Faculty of Electronics and Computer Technology and Engineering

MICROFIBER SINGLE LOOP RESONATOR FOR LIQUID SENSOR

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Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

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A project report submitted
in partial fulfillment of the requirements for the degree of
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DEDICATION

To my beloved mother, Lohambal, and father, Elango,
For their Love, Sacrifice, Encouragement and best wishes
along with my hardworking and respected supervisor,
Dr. Md Ashadi Bin Md Johari

ABSTRACT

This project explores the potential of a microfiber single loop resonator as a liquid sensor. The study focuses on using light sources with wavelengths of 1550nm and 1310nm, which fall within the acceptance wavelength range. The sensor is designed by tapering the fiber to create a microfiber and forming it into a single loop shape. The transmission of light through the sensor is influenced by the total internal reflection phenomenon, which is dependent on the transmitted spectral wavelength. A wide range of liquid levels, spanning from 0ml to 10ml, is employed for analysis. The performance of the microfiber loop resonator is evaluated in terms of sensitivity and linearity through transmitted power analysis. The results indicate that the sensor exhibits excellent performance in liquid sensing, making it a promising solution for concentration measurement applications.

ABSTRAK

Projek ini meneroka potensi penggunaan resonator gelung tunggal mikrofiber sebagai pengesan cecair. Kajian ini memberi tumpuan kepada menggunakan sumber cahaya dengan panjang gelombang 1550nm dan 1310nm, yang berada dalam julat panjang gelombang yang boleh diterima. Pengesan direka bentuk dengan meniruskan serat untuk membentuk mikrofiber dan membentuknya menjadi bentuk gelung tunggal. Transmisi cahaya melalui pengesan dipengaruhi oleh fenomena pantulan dalaman sepenuhnya, yang bergantung kepada panjang gelombang spektral yang dipancarkan. Pelbagai aras cecair yang meliputi dari 0ml hingga 10ml digunakan untuk analisis. Prestasi resonator gelung mikrofiber dinilai dari segi kepekaan dan keberkesanan melalui analisis kuasa yang dipancarkan. Keputusan menunjukkan bahawa pengesan ini menunjukkan prestasi yang sangat baik dalam pengesanan cecair, menjadikannya penyelesaian yang berpotensi untuk aplikasi pengukuran kepekatan.

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CHAPTER 1

INTRODUCTION

1.1 Background

Microfiber resonators have emerged as a promising technology for various sensing applications due to their high sensitivity, compact size, and low cost. Among the diverse range of sensing applications, liquid sensing plays a crucial role in fields such as environmental monitoring, chemical analysis, and biomedical diagnostics. The ability to accurately detect and analyze different liquid samples is the great importance in ensuring the safety and quality of various substances.

The microfiber single loop resonator represents an innovative approach to liquid sensing, leveraging the unique properties of microfiber structures to achieve high-performance detection and characterization of liquids. These resonators are typically fabricated by tapering down a section of optical fiber to a submicron diameter, creating a waveguide that can confine and interact with light at the nanoscale level. This microfiber structure is then formed into a loop configuration, allowing for efficient sensing process and interaction along the resonator.

The key principle behind the operation of a microfiber single loop resonator for liquid sensing is the strong evanescent field interaction between the guided light and the surrounding liquid medium. As light propagates through the microfiber, a portion of its power extends beyond the fiber boundary, interacting with the liquid sample. This interaction leads to changes in the optical properties of the resonator, such as the refractive index and absorption characteristics, which can be precisely measured and correlated to the properties of the liquid under investigation.

The design and fabrication of microfiber single loop resonators for liquid sensing require careful consideration of several factors. The choice of materials for the microfiber, such as silica or specialty glasses, determines the optical properties and compatibility with different liquid samples. The diameter and length of the microfiber also play a crucial role in determining the sensitivity and response time of the resonator. Additionally, the integration of microfiber resonators with other components, such as light sources and detectors, enables a complete sensing system capable of real-time analysis.

The unique advantages offered by microfiber single loop resonators make them highly suitable for a wide range of liquid sensing applications. They exhibit excellent sensitivity, allowing for the detection of minute changes in the refractive index or concentration of analytes in a liquid sample. Furthermore, their compact size enables integration into miniaturized sensor platforms, facilitating portable and on-site measurements. Additionally, their low cost and compatibility with mass production techniques make them a viable option for large-scale deployment in various industries.

In conclusion, this project on the potential of a microfiber single loop resonator as a liquid sensor can contribute to addressing global issues in several ways which is environmental Monitoring, Health and Safety, and Industrial Applications. Microfiber single loop resonators represent a promising technology for liquid sensing applications. Their ability to exploit the evanescent field interaction with the surrounding liquid medium offers high sensitivity and enables precise characterization of different liquid samples. As further advancements in fabrication techniques and system integration are made, microfiber single loop resonators hold great potential for revolutionizing liquid sensing in fields ranging from environmental monitoring to biomedical diagnostics.

1.2 Problem Statement

The problem statement of this project are as follows:

a) There is a scarcity of liquid sensing equipment available in the market.

b) The currently available options primarily rely on electronic devices, which tend to have a shorter lifespan.

c) Fiber optic technology offers a more reliable and durable solution, providing more accurate results in liquid sensing applications.

1.3 Project Objective

The main goal of this project is to develop an effective and appropriate approach for evaluating system-wide liquid sensors with satisfactory accuracy by utilizing a single loop fiber distribution network. The objectives are as follows:

a) To study the operation of Fiber Optic Liquid Sensor.

b) To develop the microfiber single loop resonator for liquid sensor.

c) To optimize the performance of liquid sensor by Microfiber Single loop Resonator with different level of concentration.

1.4 Scope of Project

The scope of this project are as follows:

a) Design by tapering the fiber into microfiber and turn them into single loop form.

b) Testing with different level of concentration.

c) Comparing the result of different level of concentration.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The development of high-performance liquid sensors is of significant interest in various fields, including environmental monitoring, biomedical diagnostics, and industrial processes. In recent years, microfiber single loop resonators have emerged as a promising platform for liquid sensing applications. Microfiber single loop resonators offer numerous advantages, such as high sensitivity, compact size, and compatibility with microfluidic system. The literature surrounding the use of microfiber single loop resonators as liquid sensors has witnessed significant growth, with researchers exploring their fundamental principles, fabrication techniques, and potential applications.

This literature review aims to provide a comprehensive overview of the research conducted on microfiber single loop resonators based liquid sensors. By analyzing the existing body of knowledge, this review seeks to identify the key findings, advancements, and challenges in this field. The review will encompass studies that investigate the design and optimization of microfiber single loop resonators structures, the techniques employed for fabrication, and the characterization of their sensing capabilities. Additionally, this review will explore the various types of liquid analytes that have been investigated using microfiber single loop resonators, along with the reported sensing mechanisms and detection methods.

Through the systematic analysis and synthesis of relevant literature, this review aims to shed light on the current state-of-the-art in microfiber single loop resonators based liquid sensing and provide valuable insights for researchers and practitioners in this field.

Furthermore, it will identify potential areas for future research and highlight the opportunities and challenges that lie ahead in harnessing the full potential of microfiber single loop resonators for liquid sensing applications.

Overall, this literature review will serve as a comprehensive resource for researchers, engineers, and professionals interested in the development and application of microfiber single loop resonators for liquid sensing. By consolidating the existing knowledge and highlighting the research gaps, this review will contribute to the advancement of this field and inspire further innovation in the design and utilization of microfiber single loop resonators for liquid sensing purposes.

2.2 Fiber Optic

Fiber optics refers to a technology that utilizes thin strands of glass or plastic called optical fibers to transmit light signals over long distances and at high speeds [1]. These optical fibers are designed to carry optical signals in the form of light pulses, which can transmit vast amounts of data over significant distances with minimal loss and interface. The structure of a fiber optic cable typically consists of three primary components:

- Core: The core is the central part of the optical fiber through which light signals travel. It is usually made of high-purity glass or plastic material and has a very small diameter, typically around 9 to 125 micrometers [2]. Typical glass cores range from as small as 3.7 micrometer up to 200 micrometer [3]. The core is designed to guide and transmit light signals along its length through a process called total internal reflection.
- Cladding: Surrounding the core is the cladding, which is made of a material with a lower refractive index than the core. The cladding helps to confine the light within the core by reflecting the light back into the core through total internal reflection[3].

This prevents the light from escaping or being absorbed by the, thus maintaining signal integrity [4].

- Buffer/Coating: The outermost layer of the fiber optic cable is the buffer or coating, which serves as a protective layer for the fiber . It provides mechanical strength, insulation, and resistance to environmental factors such as moisture, temperature, and abrasion [4]. The buffer can be made of materials like acrylate, silicone, or polyimide, depending on the specific application and environment [3].

