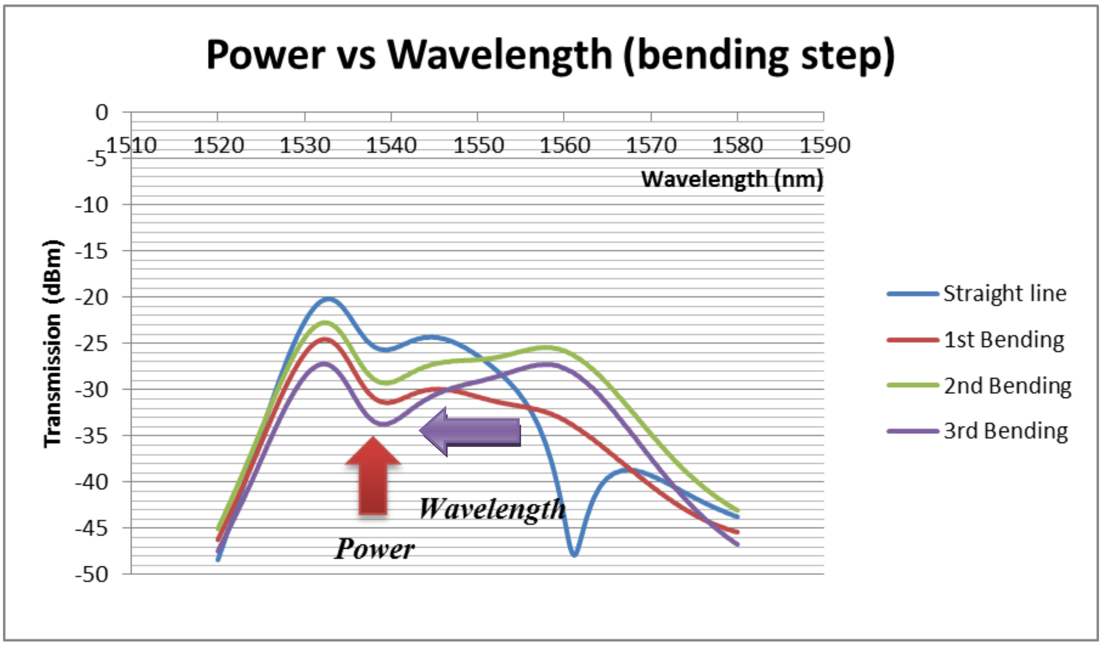
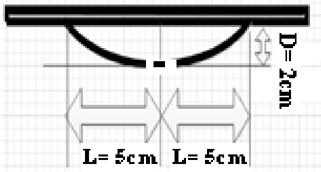
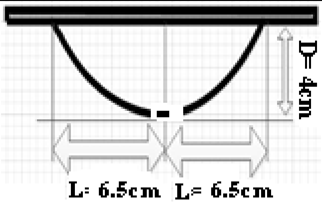
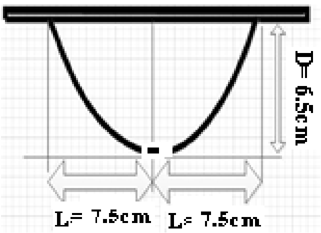


Figure 4.2-1: Bending step waveform. After implement with bending method which the wavelength has shifted to left and the power has move to upward

Table 4.2-1: The bending curvatures step

Step from straight line to bending curvature	***Original picture***	***Bending Curvature***	***Wavelength (nm)***	***Power (dBm)***
		-	1561.16	-47.896
		$c = \frac{2d}{l^2+d^2}$ $=\frac{2(2)}{5^2+2^2}$ $=13.8m^{-1}$	1539.52	-31.409
		$c = \frac{2d}{l^2+d^2}$ $=\frac{2(4)}{6.5^2+4^2}$ $=13.7m^{-1}$	1539.52	-29.286
		$c = \frac{2d}{l^2+d^2}$ $=\frac{2(6.5)}{7.5^2+6.5^2}$ $=13.2m^{-1}$	1538.96	-33.72

This Fig 4.2-1 show the measurement from straight line waveform slowly changed to bending waveform. The curvature has been used it as measurement for the bending structures undergoes rather than the depth of the deflection. The power of straight line was -47.896dBm and the wavelength was 1561.16nm. Then the power was drop to -31.409dBm and wavelength has been shifted to left when testing with 1st bending curvatures.

However, when testing in diameter of bending curvatures at $13.2m^{-1}$ which the power was shift upper there was -33.72dBm. Therefore, with the bending curvatures $13.2m^{-1}$ will give the less transmission loss and better notch.

4.3 Testing Result

4.3.1 14g with 18 Grating Period

Table 4.3-1: Fiber with 18 grating period test under air condition

Wavelength	**Power**	**Diameter**	**Medium**	**Fiber grating**
1565.158	-49.037	Straight line	Air	18
1538.553	-29.352	Free style 9cm	Air	
1538.868	-29.218	Free style 10cm	Air	
1539.5	-26.684	Petri dish 9.5cm	Air	

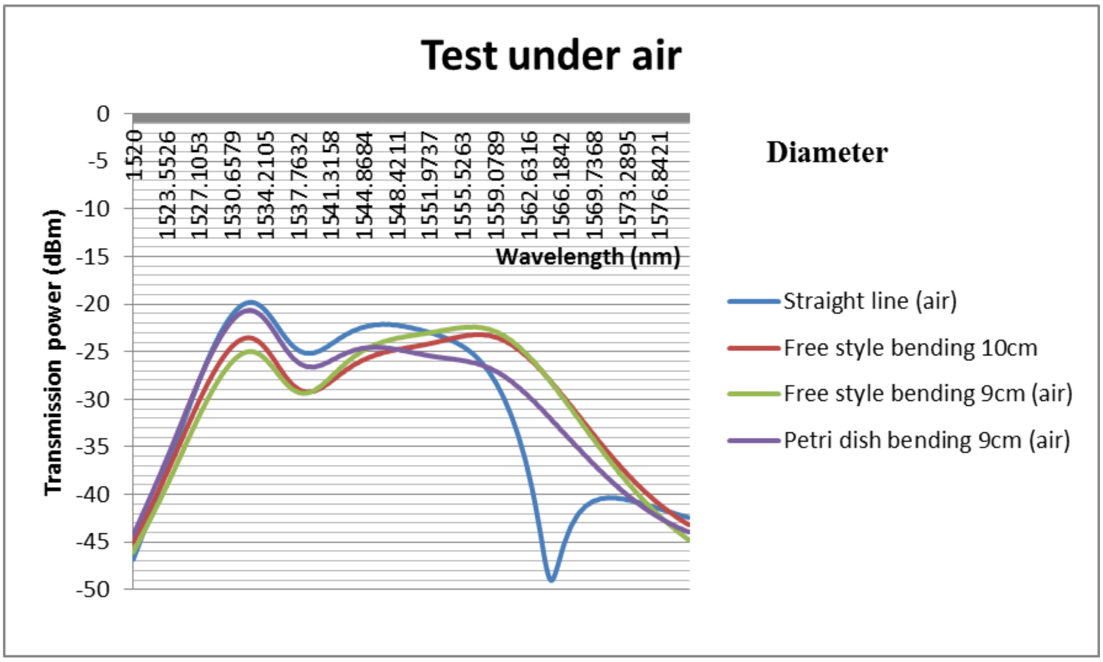


Figure 4.3-1: The weight with 14g and 18 number of grating period fiber was tested under the air condition with different structures

Table 4.3-2: Comparison the power and wavelength between straight line and bending method

Straight line vs bending				
Diameter	***Fiber grating***	***Medium***	***Wavelength (nm)***	***Power (dBm)***
Straight line	18	Air	1565.158	-49.037
Free style 9cm	18	Air	1538.553	-29.352
Total			**(shift to left) 26.605**	**-19.685**

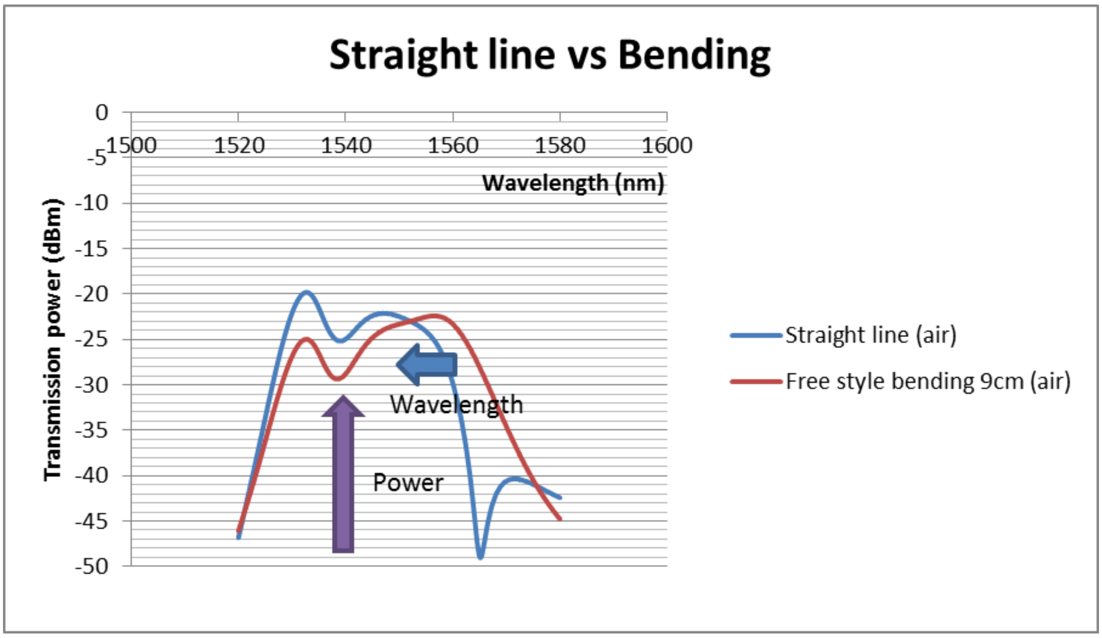


Figure 4.3-2: Comparison between straight with bending method. Power was drop from -49.037dBm to -29.352dbm. Wavelength was shift 26.605nm to left side

The Fig 4.3-1 shows the fiber with 18 number of grating period which the fiber used to test under the air condition. Based on the Fig 4.3-1, the wavelength in the waveform from the straight line to free style bending and petri dish bending was shift to the left. As compare the wavelength of bending the fiber in petri dish with wavelength of straight line there was moving to the left about 25.658nm. However, as compare the wavelength of bending the fiber in plastic sheet with wavelength of straight line there was shift to left about 26.605nm and the transmission loss was shift to the upper about 19.685dBm. The power of bending in petri dish with diameter 9.5cm and bending in plastic sheet with 9cm was not significant which only get -26.684dBm and -29.352dBm. Therefore, in Fig 4.3-2 shown this fiber was not good to use for testing due to the fiber was not sensitive for bending due to the higher transmission loss.