The fundamental principle of fiber optics relies on the principle of total internal reflection. When light enters the core of the optical fiber at a certain angle, it undergoes multiple internal reflections within the core, bouncing off the cladding. This continuous reflection allows the light to travel through the fiber with minimal loss and without significant degradation. Glass fiber offers some benefits as a tiny tube, including superior.

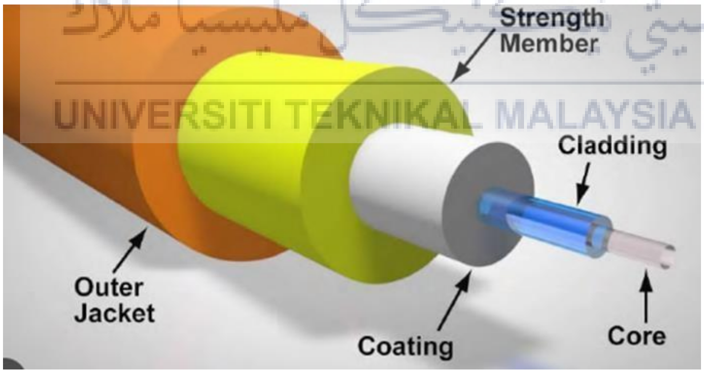

Figure 2.1 : Structure of Fiber Optic[1]

2.2.1 Single Mode

Single-mode fiber optic refers to a type of optical fiber that allows the transmission of a single mode or path of light at a time. Unlike multimode fiber, which supports multiple light modes, single-mode fiber has a smaller core diameter and is designed to propagate a single mode of light with high fidelity over long distances [5].

In single-mode fiber, the core diameter is typically around 8 to 10 micrometers, much smaller than the core diameter of multimode fiber.This small core size enables the transmission of light in a single mode, which reduces the occurrence of modal dispersion and allows for higher data rates and longer transmission distances.

The concept of single-mode transmission is based on the principle of total internal reflection, similar to multimode fiber. However, due to the smaller core size, single-mode fiber restricts light propagation to a narrow beam, resulting in a more direct and focused light path [6]. This minimizes the dispersion of the transmitted light pulses and reduces signal degradation, enabling single-mode fiber to achieve higher bandwidth and longer transmission distances compared to multimode fiber. Single-mode fiber optics offer several advantages and applications:

- Longer Transmission Distances: Single-mode fiber can transmit signals over much longer distances compared to multimode fiber. The reduced modal dispersion in single-mode fiber allows for higher transmission speeds and minimal signal loss, making it suitable for long-haul communications, such as telecommunication networks and undersea cables.
- Higher Bandwidth: Single-mode fiber provides higher bandwidth capacity compared to multimode fiber. It supports higher data rates and is commonly used in high-speed applications, such as long-distance data transmission, video streaming, and backbone networks.
- Enhanced Signal Quality: The narrow and focused light path in single-mode fiber minimizes signal degradation and improves signal quality. This results in lower

attenuation (signal loss) and lower levels of dispersion, ensuring reliable and high-quality signal transmission.

- Compatibility with Wavelength-Division Multiplexing (WDM): Single-mode fiber is compatible with wavelength-division multiplexing (WDM) technology, which allows multiple wavelengths of light to be transmitted simultaneously over a single fiber. This enables the transmission of multiple independent data streams, significantly increasing the overall capacity of the fiber.

It is important to note that single-mode fiber requires more precise alignment and specialized equipment for installation and termination compared to multimode fiber. This makes it slightly more expensive and complex to work with. However, the advantages of single-mode fiber in terms of longer reach and higher bandwidth make it the preferred choice for long-haul communications and high-capacity data transmission.

The choice between single-mode and multimode fiber depends on the specific application requirements, budget constraints, and performance needs. Single-mode fiber is typically used in applications that demand high data rates, long transmission distances, and excellent signal integrity.

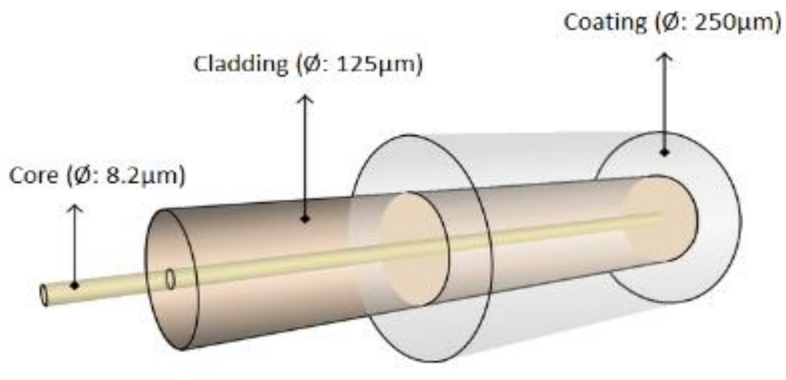

Figure 2.2 : Structure of single-mode fiber

2.2.2 Multimode

Multimode optical fiber was the first to be created and marketed, simply referring to how many modes or light beams support each other through a waveguide at the same time. Multimode fiber optic refers to a type of optical fiber that is designed to transmit multiple light modes or paths simultaneously [7]. In multimode fiber, the core diameter is larger compared to single-mode fiber, typically ranging from 50 to 62.5 micrometers. This larger core size allows for the propagation of multiple light modes.

The concept of multimode transmission is based on the principle of different light paths or modes traveling through the core of the fiber at slightly different angles. These modes can bounce off the walls of the core and the cladding, leading to a phenomenon known as modal dispersion. Modal dispersion is the spreading out of the light pulses as they travel through the fiber, which can limit the distance and data rates achievable in multimode fiber compared to single-mode fiber. There are two main types of multimode fiber:

- Step-Index Multimode Fiber: In step-index multimode fiber, the core has a uniform refractive index throughout its diameter. This means that the refractive index abruptly changes at the core-cladding interface. Step-index multimode fiber is commonly used for shorter distance applications, such as local area networks (LANs) and data centers.
- Graded-Index Multimode Fiber: Graded-index multimode fiber has a core with a varying refractive index, gradually decreasing from the center to the periphery. This refractive index profile helps to reduce modal dispersion by allowing the light to travel at different speeds depending on its position within the core. Graded-index multimode fiber is often used for medium-range applications, such as campus networks and video distribution [8].

Multimode fiber optics offer several advantages and applications:

- Cost-effectiveness: Multimode fiber is generally more affordable compared to single-mode fiber. This makes it a cost-effective option for shorter-distance applications where the higher data rates of single-mode fiber are not necessary.
- Ease of Installation: The larger core size of multimode fiber makes it easier to work with during installation and termination. It allows for a wider alignment tolerance, simplifying the connectorization process.
- Shorter Reach: Multimode fiber is typically used for shorter distance applications, typically up to a few kilometers. It is commonly employed in LANs, building backbones, and data center interconnections.
- Data Transmission: Multimode fiber can support a range of data transmission rates, including Gigabit Ethernet, 10 Gigabit Ethernet, and beyond. While the maximum data rates and reach are limited compared to single-mode fiber, multimode fiber still provides ample bandwidth for many applications.

It is important to note that multimode fiber has limitations in terms of distance and achievable data rates compared to single-mode fiber. Therefore, when longer distances or higher data rates are required, single-mode fiber is typically used. The choice between multimode and single-mode fiber depends on the specific application, budget constraints, and performance requirements.