Table 4.3-3: Fiber with 18 grating period test under water condition

Wavelength	**Power**	**Diameter**	**Medium**	**Fiber grating**
1564.684	-47.056	Straight line	Water	18
1538.553	-28.456	Free style 9cm	Water	
1539.461	-26.603	Petri dish 9.5cm	Water	

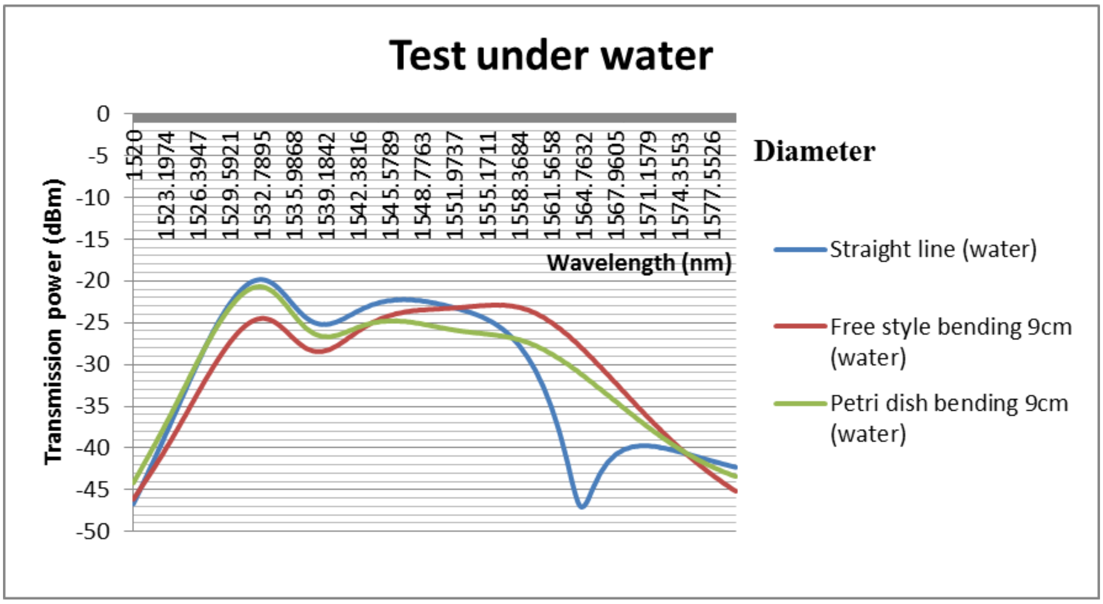


Figure 4.3-3: The weight with 14g and 18 number of grating period fiber was tested under the water condition with different structures

The Fig 4.3-3 shows the fiber with 18 number of grating period which the fiber used to test under the water condition. As compare the power from the air condition with water condition, the result was shift to upper a bit and the wavelength also moves to the left side. In the straight line under air condition show the power with -49.037dBm, but after put some water on the fiber the power will drop to -47.056dBm. Moreover, the result was shift to upward when test in bending method from air to water condition.

Table 4.3-4: Fiber with 18 grating period test under sucrose condition

Wavelength	**Power**	**Diameter**	**Medium**	**Fiber grating**
1563.342	-44.212	Straight line	Sucrose 60%	18
1562.079	-41.716	Straight line	Sucrose 65%	
1559.158	-40.064	Straight line	Sucrose 70%	
1538.711	-27.584	Free style 9cm	Sucrose 60%	
1538.75	-27.248	Free style 9cm	Sucrose 65%	
1538.79	-26.272	Free style 9cm	Sucrose 70%	
1539.382	-26.206	Petri dish 9.5cm	Sucrose 70%	

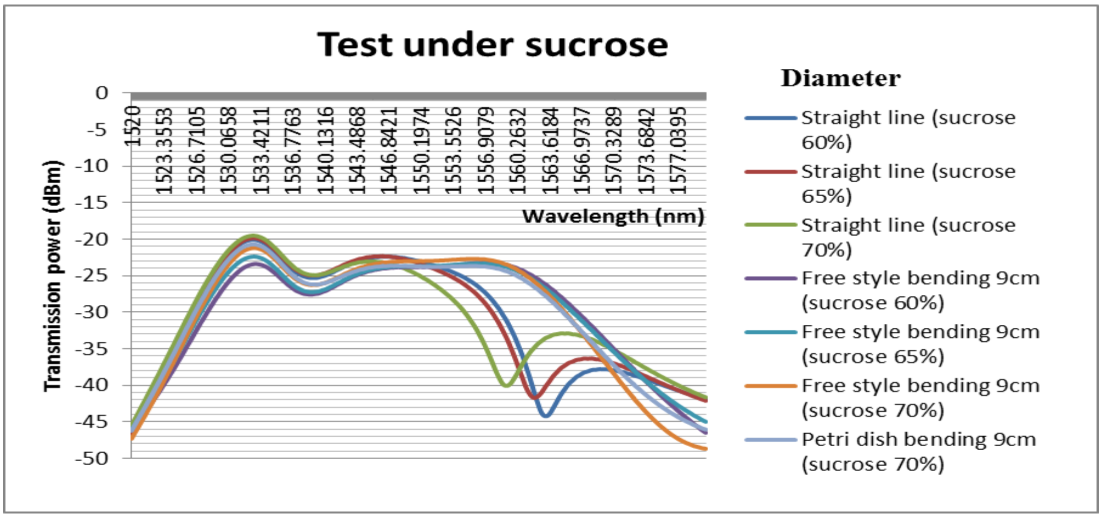


Figure 4.3-4: The weight with 14g and 18 number of grating period fiber was tested under the sucrose condition with different structures

Based on the Fig 4.3-4, the wavelength in the waveform from the straight line to free style bending and petri dish bending was shift to the left. In addition, with increasing the concentration of sucrose which the wavelength would slowly move to the left and the power was move the upward. In straight line test under sucrose 60%, power was -44.212dBm. Furthermore, when changed to 65% concentration of sucrose the result was -41.716dBm and the power test under sucrose 70% was -40.064dBm. However, the result does not much different when test with the bending under sucrose 60%, 65%,70%.

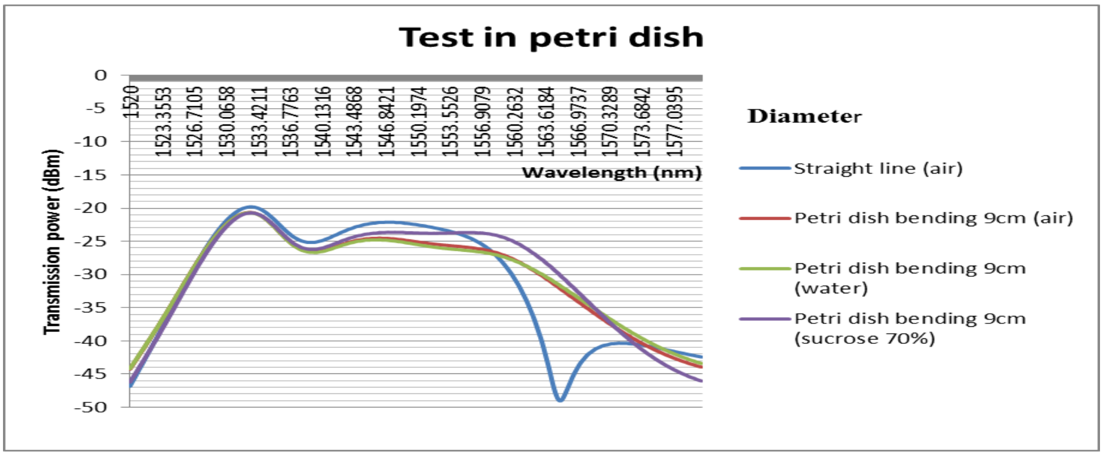


Figure 4.3-5: The weight with 14g and 18 number of grating period fiber was tested in petri dish

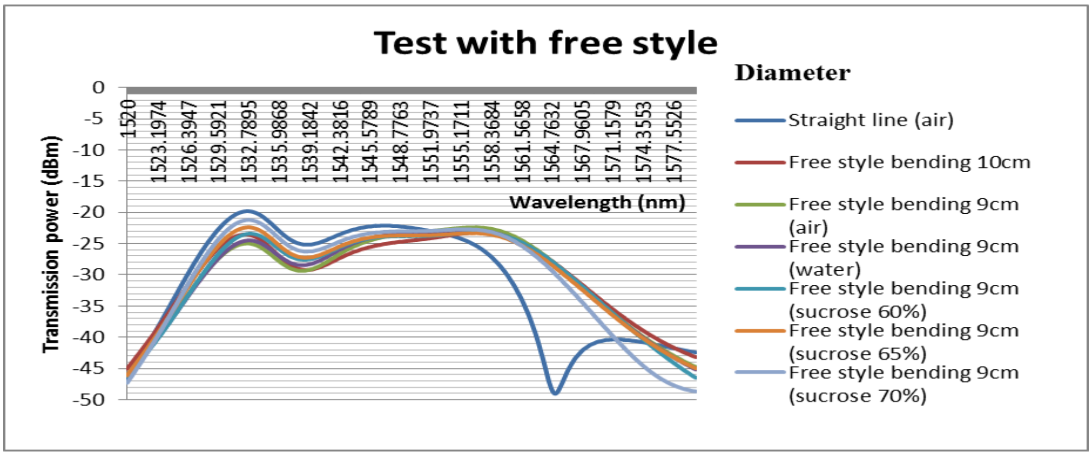


Figure 4.3-6: The weight with 14g and 18 number of grating period fiber was tested with free style in plastic sheet

Fig 4.3-5 show the result which the fiber bending in the petri dish and Fig 4.3-6 shown the test with free style in plastic sheet was test under air, water, and sucrose condition. From the result, this fiber does not have any significant response to the bending structures.

4.3.2 14g with 29 Grating Period

Table 4.3-5: Fiber with 29 grating period test under air condition

Wavelength	Power	Diameter	Medium	Fiber grating
1562.434	-51.163	Straight line	Air	29
1538.868	-32.271	Free style bending 9cm	Air	
1538.553	-32.256	Free style bending 10cm	Air	
1538.75	-28.633	Petri dish 9.5cm	Air	

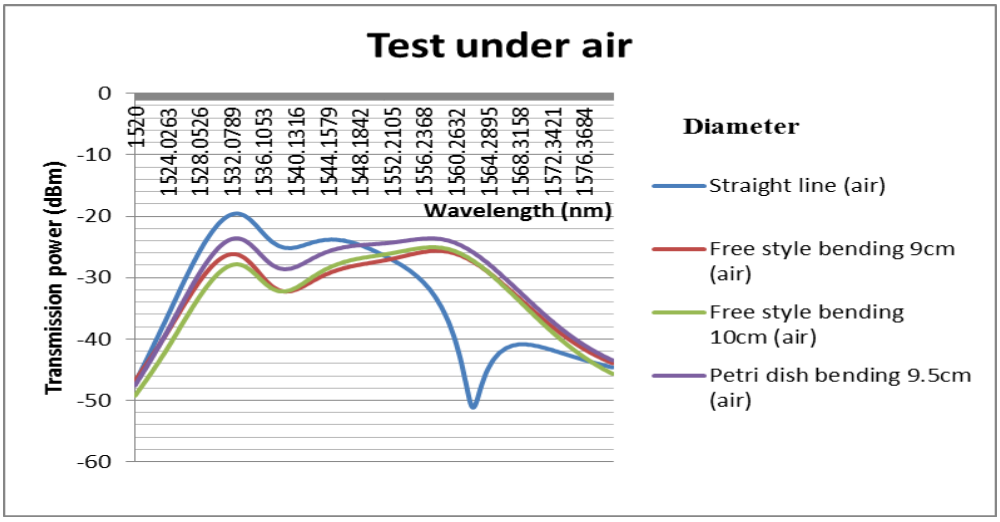


Figure 4.3-7: The weight with 14g and 29 number of grating period fiber was tested under air condition with different bending structures

Table 4.3-6: Comparison the power and wavelength between straight line and bending method

Straight line vs bending				
Diameter	***Fiber grating***	***Medium***	***Wavelength (nm)***	***Power (dBm)***
Straight line	29	Air	1562.434	-51.163
Bending 9cm	29	Air	1538.868	-32.271
		Total	***(shift to left)*** **23.566**	**-18.892**

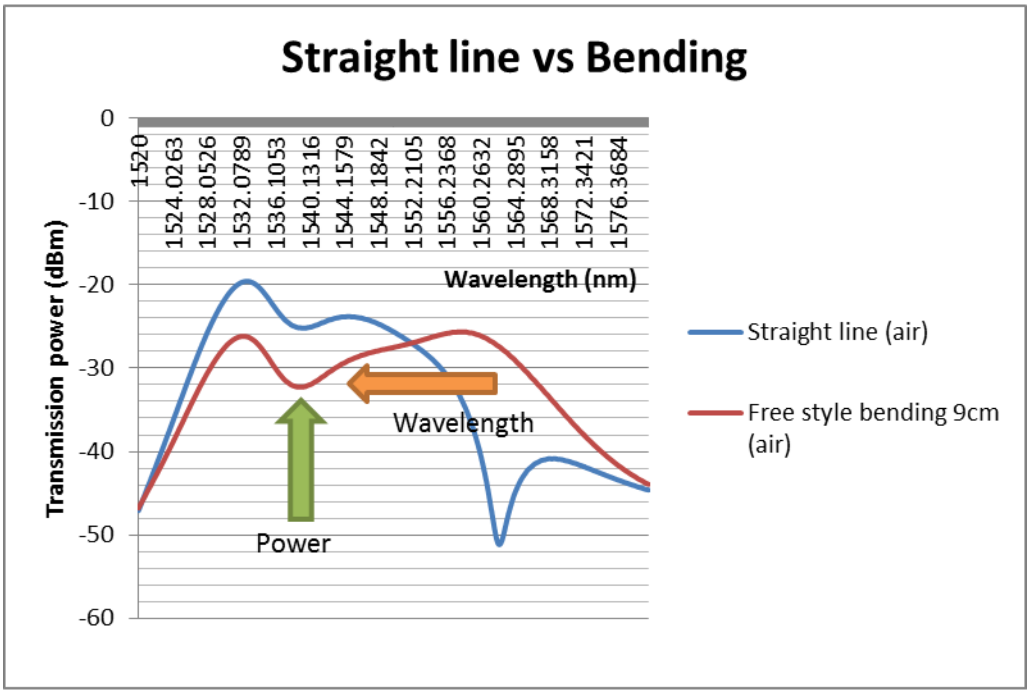


Figure 4.3-8: Comparison between straight with bending method. Power was drop from -51.163dBm to -32.271dbm. Wavelength was shift 23.506nm to left side

This Fig 4.3-8 shows the 29 number of grating period fiber was tested under air condition with different bending structures. By comparing the notch, bending with free style in diameter 9cm plastic sheet has power -32.271dBm. Besides, bending in diameter 10cm was slightly dropped to -32.256dBm. Moreover, bending in petri dish has lowest sensitivity there was only -28.633dBm. However, by comparing the wavelength from the straight line to bending structures there was shifted to the left with 23.566nm and the power loss between straight line and bending structures was -18.892dBm. Thus, this fiber has slightly more sensitivity as compare to the fiber with 18 grating period.

Table 4.3-7: Fiber with 29 grating period test under water condition

Wavelength	**Power**	**Diameter**	**Medium**	**Fiber grating**
1562.079	-50.496	Straight line	Water	29
1538.75	-31.552	Free style bending 9cm	Water	
1537.79	-28.334	Petri dish 9.5cm	Water	

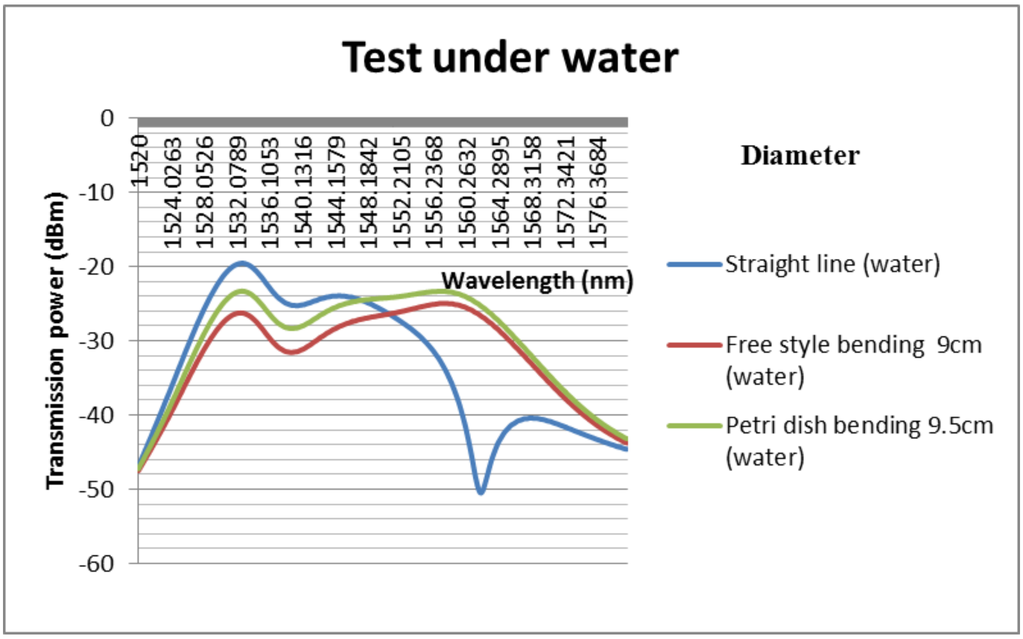


Figure 4.3-9: The weight with 14g and 29 number of grating period fiber was tested under water condition with different bending structures

As shown in Fig 4.3-9, the 29 number of grating period fiber was tested under water condition with different bending structures. By comparing the notch between the waveform from air to water in straight line is moving about 0.036nm in wavelength. Furthermore, after implement with the bending method, the bending in petri dish method has higher transmission loss compare as free style bending method.

Table 4.3-8: Fiber with 29 grating period test under sucrose condition

Wavelength	**Power**	**Diameter**	**Medium**	**Fiber grating**
1561.013	-48.747	Straight line	Sucrose 60%	29
1559.79	-47.465	Straight line	Sucrose 65%	
1556.987	-43.318	Straight line	Sucrose 70%	
1538.75	-28.845	Free style bending 9cm	Sucrose 60%	
1538.75	-27.866	Free style bending 9cm	Sucrose 65%	
1539.421	-26.767	Free style bending 9cm	Sucrose 70%	
1539.382	-26.206	Petri dish 9.5cm	Sucrose 70%	

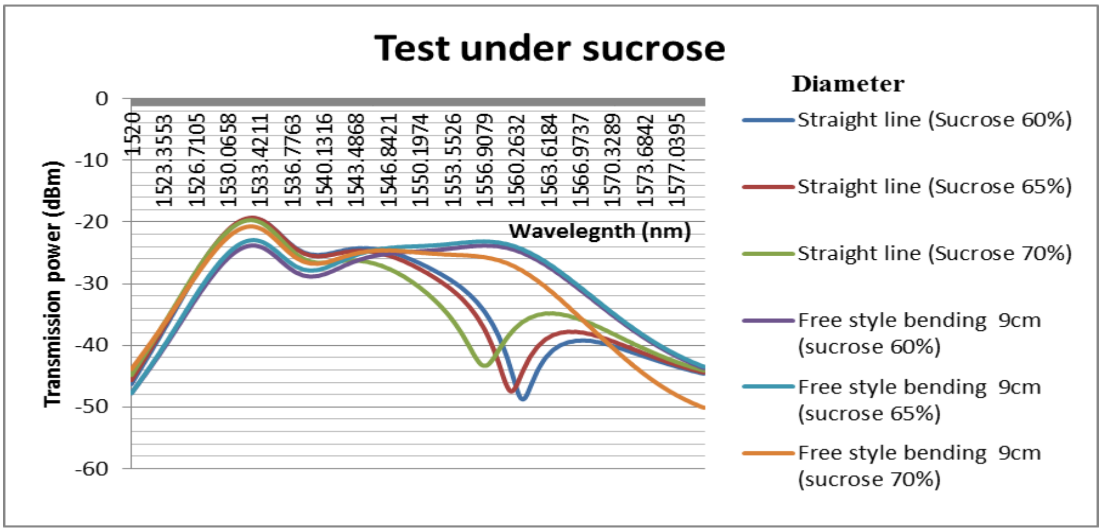


Figure 4.3-10: The fiber with 29 number of grating period was tested under sucrose condition

This Fig 4.3-10 shows the fiber with 29 number of grating period was tested under sucrose condition. In straight line test under sucrose 60%, wavelength was 1561.013nm, wavelength slightly moves to the left when increase 5% concentration of sucrose which the wavelength shifted to left about 1.223nm and 70% concentration of sucrose was move about 4.026nm. Hence, with concentration 70% of sucrose gives better result due to the higher refractive index with 1.45.