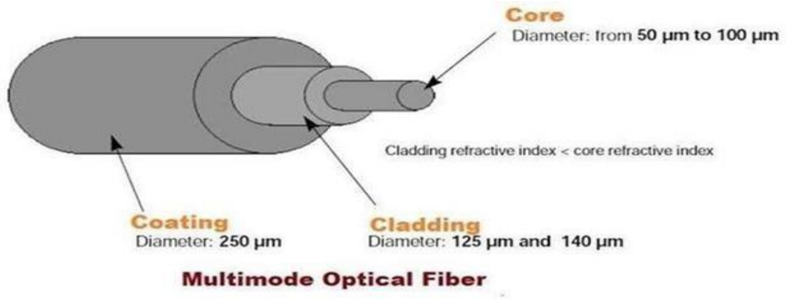

Figure 2.3 : Multimode Optical fiber

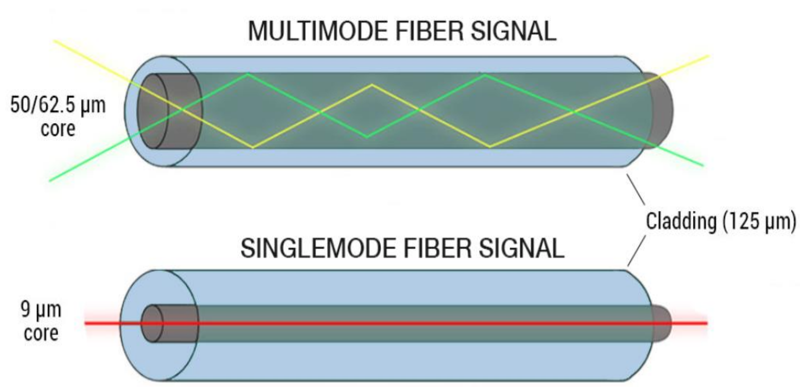

Figure 2.4 : Difference between Mutimode and Single mode fiber

2.2.3 Propagation of Light among a fiber

The propagation of light in a fiber optic cable involves the transmission of light signals through the core of the fiber, guided by the principle of total internal reflection. In fiber optics, the information carrier is a light beam that travels at a speed of 3x108ms, which is far faster and more efficient than electronics in an electric current. The core of the fiber, typically made of glass or plastic, has a higher refractive index than the surrounding cladding, which allows for the confinement and efficient transmission of light [9]. Here's a step-by-step explanation of how light propagates through a fiber optic cable:

- Injection of Light: Light signals are injected into one end of the fiber optic cable using a light source, such as a laser or LED. The light travels through the core of the fiber, guided by the refractive index difference between the core and cladding.
- Total Internal Reflection: As the light enters the core, it encounters the core- cladding interface. Due to the higher refractive index of the core, the light undergoes total internal reflection, meaning it reflects back into the core rather than being refracted out into the cladding. This reflection occurs because the light hits the interface at an angle greater than the critical angle, which is determined by the refractive index difference between the core and cladding.

- Multiple Total Internal Reflections: The light continues to bounce off the core-cladding interface as it propagates along the length of the fiber. Each reflection ensures that the light remains confined within the core and undergoes minimal loss or dispersion.
- Single-Mode or Multimode Propagation: Depending on the type of fiber optic cable (single-mode or multimode), the light can propagate in different ways. In single-mode fiber, the core diameter is small enough to support the transmission of a single mode of light, resulting in a tightly focused beam with minimal dispersion. In multimode fiber, the larger core diameter allows for the propagation of multiple modes, resulting in a broader beam that may experience some dispersion over long distances.
- Signal Attenuation: As the light propagates through the fiber, it experiences some attenuation, which is the gradual loss of signal strength due to factors like absorption, scattering, and bending losses. However, optical fibers are designed to minimize attenuation and allow for long-distance transmission of light signals.
- Reception of Light: At the receiving end of the fiber optic cable, a photo detector or receiver converts the transmitted light signals back into electrical signals. The receiver interprets these electrical signals and can process them further for various applications such as data transmission, telecommunications, or sensing.

The propagation of light in a fiber optic cable allows for the efficient and reliable transmission of data, voice, or video signals over long distances. The principle of total internal reflection ensures that the light remains confined within the core, minimizing signal loss and maintaining signal integrity throughout the transmission [10]. The use of fiber optics has revolutionized telecommunications, internet connectivity, and many other fields by providing high-speed, high-bandwidth, and low-loss transmission capabilities.

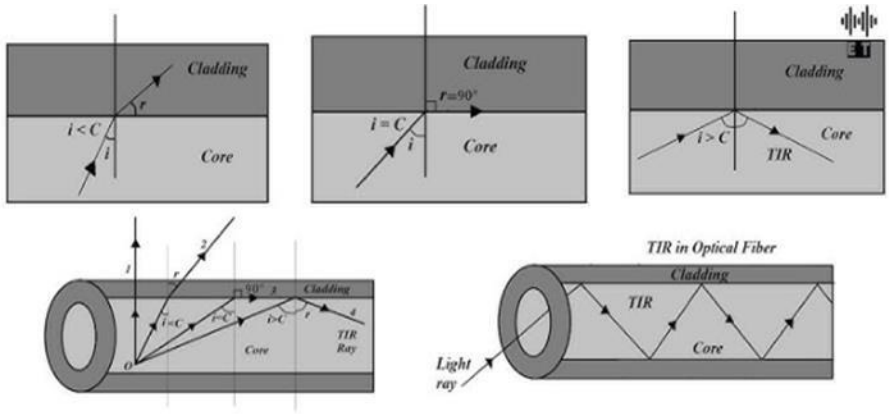

Figure 2.5 : Light propagation in optical fiber

2.2.4 Reflective and Refractive

The notion of total internal reflection is used in fiber optics to collect the transmitted light and restrict it to the fiber's core. The speed at which light travels from one material to other changes, causing the light to change direction [11]. The refractive index measurement is one of the essential components of researching materials' physical, chemical, and biological properties. The intensity of light reflected from a surface is determined by the texture of the surface and the distance between it and the light source. The refractive index of glass or other optical materials is a measurement of the speed of light in the material, and variations in the refractive index cause light to bend. According to Snell's law, as light propagates from one substance to another, the angle at which it reflects is determined by the refractive index of the two materials (core and cladding).

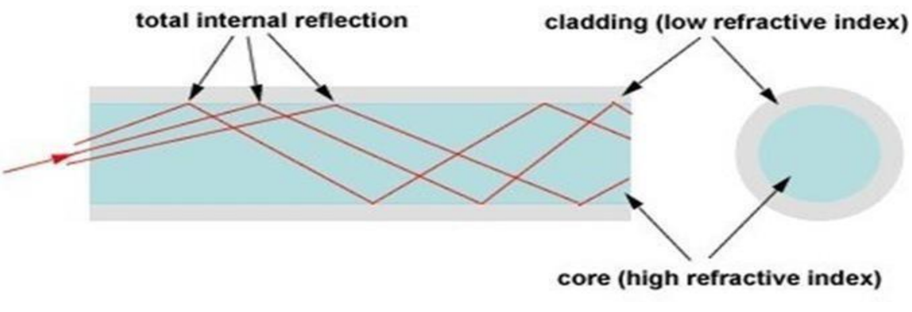

Figure 2.6 : Total Internal Reflection

2.2.5 Numerical Aperture

The light ray phenomenon inside the optic fiber core was previously explained. It is now time to grasp the concept of the amount of light that can be accepted at the optical fiber core's entrance before it can proceed into the core [12]. The acceptance angle, often known as the maximum angle, is the angle at which something is accepted. We calculate the numerical aperture (NA), the sine of the acceptance angle, a, to determine the capacity of light acceptance. According to the formula, the difference in refractive index between the core and the cladding is what determines NA [13].

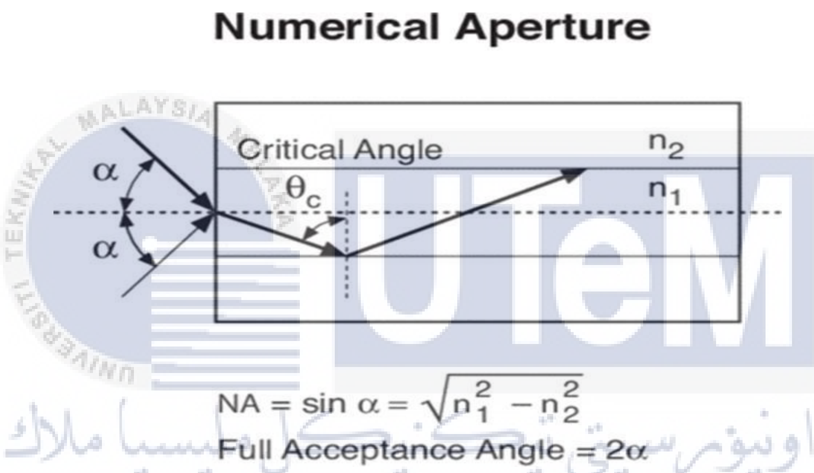

Figure 2.7 : Numerical Aperture of Optical Fiber

The equation from Figure 2.7 shows that a more considerable NA value corresponds to a larger acceptance angle, implying that more light rays are gathered. The acceptance cone or total acceptance angle will be twice as large as the acceptance angle. The efficiency of light coupling, which is occasionally necessary for implementing this technology, will benefit as the acceptance angle grows.