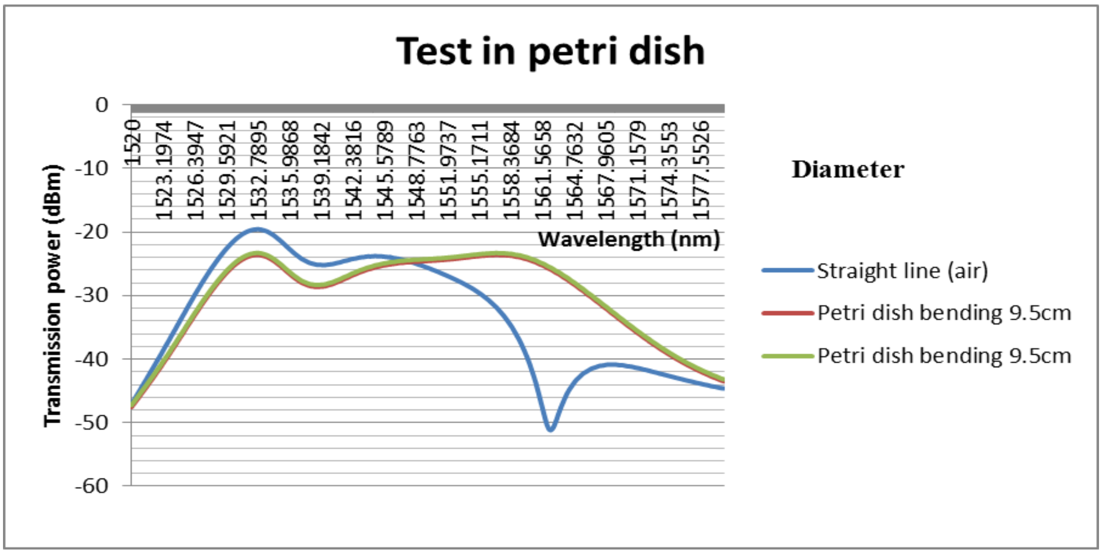


Figure 4.3-11: The weight with 14g and 29 number of grating period fiber was tested in petri dish

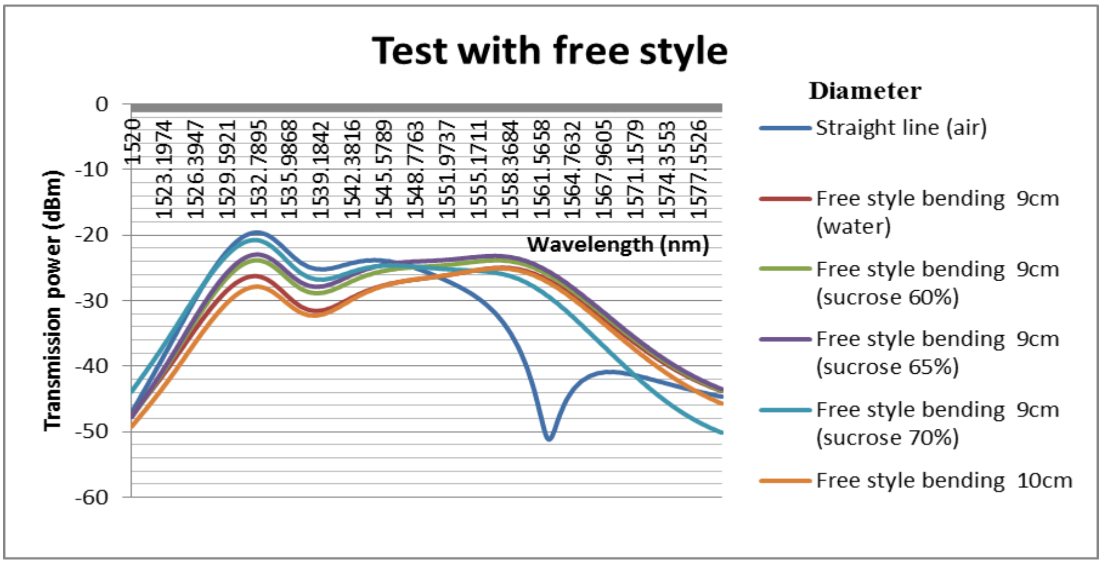


Figure 4.3-12: The weight with 14g and 29 number of grating period fiber was tested with free style in plastic sheet

Fig 4.3-11 show the result which the fiber bending in the petri dish and Fig 4.3-12 shown the result test with free style in plastic sheet was test under air, water, and sucrose condition. Based on the result, the free style bending method have higher sensitivity compare to bending in petri dish.

4.3.3 14g with 40 Grating Period

Table 4.3-9: Fiber with 40 grating period test under air condition

Wavelength	**Power**	**Diameter**	**Medium**	**Fiber grating**
1561.25	-46.855	Straight line	Air	40
1538.908	**-35.826**	**Free style bending 9cm**	**Air**	
1539.342	-29.944	Free style bending 10cm	Air	
1538.75	-35.615	Re-do 9cm	Air	

1539.579	-34.763	Re-do 9cm	Air	
1538.75	-34.856	Re-do 9cm	Air	
1539.303	-29.704	Petri dish bending 9.5cm	Air	

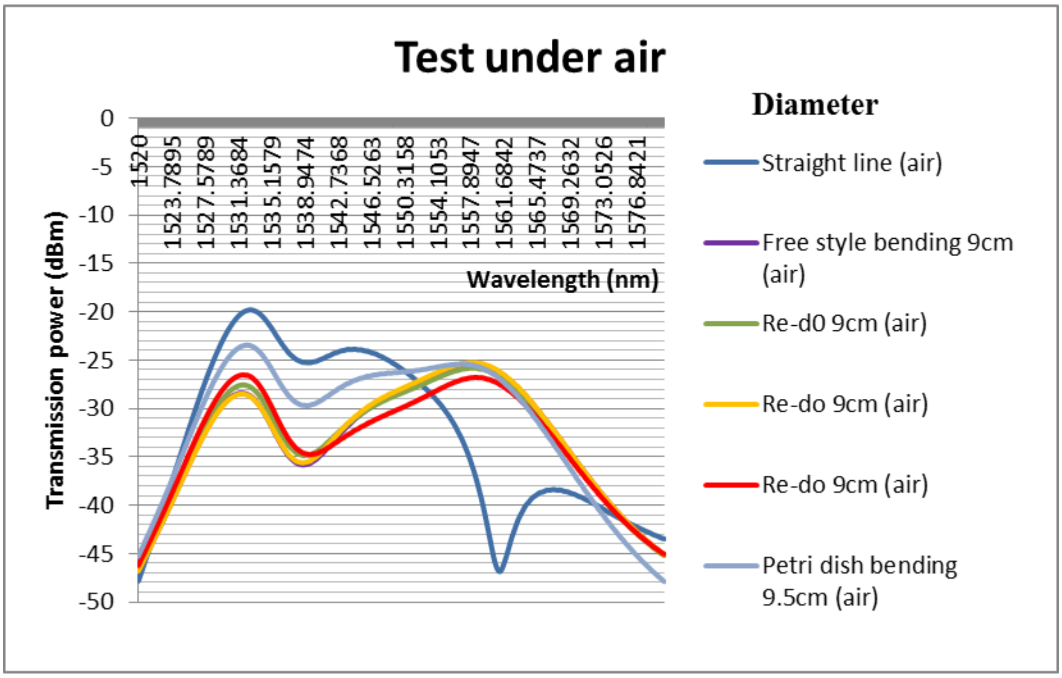


Figure 4.3-13: The weight with 14g and 40 number of grating period fiber was tested under air condition with different bending structures

Table 4.3-10: Comparison the power and wavelength between straight line and bending method

Straight line vs bending				
Diameter	***Fiber grating***	***Medium***	***Wavelength (nm)***	***Power (dBm)***
Straight line	40	Air	1561.25	-46.855
Bending 9cm	40	Air	1538.908	-35.826
Total			***(shift to left)*** **22.342**	**-11.029**

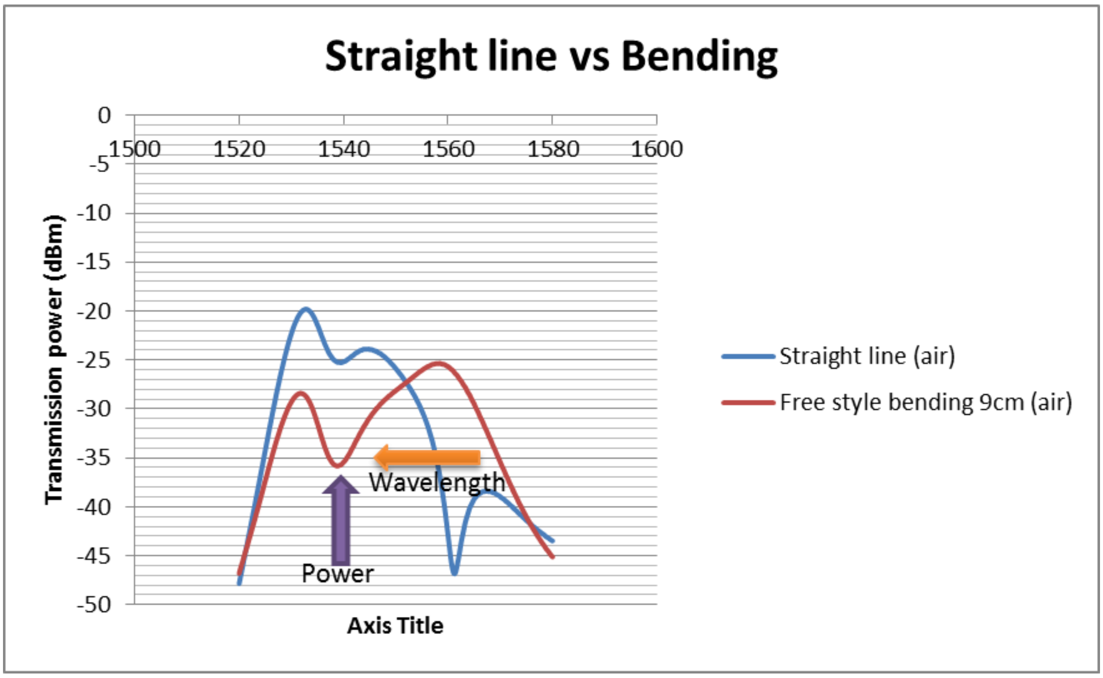


Figure 4.3-14: Comparison between straight with bending method. Power was drop from -46.855dBm to -35.826dbm. Wavelength was shift 22.342nm to left side

This Fig 4.3-13 shows the fiber with 40 number of grating period was tested under air condition and different structures. Based on the Fig 4.3-13, the wavelength in the waveform from the straight line to free style bending and petri dish bending was shift to the left. As compare the wavelength of bending the fiber in petri dish with wavelength of straight line there was moving to the left about 21.947nm. However, Fig 4.3-20 shown the wavelength of bending the fiber in plastic sheet with wavelength of straight line there was shift to left about 22.342nm and the transmission loss was shift to the upper about 11.029dBm. Result has been repeated for few times to verify that bending curvatures will able to gives the same waveform. Therefore, these fibers are suitable to use because the fiber has high sensitive for bending and also low transmission loss.