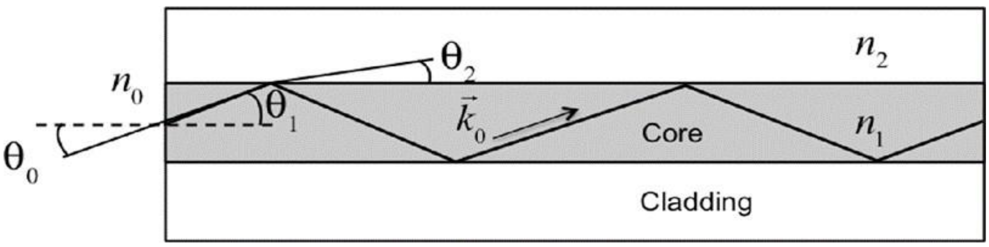

Figure 2.8 : The way light enters and propagates through an optical fiber core

Figure 2.8 shows that the medium count before entering the core was air, with n=1. When light strikes a core with a differing refractive index, it undergoes refraction and bends away from or toward the regular line, depending on the incidence angle. The total internal reflection (TIR) occurs in the core. In order for total internal reflection to occur, the angle at which light enters the denser medium must be larger than the critical angle of the denser medium in relation to the rarer medium [9].

2.3 Related Previous Project

2.3.1 High resolution and large sensing range liquid level measurement using phase-sensitive optic distributed sensor.

The article titled "High resolution and large sensing range liquid level measurement using phase-sensitive optic distributed sensor " by Liu et al. [14] discusses a study of a distributed optical fiber liquid level sensor using phase-sensitive optical time domain reflectometry (φ-OTDR) which is introduced for industrial monitoring applications.

The sensor offers a wide sensing range and high resolution. By leveraging the thermal optic effect, temperature changes cause variations in the effective refractive indexes of the fiber core, leading to fluctuations in the optical path of light transmitted through the fiber. This allows the φ-OTDR to accurately detect liquid levels over a large measurement range by analyzing the phase information along the fiber, which arises from the temperature difference between the liquid and the surrounding air.

To enhance the signal-to-noise ratio (SNR) of the phase signal, a scattering enhanced optical fiber (SEOF) is utilized as the sensing fiber. Additionally, a liquid level sensing head is designed by wrapping the SEOF around a heat conductive cylinder, resulting in a highly sensitive configuration that improves the sensing resolution.

Experimental results demonstrate that the proposed distributed liquid level sensor achieves a high sensitivity of 73.4 rad/mm, corresponding to a competitive liquid level resolution of 142µm based on a noise floor of 10.4 rad over a 160-second period. Field tests confirm a large sensing range of 20 cm, limited by the length of the cylinder, while indicating a potential sensing range of up to 320 m using a sensing fiber of 40 km, resulting in a dynamic range of 127.1 dB [14].

The proposed liquid level sensor, offering a wide dynamic range and high sensing resolution, holds promise for applications in smart industry platforms and biomedical monitoring.

2.3.2 Plastic fiber optic sensor for continuous liquid level monitoring

The article " Plastic fiber optic sensor for continuous liquid level monitoring" by Allwyn S. Rajamani [15] focuses on This study presents the development of an innovative and cost-effective sensor for liquid level measurement using plastic optical fiber (POF). Unlike traditional evanescent wave-based sensing, this sensor operates on the principle of reduced scattering-based optical losses in a decladded fiber as the liquid level increases, due to changes in the surrounding medium's refractive index.

A compact optical setup is created, consisting of two U-bent fiber probes connected to a single LED on one end and two photodetectors on the other end. The decladded section of one probe serves as the test probe for measuring the liquid level, while the other probe acts as a reference to compensate for light intensity fluctuations caused by factors such as light source instability and ambient conditions. The voltage responses from the two photodetectors are compared to determine the liquid level. The fiber optic level sensor's response is investigated for rising and falling liquid levels over a range of 55 cm, using aqueous liquids with varying refractive index values (1.33 to 1.38), 95% ethanol, and DI water at temperatures ranging from 16°C to 70°C. The sensor exhibits a level sensitivity of 1.4 mV/mm for water level changes below 45 cm and 3.3 mV/mm for changes above 45 cm [15]. Furthermore, the sensor demonstrates stable and reproducible responses over multiple cycles of 30-minute durations at different liquid levels.

The results indicate that this fiber optic level sensor is not only easy to fabricate, cost-effective, and robust, but also provides sensitive, stable, and reliable instantaneous measurements of liquid levels.

2.3.3 Microfiber loop resonator for formaldehyde liquid sensing

The article titled “Microfiber loop resonator for formaldehyde liquid sensing”by Jali, M. F. M., Rahim, H. R. A., Hamid, S., Johari, A. M., Yusof, H. H. M., Thokchom, S., Harun, S. W., Khasanah, M., & Yasin, M. [16] is to study the whispering gallery mode (WGM) of a microfiber loop resonator (MLR) to detect and measure formaldehyde (CH2O) liquid concentrations. The researchers observed a notable sensing response when exposed to various concentrations of formaldehyde, ranging from 0% to 5%. This response was attributed to the absorption of formaldehyde on the surface of the microfiber and the resulting changes in the refractive index, leading to different levels of light attenuation within the silica microfiber.

As the concentration of formaldehyde increased, the MLR exhibited a linear decrease in output power, ranging from −18.9 dBm to −36.2 dBm. The sensitivity of the MLR was found to be 2.5 times higher compared to a straight microfiber (SmF). Additionally, the MLR demonstrated a resolution improvement of 3.28 times compared to SmF [16].

2.3.4 Polyvinyl alcohol coating microbottle resonator on whispering gallery modes for ethanol liquid sensor.

The article titled "Polyvinyl alcohol coating microbottle resonator on whispering gallery modes for ethanol liquid sensor." by to Johari, A. M., Jali, M. H., Yusof, H. H. M., Rahim, H. R. A., Ahmad, A., Khudus, M. I. M. A., & Harun, S. W [17] discusses a novel approach the influence of polyvinyl alcohol (PVA) coating on whispering gallery modes on the microbottle resonator (MBR) as liquid ethanol sensor. Utilising the "soften-and-compress" method, silica fibre SMF-28 is produced into three sizes of microbottle resonators, each with a different bottle length, stem diameter, and bottle diameter. The PVA was then applied to the MBR using a drop-casting process, with a uniform coating diameter of 10 metres. The maximum Q-factor for all conditions, 2.783 104, was achieved by the MBR-PVAs, which are characterised by microfibers of 2 m. For sensing purposes, ethanol liquid with concentrations ranging from 10% to 100% ppm is utilised.

The performance of MBR-PVAs in terms of sensitivity, linearity, repeatability, and stability was then evaluated between transmitted spectrum and wavelength shift analysis. The MBR-PVA-C is said to perform better overall than previous MBR-PVA sizes. In terms of transmitted spectral analysis, the sensitivity was 0.2699 dB/%ppm with a respectable linearity of 99.2%, and in terms of wavelength shift analysis, it was 0.2 pm/%ppm with a respectable linearity of 98.01% [17]. In order to optimise performance, MBR-PVAs underwent three cycles of repeatability and a 60-second stability procedure.

2.3.5 Formaldehyde sensing using ZnO nanorods coated glass integrated with microfiber

The article titled "Formaldehyde sensing using ZnO nanorods coated glass integrated with microfiber" by Jali, M. F. M., Rahim, H. R. A., Johari, A. M., Yusof, H. H. M., Rahman, B. M. A., Harun, S. W., & Yasin, M. [18] explores the application a formaldehyde (CH2O) sensor which is developed by utilizing the evanescent wave effect on a glass surface coated with Zinc Oxide (ZnO) nanorods integrated with a microfiber. The silica fiber is tapered using a flame brushing technique to reduce its diameter to 6 µm at the waist. ZnO nanorods are grown on the glass surface through a hydrothermal synthesis method. The sensor exhibits a significant response to formaldehyde concentrations ranging from 0 ppm to 0.18 ppm. This response is attributed to the strong chemisorption process and the variable refractive index of the ZnO nanorods coated on the glass surface.

As a result, the output power of the sensor decreases linearly from -22.64 dBm to -24.24 dBm, with a sensitivity of 9.78 dBm/ppm and a resolution of 0.0016 ppm. Coating the glass surface with ZnO nanorods enhances the sensitivity by a factor of 3 and the resolution by a factor of 2.5 compared to an uncoated glass surface [18]. The proposed sensor takes advantage of the unique properties of the strong evanescent wave generated by the silica microfiber and the surface absorption capability of the ZnO nanorods coated on the glass surface. This combination simplifies the synthesis process and improves the sensor's performance in formaldehyde sensing applications.

Overall, the experimental results demonstrate that the proposed sensor exhibits excellent performance in detecting formaldehyde, making it a promising solution for formaldehyde sensing.