Table 4.3-11: Fiber with 40 grating period test under water condition

Wavelength	**Power**	**Diameter**	**Medium**	**Fiber grating**
1560.974	-45.818	Straight line	Water	40
1538.079	-34.398	Free style bending 9cm	Water	
1539.263	-29.916	Petri dish bending 9.5cm	Water	

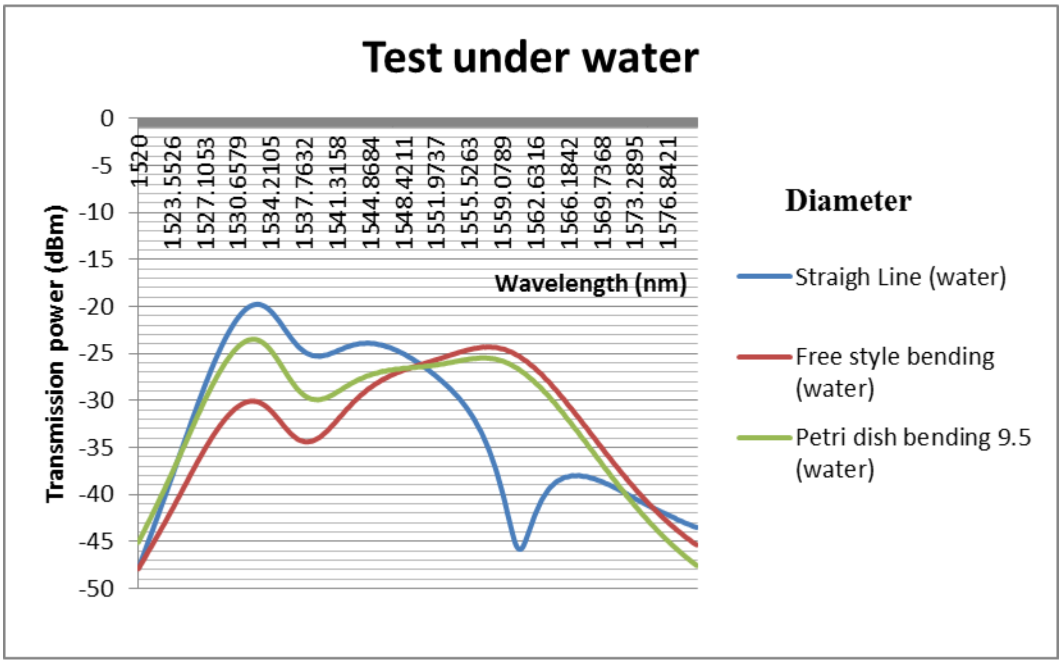


Figure 4.3-15: The weight with 14g and 40 number of grating period fiber was tested under water condition with different bending structures

This Fig 4.3-15 shows the 40 number of grating period fiber was tested under water condition with different bending structures. By comparing the notch between the waveform from air to water in straight line is moving about 0.276nm in wavelength. Besides, the power was drop from -46.855dBm to -45.818dBm. However, bending in plastic sheet has lower transmission loss compare with bending in petri dish method.

Table 4.3-12: Fiber with 40 grating period test under sucrose condition

Wavelength	Power	Diameter	Medium	Fiber grating
1558.842	-40.905	Straight line	Sucrose 60%	40
1559.158	-38.228	Straight line	Sucrose 65%	
1554.105	-37.016	Straight line	Sucrose 70%	
1538.079	-32.198	Free style bending 9cm	Sucrose 60%	
1539.263	-28.569	Free style bending 9cm	Sucrose 65%	
1539.303	-26.858	Free style bending 9cm	Sucrose 70%	
1539.263	-29.368	Petri dish bending 9.5cm	Sucrose 70%	

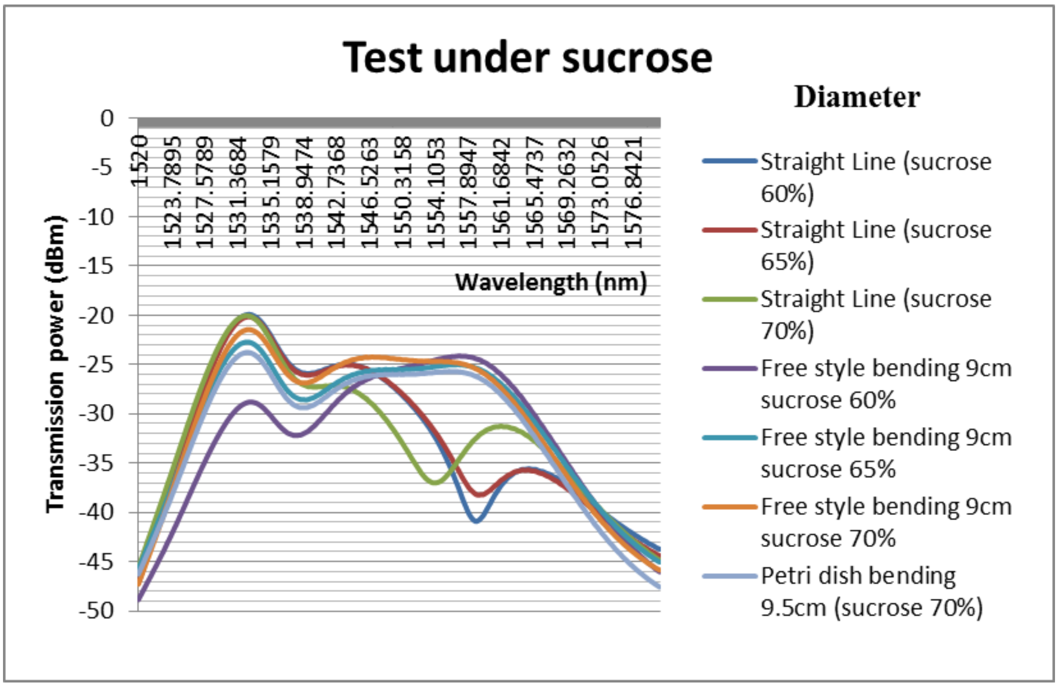


Figure 4.3-16: The weight with 14g and 40 number of grating period fiber was tested under sucrose condition with different bending structures

As show in Fig 4.3-16 shows the fiber with 40 number of grating period was tested under sucrose condition with different bending structures. Based on the Fig

4.3-16, the wavelength in the waveform from the straight line to free style bending and petri dish bending was shift to the left. Besides, 60% sucrose consist 1.43 of refractive index, 65% sucrose consist 1.43 of refractive index and 70% sucrose consist of 1.45 of refractive index. Hence, with higher concentration of sucrose will gives the better result.

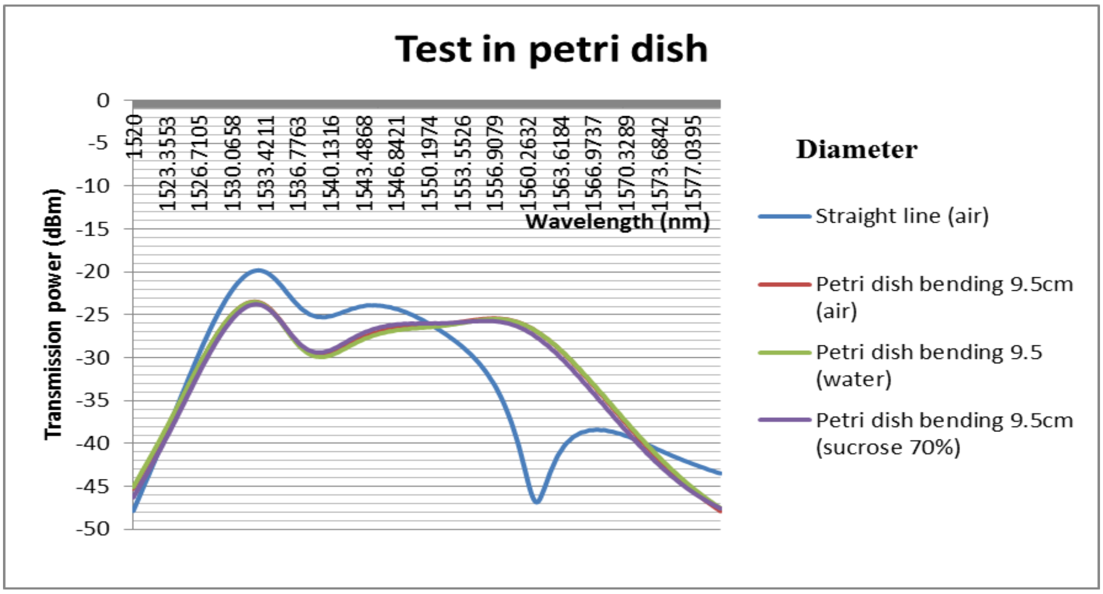


Figure 4.3-17: The weight with 14g and 40 number of grating period fiber was tested in petri dish

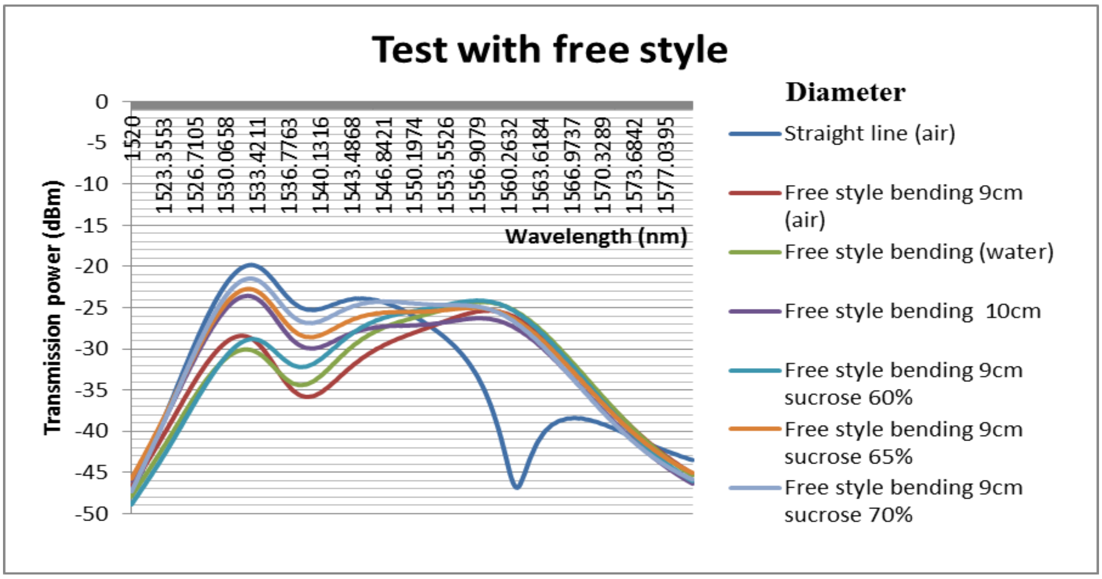


Figure 4.3-18: The weight with 14g and 40 number of grating period fiber was tested with free style in plastic sheet

Fig 4.3-17 show the result which the fiber bending in the petri dish and Fig 4.3-18 show the test with free style in plastic sheet was test under air, water, and sucrose condition. Based on the waveform, the free style bending method have higher sensitivity compare to bending in petri dish.