2.3.6 Double helix microfiber coupler enhances refractive index sensing based on Vernier effect.

The article titled "Double helix microfiber coupler enhances refractive index sensing based on Vernier effect " by Zhang et al. [19] presents the fabrication and investigation of a double helix microfiber coupler (DHMC) with a minimum diameter of 3.4 µm. The internal mechanism of the Vernier effect is thoroughly examined through both theoretical analysis and experimental study. The sensor utilizing the Vernier effect exhibits a remarkable refractive index (RI) sensitivity, reaching up to 27326.59 nm/RIU within the RI range of 1.3333–1.3394 [19]. This sensitivity is nearly six times higher compared to the sensor that lacks the Vernier effect. The proposed microfiber structure is characterized by its simplicity in manufacturing, along with its robustness, making it suitable for various applications, including high-resolution chemical measurement and biomolecular detection.

2.3.7 Microfiber Optical Sensors: A Review

The article titled " Microfiber Optical Sensors: A Review" by Jingyi Lou et al [20]. In recent years, there has been a growing interest in optical microfibers due to their unique wave guiding properties, which are achieved through a combination of small diameter (comparable to or smaller than the wavelength of guided light) and high index contrast between the fiber core and the surrounding medium. These microfibers offer customizable optical confinement, evanescent fields, and waveguide dispersion, making them highly versatile for various applications. Optical sensing, in particular, has emerged as a promising area of research, as microfibers enable the development of miniaturized fiber optic sensors with several advantages such as a small footprint, high sensitivity, fast response, flexibility, and low optical power consumption.

This review focuses on the recent advancements in microfiber optical sensors, encompassing their fabrication techniques, waveguide properties, and sensing applications. Various types of microfiber-based sensing structures are discussed, including biconical tapers, optical gratings, circular cavities, Mach-Zehnder interferometers, and functionally coated or doped microfibers. These structures are categorized based on their sensing capabilities, such as refractive index, concentration, temperature, humidity, strain, and current measurements in both gas and liquid environments.

The article concludes with an assessment of the challenges and opportunities in the field of microfiber optical sensors. It highlights the need for addressing the remaining obstacles and explores the potential for further advancements in this exciting area of research.

2.4 Advantage and Disadvantage of Fiber Optic

2.4.1 Advantages of Fiber Optic

Advantages	Explanation
High Bandwidth	Fiber optics can transmit a large amount of data at high speeds, providing a high bandwidth for data communication.
Long Distances	Signals can travel over long distances without significant loss of signal quality, making fiber ideal for long-range communication.
Immunity to Interference	Fiber optics are immune to electromagnetic interference and radio frequency interference, ensuring reliable data transmission even in noisy environments.
Security	Fiber optic cables are difficult to tap into or intercept, making them highly secure for transmitting sensitive information.
Lightweight and Compact	Fiber optic cables are thin, lightweight, and flexible, allowing for easy installation and enabling high-density cabling in tight spaces.
Immunity to Electrical Hazards	Fiber optics do not conduct electricity, eliminating the risk of electrical hazards such as shocks and short circuits.

Table 2.1 : Advantages of fiber optic

2.4.2 Disadvantages of Fiber Optic

Disadvantages	Explanation
Initial Cost	Fiber optic cables and related equipment can be more expensive compared to traditional copper-based communication systems [21].
Fragility	Fiber optic cables are delicate and can be easily damaged if mishandled, requiring careful handling and protection during installation and maintenance.
Limited Accessibility	Fiber optic networks may be less accessible in certain areas, as they require specialized equipment and expertise for installation and maintenance.
Power Dependency	Active components in fiber optic systems, such as transceivers and repeaters, require a power source, making the system dependent on continuous power supply.
Difficulty in Splicing	Fiber optic cables are more challenging to splice compared to copper cables, requiring specialized tools and expertise for proper installation and repairs.
Susceptibility to Bending	Excessive bending or twisting of fiber optic cables can cause signal loss or degradation, necessitating proper bending radius considerations during installation.

Table 2.2 : Disadvantages of fiber optic

2.5 Journal Comparison from Previous Work Related to the Project

Article Title	References	Main Objective	Key Findings	Advantages	Disadvantages
High resolution and large sensing range liquid level measurement using phase-sensitive optic distributed sensor	[14]	Develop a distributed optical fiber liquid level sensor with a wide sensing range and high resolution	Achieved high sensitivity of 73.4 rad/mm and competitive resolution of 142μm for liquid level measurement	Wide sensing range and high resolution - Utilizes thermal optic effect for accurate measurement - Potential for industrial and biomedical applications	Requires a scattering enhanced optical fiber (SEOF) for improved signal-to-noise ratio - Limited sensing range of 20 cm in field tests
Plastic fiber optic sensor for continuous liquid level monitoring	[15]	Develop an innovative and cost-effective sensor for continuous liquid level measurement using plastic optical fiber (POF)	Level sensitivity of 1.4 mV/mm for water level changes below 45 cm and 3.3 mV/mm for changes above 45 cm	Easy to fabricate, cost-effective, and robust - Provides sensitive, stable, and reliable measurements of liquid levels	Limited to point measurements - Requires calibration for different liquids and temperatures
Microfiber loop resonator for formaldehyde liquid sensing	[16]	Study the formaldehyde sensing capabilities of a microfiber	- MLR demonstrated a linear decrease in output power	- Enhanced sensitivity and resolution compared to SmF - Simple	- Limited to formaldehyde sensing application

		loop resonator (MLR)	with increasing formaldehyde concentration - MLR had higher sensitivity and resolution compared to a straight microfiber (SmF)	and low-cost fabrication process - Potential for formaldehyde sensing applications	
Polyvinyl alcohol coating microbottle resonator on whispering gallery modes for ethanol liquid sensor	[17]	Investigate the influence of polyvinyl alcohol (PVA) coating on microbottle resonator (MBR) for ethanol liquid sensing	- MBR-PVA-C exhibited better sensitivity and linearity compared to previous MBR-PVA sizes	- Improved sensitivity and linearity compared to previous MBR-PVA sizes - Coating with PVA enhances sensor performance - Suitable for ethanol liquid sensing	- Limited to ethanol liquid sensing application
Formaldehyde sensing using ZnO nanorods coated glass integrated	[18]	Develop a formaldehyde (CH_2O) sensor using a microfiber integrated	- Linear decrease in output power with increasing formaldehyde	- Strong evanescent wave effect and surface absorption capability for	- Limited to formaldehyde sensing application

with microfiber		with ZnO nanorods coated glass surface	concentration - Enhanced sensitivity and resolution compared to uncoated glass surface	formaldehyde sensing - Enhanced performance with ZnO nanorods coating	
Double helix microfiber coupler enhances refractive index sensing based on Vernier effect	[19]	Fabricate and investigate a double helix microfiber coupler (DHMC) with enhanced refractive index sensing based on the Vernier effect	- DHMC exhibited significantly higher refractive index sensitivity compared to a sensor without the Vernier effect	- High refractive index sensitivity - Simple manufacturing process - Suitable for high-resolution chemical measurement and biomolecular detection	- Limited information on other potential applications
Microfiber Optical Sensors: A Review	[20]	Review recent advancements in microfiber optical sensors and discuss their fabrication techniques, waveguide properties,	- Discusses various types of microfiber-based sensing structures and their sensing capabilities	- Small footprint, high sensitivity, fast response, flexibility, and low optical power consumption - Versatile for refractive index,	- Provides an overview rather than specific findings for individual sensors

		and sensing applications		temperature, humidity, strain, and current measurements in gas and liquid environments	

Table 2.3 : Comparison on previous research paper

2.6 Summary

Different analyses and methods for optical loop fiber liquid sensors were discussed in this chapter. According to the research, there were a variety of approaches to developing the fiber optic sensor. Fiber optics can transmit more data at faster speeds over longer distances than other technologies. As a result, the review concludes with a detailed analysis of the various optical fiber sensing technologies used in the study for liquid monitoring. Finally, it is a good idea to look over the numerous extrinsic and intrinsic approaches that have been published over the years, with many of them focusing on sensory qualities gained in a controlled laboratory setting.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology of a project is a set of principles that quickly describe the project's flow from start to finish. The method of stripping, cleaning, cleaving, splicing, tapering, and looping the optical fiber cable was discussed in this chapter and the rest of the experiment.