4.4 Comparison between 18, 29 and 40 Grating

4.4.1 Transmission Loss

Table 4.4-1: Power loss from straight line to bending method

grating	*straight line power*	*bending power*	*Different (straight line power – bending power)*
18	-49.037dBm	-29.352dBm	-19.685dBm
29	-51.163dBm	-32.271dBm	-18.892dBm
40	-46.855dBm	-35.826dBm	-11.029dBm

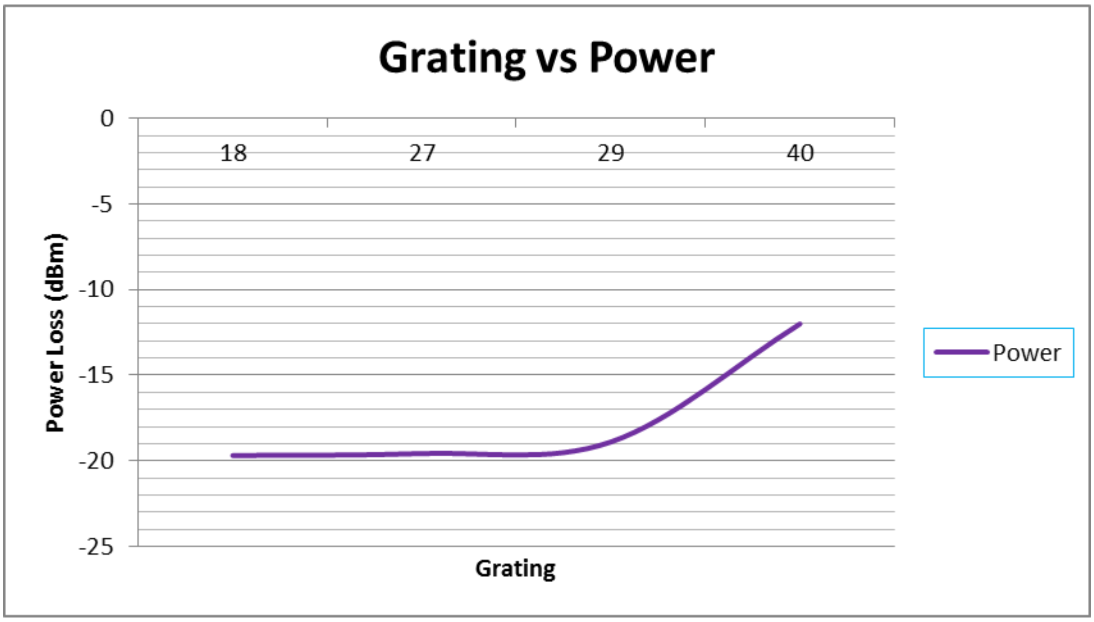


Figure 4.4-1: Power loss has been measure from straight line to bending method in different grating. More grating has lower transmission loss

As Fig 4.4-1 shown the comparison the transmission loss between straight line with bending within the grating period of 18, 29 and 40. Based on the Fig 4.4-1 and Table 4.4-1, with number of 18 grating the power losses was -19.685dBm. Moreover, with number of 29 grating the power losses have slightly decreased which the transmission loss was -18.892dBm. However, with number of 40 grating has lower transmission loss because it only observed with -11.029dBm power loss. Therefore, more grating will get higher sensitivity due to the lower transmission losses.

4.4.2 Wavelength

Table 4.4-2: Wavelength from straight line to bending method

grating	***straight line wavelength***	***bending wavelength***	***Different (straight line wavelength – bending wavelength)***
18	1565.158nm	1538.553nm	26.605nm
29	1562.434nm	1538.868nm	23.566nm
40	1561.25nm	1538.908nm	22.342nm

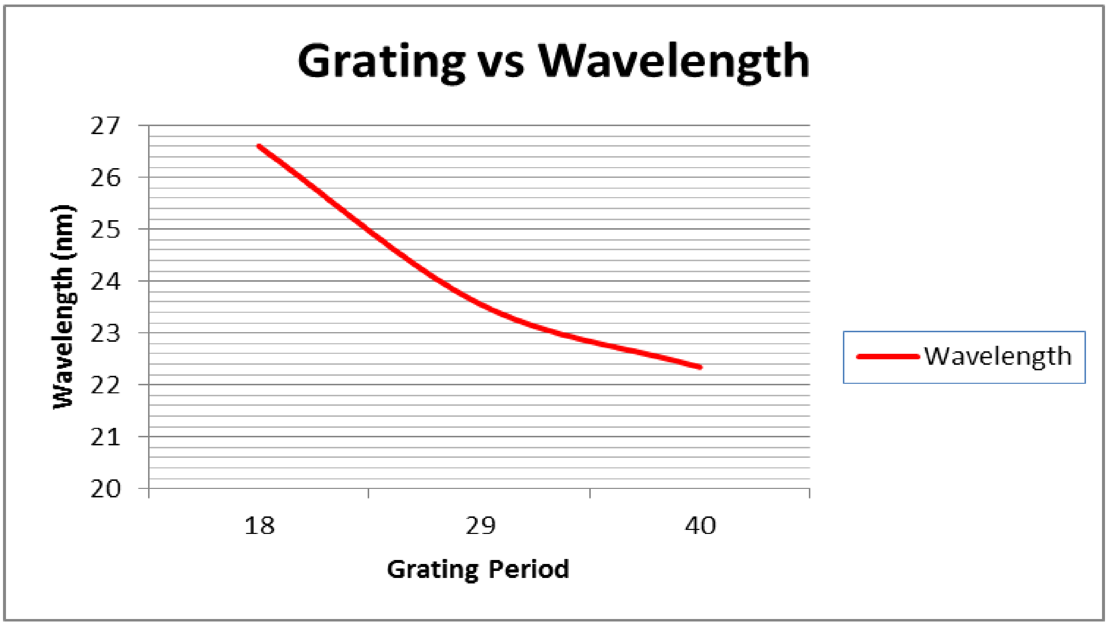


Figure 4.4-2: Wavelength has been measure from the straight line to bending method. Less grating has larger shift

As Fig 4.4-2 show the comparison wavelength shifted between the straight line with bending within the grating period of 18, 29 and 40. Based on the Fig 4.24-2and Table 4.4-2, with number of 18 grating the wavelength was shift to left about 26.605nm. Moreover, with number of 29 grating the wavelength was shifted to left with 23.566nm. However, with number of 40 grating has lower gap wavelength shifted because it only observed with 22.342nm. Hence, after implement the bending method which less grating will have more moving gap in the wavelength.

4.4.3 The waveform between 18, 29, 40 (under air & water)

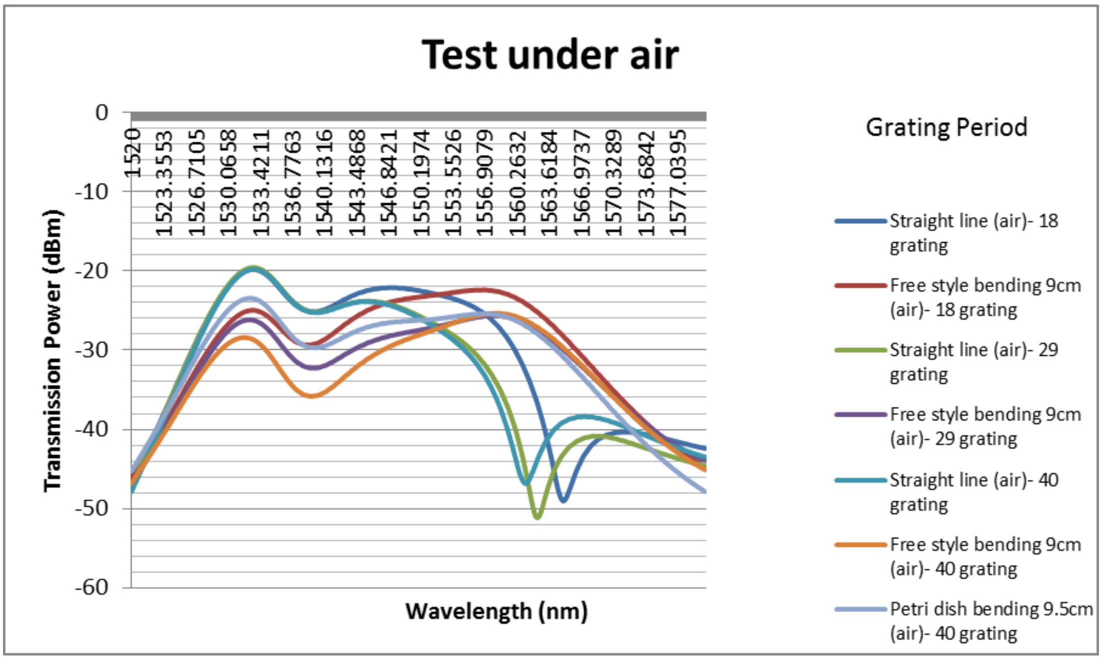


Figure 4.4-3: The number of 18, 29 and 40 grating has used to test under air condition in straight line and bending method

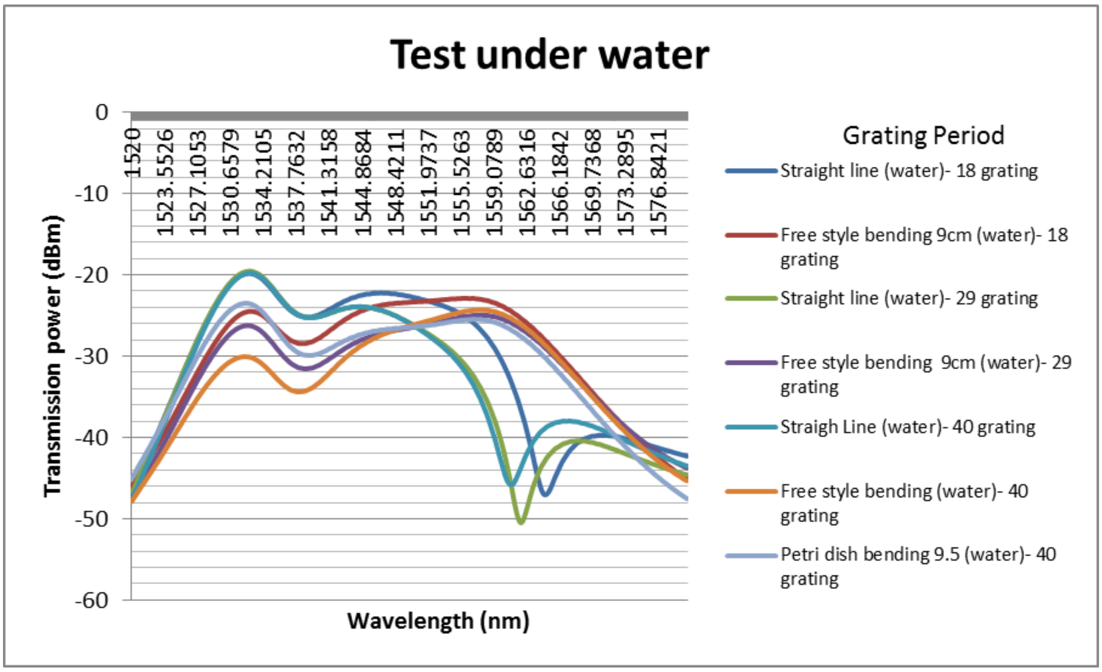


Figure 4.4-4: The number of 18, 29 and 40 grating has used to test under air condition in straight line and bending method.

Table 4.4-3: The 18, 29, 40 number of grating test under air and water condition

Fiber grating	Wavelength (nm)	Power (dBm)	Diameter	Medium	Wavelength shifted (air to water) $\delta\lambda = \lvert \lambda water - \lambda air \rvert$
18	1565.158	-49.037	Straight line	Air	0.474nm
	1564.684	-47.056	Free style bending 9cm	Water	
	1538.553	-29.352	Straight line	Air	0
	1538.553	-28.456	Free style bending 9cm	Water	
				Efficiency (%)	$\frac{0.474-0}{0.474}$ x 100 = 1
29	1562.434	-51.163	Straight line	Air	0.355nm
	1562.079	-50.496	Free style bending 9cm	Water	
	1538.868	-32.271	Straight line	Air	0.118nm
	1538.75	-31.552	Free style bending 9cm	Water	
				Efficiency (%)	$\frac{0.355-0.118}{0.335}$ x 100 = 0.6
40	1561.25	-46.855	Straight line	Air	0.276nm
	1560.974	-45.818	Free style bending 9cm	Water	
	1538.908	-34.856	Straight line	Air	0.829nm
	1538.079	-35.615	Free style bending 9cm	Water	
				Efficiency (%)	$\frac{0.276-0.829}{0.276}$ x 100 = 2

Both Fig 4.4-3 and Fig 4.4-4 were shown the waveform test under air and water between 18, 29 and 40 grating. By comparing the wavelength of 40 grating from the air to water, straight line was shift left 0.276 nm and the bending was shift left 0.829 nm. So percentage was increment of 2 times than straight line. Therefore, the 40 number of grating have higher sensitivity compare 18 and 29 grating even test in straight line or bending method.

4.5 22g with 33 Grating Period

Table 4.5-1: Fiber with 33 grating period with 22g test under air and water condition

Wavelength	Power	Diameter	Medium	Fiber grating
Out of range	Out of range	Straight line	Air	33
Out of range	Out of range	Straight line	Water	
-	-	Free style 9cm	Air	
-	-	Free style 9cm	Water	
-	-	Petri dish 9.5cm	Air	
-	-	Petri dish 9.5cm	Water	

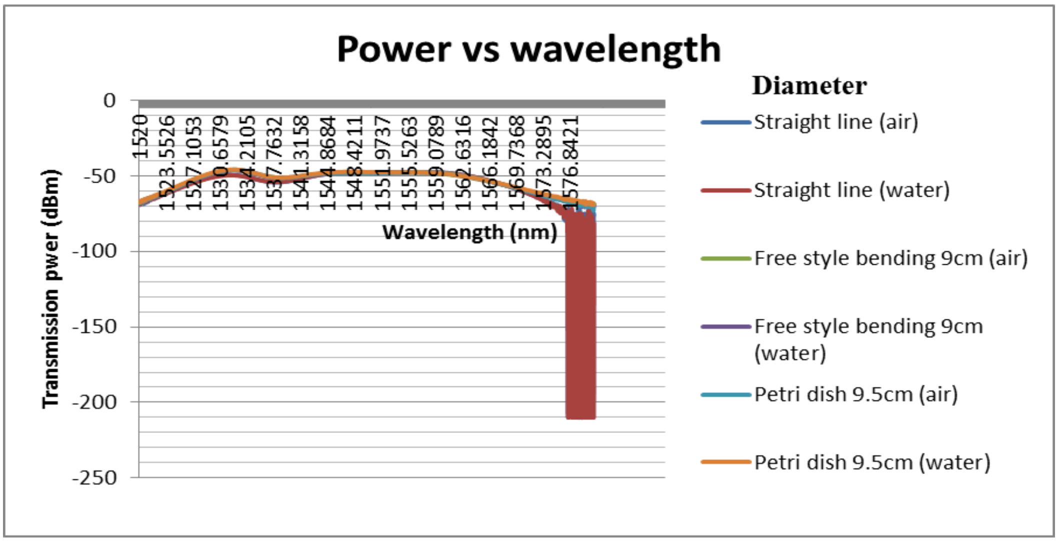


Figure 4.5-1: Fiber with 33 grating period with 22g test under air and water condition with different bending structures

As shown in Fig 4.5-1, the 33 number of grating period fiber was tested under air and water condition with different bending structures. This fiber was not suitable to use for testing due to the notch already out of range. Because the wavelengths range for the SMF-28 standard fiber is around 1500nm until 1600nm only.

4.6 22g with 25 Grating Period

Table 4.6-1: Fiber with 25 grating period with 22g test under air and water condition

Wavelength	Power	Diameter	Medium	Fiber grating
1541.553	-45.988	Straight line	Air	25
1541.632	-45.322	Straight line	Water	
1539.618	-32.236	Free style 9cm	Air	
1539.54	-33.229	Free style 9cm	Water	
1539.382	-32.45	Petri dish 9.5cm	Air	
1539.658	-32.252	Petri dish 9.5cm	Water	

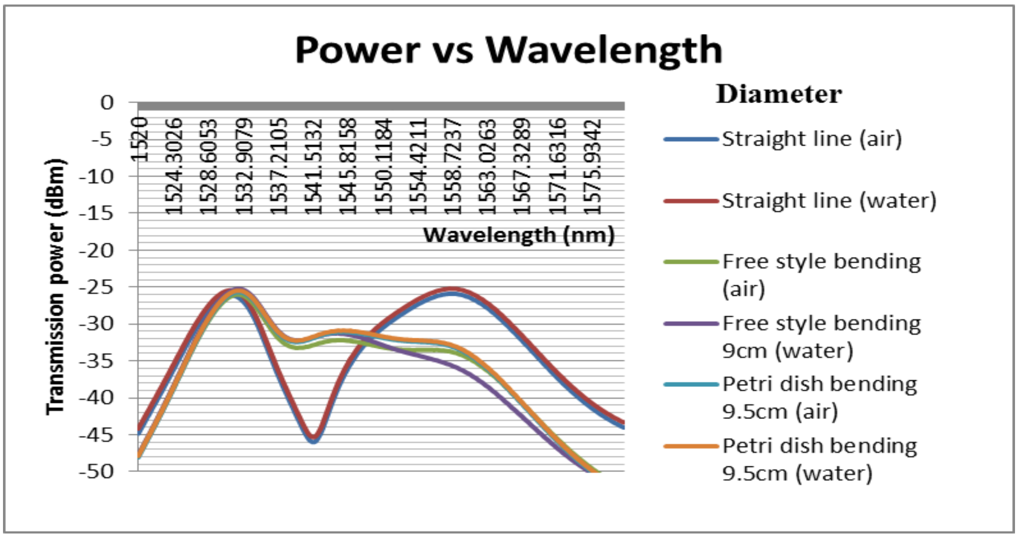


Figure 4.6-1: Fiber with 25 grating period with 22g test under air and water condition with different bending structures

This Fig 4.6-1 shows the 25 number of grating period fiber was tested under air and water condition with different bending structures. As compare the waveform between straight lines tests under air condition with straight line test under water condition where the wavelength has move to right about 0.079nm. Moreover, when testing with the bending structures the result does not have observe significant notch. Hence, this fiber did not suitable to use in the bending structure.

4.7 22g with 57 Grating Period

Table 4.7-1: Fiber with 57 grating period with 22g test under air and water condition

Wavelength	Power	Diameter	Medium	Fiber grating
1543.2	-72.206	Straight line	Air	57
1542.8	-71.111	Straight line	Water	
-	-	Free style 9cm	Air	
-	-	Free style 9cm	Water	
-	-	Petri dish 9.5cm	Air	
-	-	Petri dish 9.5cm	Water	

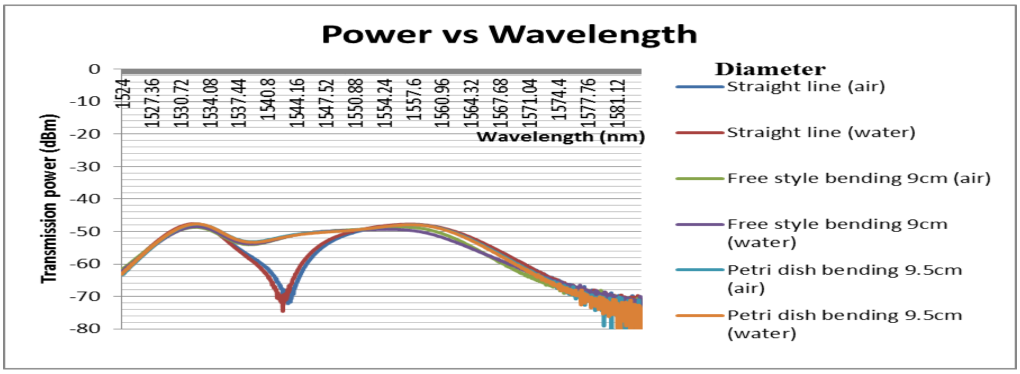


Figure 4.7-1: Fiber with 57 grating period with 22g test under air and water condition with different bending structures

This Fig 4.7-1 shows the 57 number of grating period fiber was tested under air and water condition with different bending structures. By comparing the notch between the waveform from air to water in straight line just shift left about 0.4nm. But when implement in bending method, this fiber did not have good response.