3.2 Hardware Specifications

1. Single mode Fiber Pigtails

Figure 3.1 : SC/UPC connectors for single mode fiber pigtails

2. Fiber Cutter and Jacket Remover

Figure 3.2 : Jacket and cladding of the optical fiber cable are stripped away with a fiber cutter

3. Isopropyl Alcohol

Figure 3.3 : Cleaning tools used for optical fiber cable after stripping process

4. Hand Cleaver

Figure 3.4 : The Fujikura Hand Cleaver was used to cut the fiber tips to the proper length for splicing

5. Fusion Splicer

Figure 3.5 : Fusion splicer machine which spliced two fibers together

6. Cetirizine

Figure 3.6 : Cetirizine Hydrochloride Oral Solution

7. Amplified Spontaneous Emitter(ASE)

Figure 3.7 : The light source that transmits 1350 nm and 1550 nm light

8. Mini Pro Optical Time Domain Reflectometer(OTDR)

Figure 3.8 : Pulsed laser light flowing via an optical fiber is transmitted and analyzed during OTDR testing

3.3 Project Flow Chart

The field of sensing technology has witnessed remarkable advancements in recent years, with an increasing focus on developing efficient and reliable liquid sensors. These sensors play a crucial role in various applications, including environmental monitoring, biomedical diagnostics, and industrial processes. This research can provide one promising approach to enhance the performance of liquid sensors is through the integration of microfiber single loop resonators. Microfiber Single loop resonator for liquid sensor can offer numerous advantages such as high sensitivity, compact size, and compatibility with microfluidic systems. This flow chart-based study aims to explore the fundamental principles, fabrication techniques, and potential applications of Microfiber single loop resonator as liquid sensors. By providing a comprehensive overview of the flow chart associated with Microfiber single loop resonator based liquid sensing, this research strives to contribute to the growing field of sensing technology and pave the way for the development of innovative liquid sensing devices.

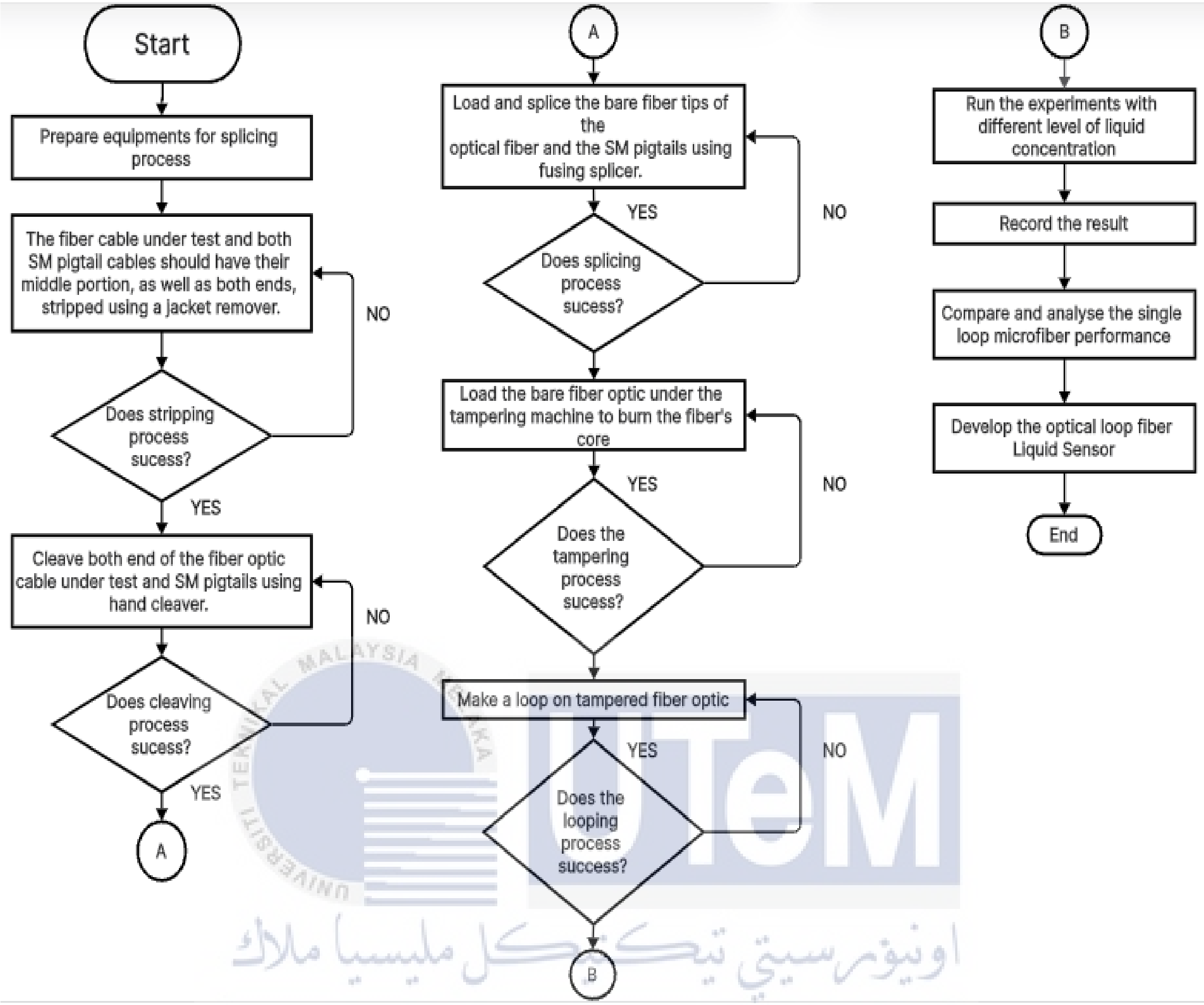

Figure 3.9 : Flowchart of the project

3.4 Procedure of setting up an Experiment with Fiber Optic Sensors

3.4.1 Setting up Experiment with Fiber Optic Sensors

The required equipment has been arranged as follows. The ASE functions as the transmitter, emitting a light pulse at 1550nm. Serving as the receiver, the OTDR measures the optical power. The microfiber optical loop to be tested is also depicted below.

Figure 3.10 : The setup of the equipment

3.4.2 Stripping process

The stripping process in fiber optics refers to the removal of protective coatings or buffers from optical fibers in order to expose the bare fiber for subsequent splicing, termination, or connectorization. This process is necessary to ensure proper signal transmission and connection quality in fiber optic networks. The holes in the stripper blade are normally laser cut to precise tolerances. The opening is large enough for the stripper to cut without breaking the glass fiber.

Figure 3.11 : Fiber optic cable being stripped

3.4.3 Cleaning Process

The cleaning process of fiber optics is a crucial step to ensure the optimal performance and reliability of the fiber optic system. Contaminants such as dust, oil, dirt, or residues can significantly impact the quality of the optical signal and cause signal loss or degradation. Therefore, it is essential to follow proper cleaning procedures to maintain the cleanliness of the fiber optic connectors and cables. Here are the general steps involved in the cleaning process of fiber optics:

i. Inspection: Before cleaning, visually inspect the fiber optic connectors, adapters, and cables for any visible contamination, damage, or defects. Check for dust, fingerprints, or any debris that might hinder the proper transmission of light.

ii. Safety Measures: Ensure that you follow appropriate safety measures, such as wearing clean gloves and working in a clean environment to prevent introducing additional contaminants during the cleaning process.

iii. Dry Cleaning: Begin the cleaning process by using a dry cleaning method to remove loose particles and dust. This can be done using a specialized lint- free cleaning cloth, wipes, or compressed air. Gently wipe or blow away any visible contaminants on the fiber connectors or cables.

iv. Wet Cleaning: For better performance, wet cleaning process is required. Wet cleaning involves using a fiber optic cleaning solution or isopropyl alcohol (IPA) on a lint-free cleaning wipe. Moisten the cleaning wipe with the solution and gently clean the connector end face or the exposed fiber, using a circular motion. Be cautious not to touch the fiber core or damage the connector end.

v. Inspection and Repeated Cleaning: After the cleaning process, perform a visual inspection again to ensure the removal of all contaminants. If necessary, repeat the cleaning steps to achieve the desired cleanliness.

It is important to note that proper cleaning tools, cleaning solutions, and techniques should be used, following industry standards and guidelines. Regular cleaning and maintenance are recommended to keep the fiber optic system in optimal condition and ensure reliable performance.