4.8 Discussion

SMF-28 model of fiber has been used in this project. Basically, this fiber has low attenuation with the wavelength ranges from 1500nm to 1600nm. Fabrication process is the one of the important part in this project. Because during cleaning process, must ensure that the fiber has been cleaned out the dust or contaminants block the propagation of light then only able to proceed the next step. However, the weight that tied to the fiber which able to effect the number of gratings formation. In addition, with heavy weight will perform with less number gratings period to get the notch. In other hand means, the number of grating increased with the lighter weight applied.

During testing on bending method in petri dish, fiber with uncoated part will easily broke when put in smaller diameter of petri dish. So to prevent this issue happen, use the reject fiber to try in different diameter of petri dish. Therefore, with larger size of diameter would be better to use in this project. Every times testing the bending in petri dish, the grating part must put in the center so it can enhance the sensitivity of bending structures. In this method, the changes are very small when test under different medium.

For testing bending method with free style in plastic sheet, it could be adjust with any bending structures. Besides, Every times testing the bending in plastic sheet, the grating part must put in the center so it can enhance the sensitivity of bending structures. Result has been repeated for few times to verify that bending curvatures will able to gives the same waveform. However, in this method can clearly see how the notch was performing under different type of medium.

Based on the result, after comparing the notch from straight line to bending method which can clearly observe that the wavelength would shift to left side and the power shifted to upper due to the changing mode. The reason is when the fiber bent in some critical angle, it will relate to the cladding mode and way of incident angle. Hence, this effect will increase the depth of bending curvatures would affect to the coupled mode and increase the optical radiation that interacts with medium in surrounding.

For different type of medium, the result was obtained in different wavelength and power. The refractive index of air, water and sucrose 60%, 65%, 70% is 1, 1.33, 1.43, 1.44 and 1.45 respectively. By comparing the fiber under the air, water and sucrose, fiber test under sucrose 70% always has better performance compare with other medium. Therefore, with higher of refractive index would give better performance.

By compare the 18, 29 and 40 number of grating periods. The result was observed that with number of 40 grating has lower transmission loss because it only observed with -11.029dBm power loss. While 29 of grating were obtain with -18.892dBm power loss and 18 of grating have -19.685dBm power loss. Therefore, more grating will get higher sensitivity due to the lowest transmission loss.

Some precaution has been taken in this project. Since the core of the fiber was making with the glass so during fabrication process or testing process those uncoated part of the fiber must place in proper way so that the core of fiber did not easily broken. When testing under water or sucrose condition, all of this medium must put on the grating part of fiber so there only have sensitivity response against fiber.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, fabrication process is one of the critical stage to get the designed LPFG for bending test. With the good control of fabrication process, LPFG with different number of gratings through the changing of weight applied on the fiber was obtained. This will able to study the effect of number of gratings on bending fiber for refractive index testing and also perform the comparison with the straight line on the same fiber.

In this project, it was proved that the bending method will have higher sensitivity as compared with straight line in SMF-28 fiber. In the result, it shown that 40 number of gratings was achieved with two times higher sensitivity than straight line. In addition, with the increment of number of gratings period for LPFG, it would get better performance due to the less transmission losses.

5.2 Recommendations

It is recommended to further study the bending configuration for LPFG fabricated under weight of 18g and 20g whether it would demonstrate with the same response. Since the position of bending curvatures in petri dish was fixed, it would give the more accuracy of notch. So implement the bending curvatures in smaller diameter of petri dish as they should able to get the better performance. Besides, it is suggested to continue the testing with higher number of grating as 45 and 50 with 14g.

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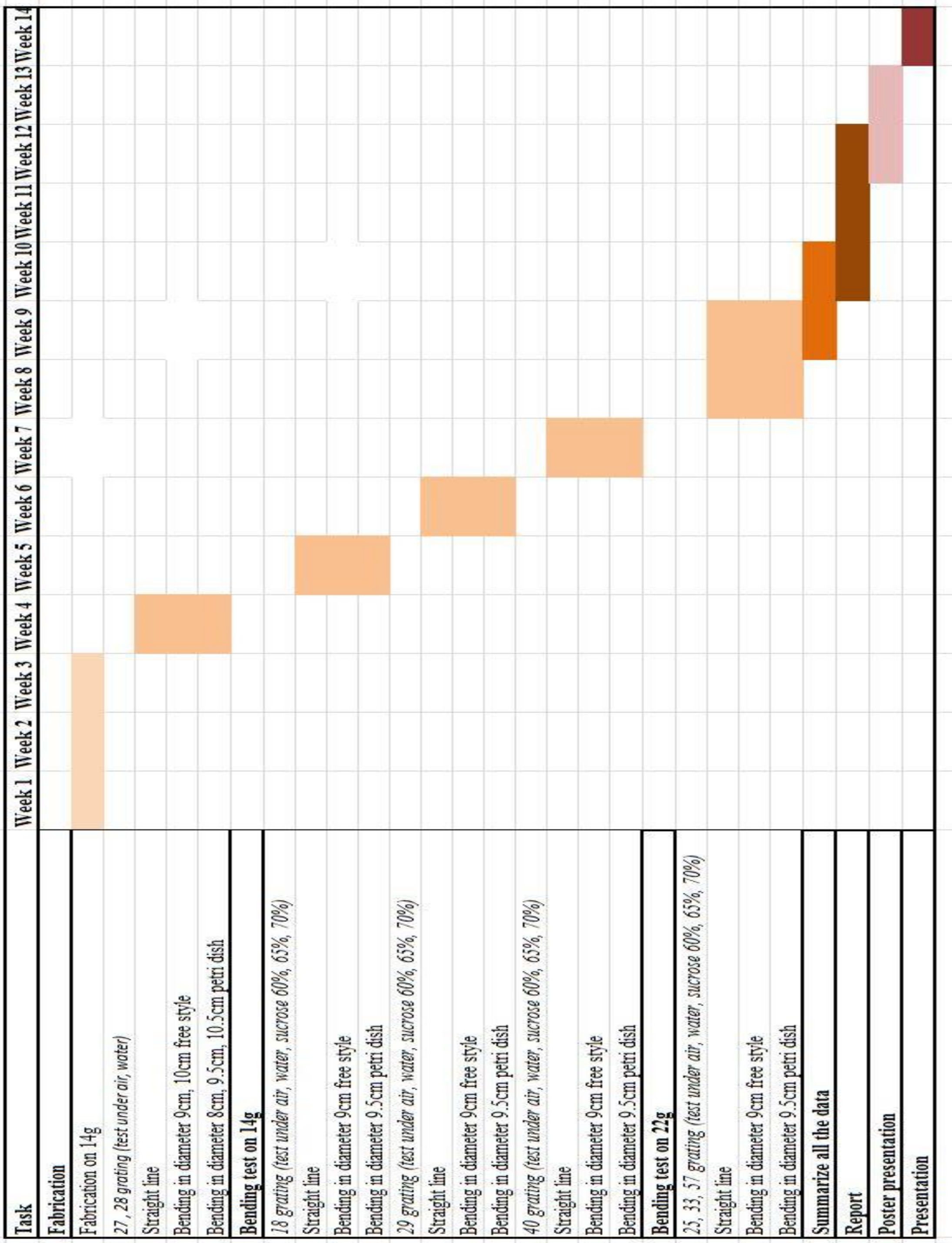
APPENDICES

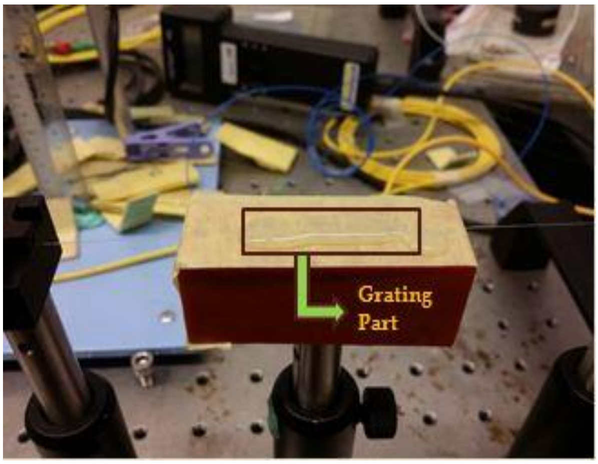
APPENDIX A: Gantt chart ***(FYP 1 Progress)***

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project proposal														
Research project														
Project work (Fabricate at long wavelength only)														
Report submission														
Presentation														

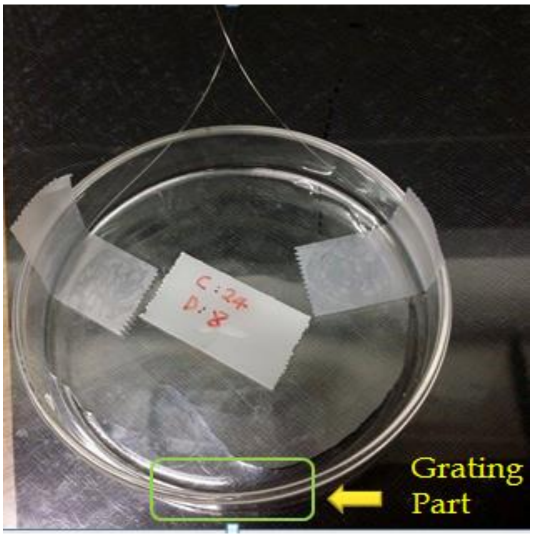
APPENDIX B: Gantt chart ***(FYP 2 Progress)***



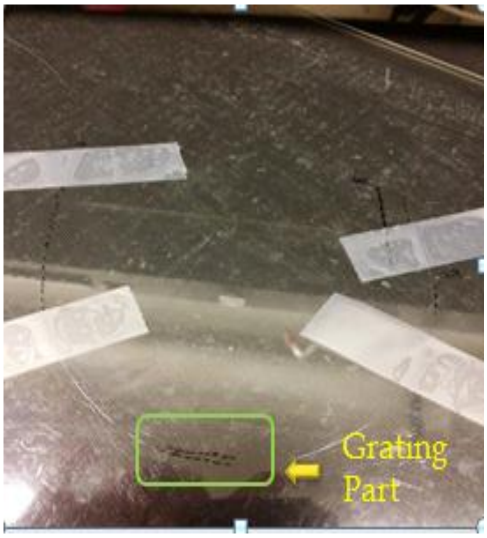
APPENDIX C: Testing Method



Test in straight line



Bending test in Petri Dish



Bending test in Plastic Sheet