Figure 3.12 : Fibre optic cable being cleaned

3.4.4 Cleaving Process

The cleaving process in fiber optics refers to the precise and controlled cutting of an optical fiber to obtain a flat and smooth end face. The cleaving process is a critical step in fiber optic termination, splicing, or connectorization, as it determines the quality of the fiber end face and ultimately affects the optical signal transmission. Here is an overview of the cleaving process:

i. Selecting the Cleaving Tool: The first step is to choose an appropriate cleaving tool. Various types of cleavers are available, including scribe-based cleavers, blade-based cleavers, and automated cleaving systems. The choice of cleaver depends on factors such as fiber type, application, and required cleave quality.

ii. Fiber Preparation: Before cleaving, the fiber optic cable is prepared by removing the outer jacket, buffer, and coating layers, following the stripping process. This exposes the bare fiber for cleaving.

iii. Fiber Fixation: The fiber is securely fixed or held in place using a fiber holder or fixture. Proper alignment is crucial to ensure accurate cleaving and to maintain the fiber's orientation and position

iv. Score Line: In the cleaving process, a small score line or indentation is made on the fiber surface, typically using a diamond or tungsten carbide scribe. The score line weakens the fiber structure and creates a controlled break point for cleaving.

v. Cleaving Operation: Depending on the type of cleaver being used, the actual cleaving operation can differ:

   - Scribe-based Cleaving: In scribe-based cleavers, a controlled force is applied to the scored line to initiate the cleave. The fiber is typically bent or broken by hand or using a cleaver's lever mechanism. The operator's skill and experience are crucial in achieving a clean and smooth cleave.
   - Blade-based Cleaving: Blade-based cleavers employ a sharp blade or cutting wheel to cleave the fiber. The fiber is precisely positioned under the blade, and the cleaver's mechanism is activated, causing the blade to move across the fiber and create a cleave. Automated blade-based cleavers provide consistent and repeatable results.

- Automated Cleaving Systems: Automated cleaving systems utilize advanced technology, such as laser cleaving or mechanical scoring, combined with precise control and alignment mechanisms. These systems offer high precision and accuracy, resulting in consistent and reliable cleaves.

vi. Inspection: After the cleaving operation, the fiber end face is inspected using a fiber optic microscope or inspection tool. The end face should exhibit aclean, flat, and smooth surface perpendicular to the fiber axis. Any defects, chips, or debris on the cleaved end face should be avoided, as they can cause signal loss or disruptions.

vii. Cleaning: After cleaving, the fiber end face should be cleaned using appropriate cleaning tools and techniques, as mentioned in the previous response. This ensures the removal of any particles or contaminants generated during the cleaving process.

Proper cleaving techniques are essential to achieve high-quality cleaves with minimal fiber end face defects. The cleave quality directly impacts the success and performance of subsequent fiber optic processes, such as splicing or connectorization. Following manufacturer guidelines and best practices for cleaver setup, operation, and maintenance is crucial to ensure consistent and reliable results.

Figure 3.13 : The process of cleaving the fiber optic cable

3.4.5 Splicing Process

The splicing process in fiber optics refers to the permanent joining of two fiber optic cables or fibers to create a continuous optical path for efficient signal transmission. Splicing is a critical step in fiber optic network installations, repairs, or expansions and involves precise alignment and fusion of the fibers to minimize signal loss and maintain optical performance. Here is an overview of the splicing process:

i. Fiber Preparation: Before splicing, the fibers to be joined need to be prepared. This involves stripping the protective coatings and buffers from the fiber ends, following the stripping process explained earlier. The bare fibers are then cleaned to remove any contaminants and ensure optimal fusion.

ii. Fiber Cleaving: Each fiber end needs to be cleaved to create a clean, flat, and perpendicular surface for fusion. Cleaving can be done using a cleaving tool or a cleaver, as explained in the previous response. High-quality cleaving is crucial to minimize splice loss and maintain signal integrity.

iii. Fiber Alignment: The cleaved fiber ends are carefully aligned to ensure precise core- to-core alignment. This can be done using various alignment techniques, including manual alignment, active alignment, or fusion splicing machines. The alignment process involves adjusting the position of the fibers to achieve the best possible alignment for optimal light transmission.

iv. Fusion Splicing: Fusion splicing is the actual process of permanently joining the fiber ends by fusing them together. This is achieved through the application of heat to melt the fiber ends and then bringing them into contact to form a seamless connection. Fusion splicing machines, also known as fusion splicers, are used for this purpose. The splicer applies an electric arc or laser to generate the heat required for fusion. The melted fibers are fused together, resulting in a strong and low-loss splice.

v. Splice Protection: After fusion, it is important to protect the spliced area to prevent mechanical damage, moisture ingress, or signal degradation. Splice protection can be achieved using various methods, including heat-shrink sleeves, splice trays, or mechanical splicing devices. These protective measures help maintain the strength and reliability of the spliced connection.

vi. Splice Testing and Verification: Once the splicing is complete, the spliced fiber should be tested and verified to ensure proper alignment and low splice loss. This is typically done using an optical time-domain reflectometer (OTDR) or other optical testing equipment. The tests verify the continuity of the fiber, measure the splice loss, and check for any defects or anomalies.

It is worth noting that there are different types of splicing methods available, including fusion splicing and mechanical splicing. Fusion splicing provides the lowest loss and highest reliability but requires specialized equipment. Mechanical splicing, on the other hand, uses mechanical connectors or devices to align and join the fibers but may result in slightly higher losses. The choice of splicing method depends on factors such as the application, budget, and specific requirements of the fiber optic installation.

Figure 3.14 : The process of splicing the fiber optic cable

3.4.6 Tapering Process

This process is made and carried out to produce a microfiber sensor loop. In this process, the fiber's core will be burned using a special tool known as tapering machine. This process requires a lot of perseverance and patience because there is a risk of affecting the microfiber like it is broken, broken, and similar. Figure 3.15 shows the tapered process made.

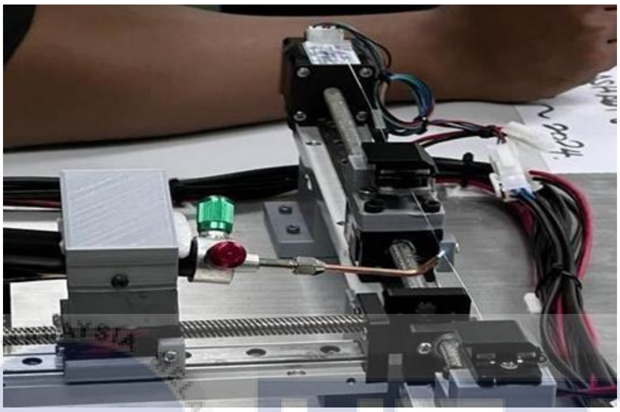

Figure 3.15 : The process of tapering the fiber optic cable

3.4.7 Looping Process

Long-distance transmission in optical fiber communication networks is one of its principal applications. This approach is an extension of self-heterodyne line width measurement. It is a setup where the light beam can go around the loop by optical fiber for this looping technique. A long single-mode fiber delay is employed to obtain a reference signal directly from the laser output, eliminating the need for a separate reference laser. Fiber optic looping is shown in Figure 3.16.

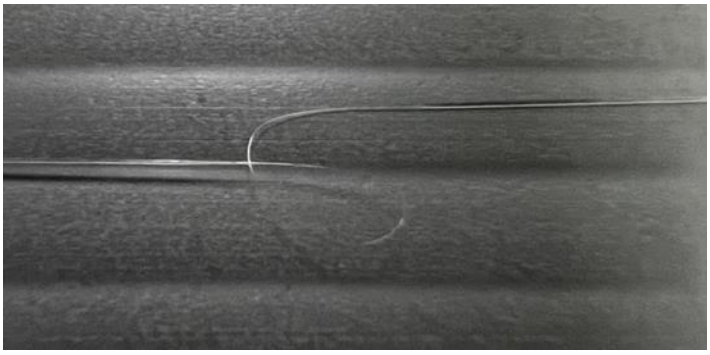

Figure 3.16 : The process of looping the fibre optic cable

3.4.8 Final Check on fiber

This procedure is implemented to verify the integrity of the fiber. This precaution is recommended due to apprehensions about the fiber's state in the event of breakage or failure of the laser light to reach its destination. This potential issue arises during the tapering process, where there is a risk of the fiber core being damaged and converted into a microfiber. The most critical concern is the looping phase, where the fiber is exceptionally delicate and slender, posing a risk of breakage. The laser testing protocol is employed to assess the status of the fiber optic connection.

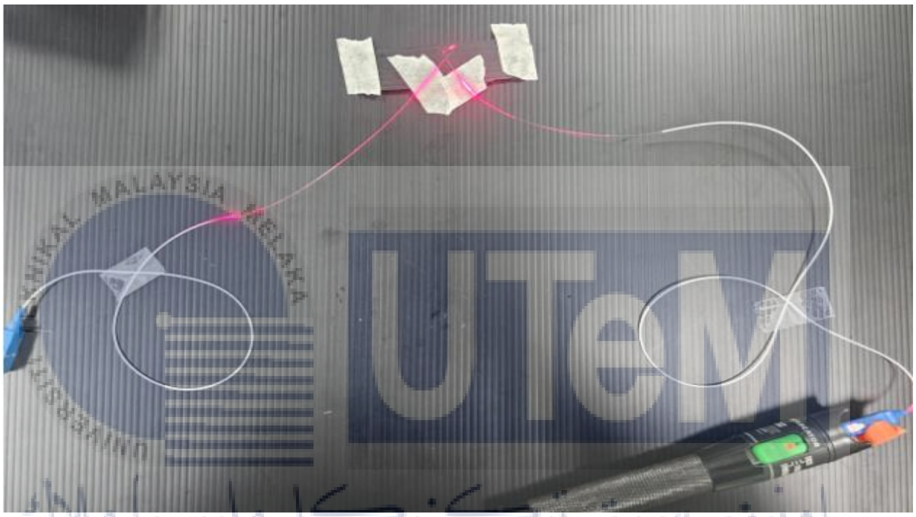

Figure 3.17 : Testing fiber using laser

3.4.9 Measuring the fiber

This process is to measure the concentration of single loop resonators. Starting from 0ml to 5ml of Cetirizine Liquid in 7 minutes. The graphs and analysis will be done after this process.

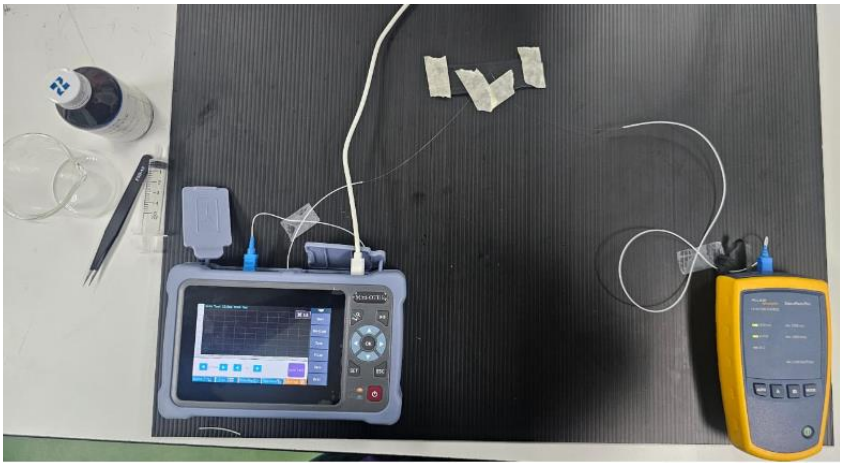

Figure 3.18 : Setup before start the experiment

Figure 3.19 : One drop of cetirizene solution the tempered fiber

Figure 3.20 : Results of the selected concentration

3.5 Characterization of Fiber Optic Loop Sensor

In the assessment of this project, referred to as the characterization of a fiber optic loop sensor, numerous evaluations of the experimental setup are conducted to gauge its capabilities. Fiber characterization involves examining insertion loss, optical return loss, polarization, and dispersion to ensure the fiber's ability to effectively transmit traffic and to establish a reference for subsequent debugging and troubleshooting endeavors.

3.5.1 Connector Inspection

Unclean connections can lead to corruption in receivers due to connector loss. One approach is to cleanse the connections using 99 percent isopropyl alcohol. An alternative method involves cleaning the connections with clean wipes, where the moist section of the wipe loosens the dirt, while the dry part eliminates it.

Figure 3.21 : Example of wet to dry cleaning

3.5.2 Insertion Loss Test

The objective of the insertion loss test is to replicate the operational conditions of the line by supplying power to the optical fiber or cable under examination using the test source and gauging the attenuation at the opposite end with the power meter. In this experiment, the test source and power meter are positioned between the fiber optic cable and the test source. Prior to connecting with the optical fiber used in this project, the power meter is adjusted to 0dB when the source is activated.

Figure 3.18 illustrates the process of setting a 0dB reference on a power meter, while Figure 3.19 provides a visual guide on measuring insertion loss.

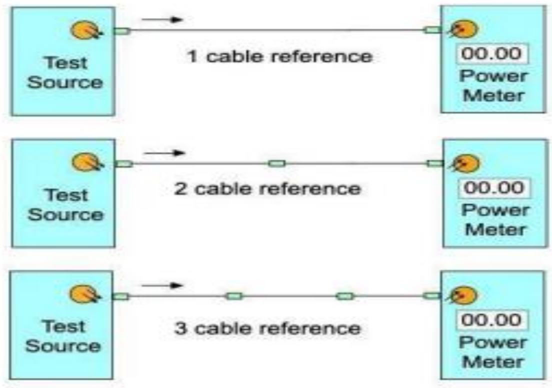

Figure 3.22 : Ways to set 0dB reference at power meter

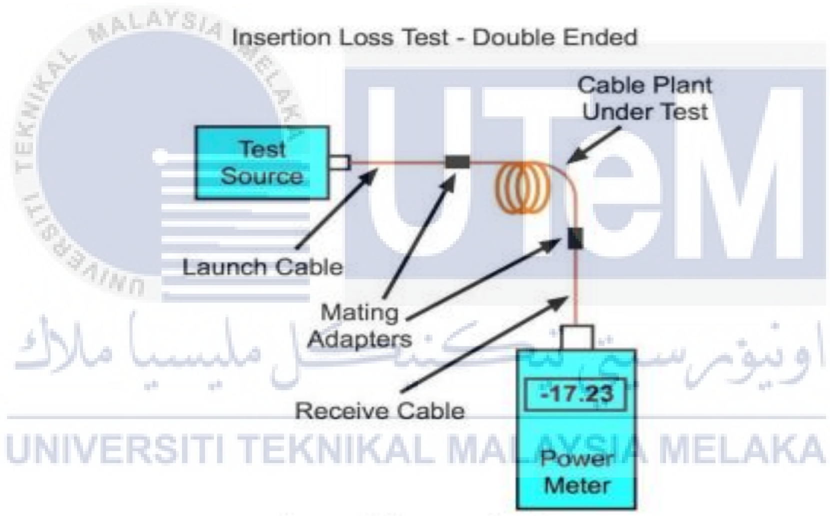

Figure 3.23 : Insertion loss test

3.5.3 Reflectance and Return Loss Test

Reflectance refers to the optical return loss observed in individual events. As an illustration, it signifies the reflection above the fiber backscatter level in relation to the source pulse. In the context of passive optics, optical return loss is quantified in decibels (dB), consistently maintaining a negative value. Closeness to 0 dB indicates more substantial reflections, indicative of poorer connections. Optical Return Loss (ORL) encompasses the return loss for the entire fiber under examination, encompassing both fiber backscatter and reflections relative to the source pulse. Similarly expressed in decibels (dB), ORL is consistently positive, with values closer to 0 dB denoting a higher total light reflected.

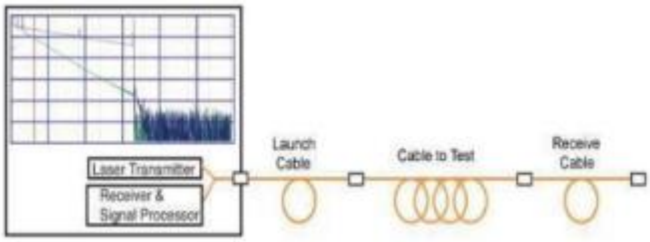

Figure 3.24 : OTDR testing

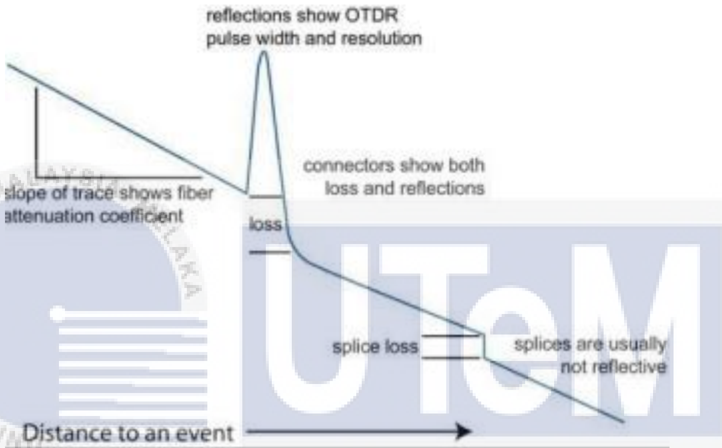

Figure 3.25 : Example of information in the OTDR Trace

3.5.4 Polarization Mode Dispersion

Polarization Mode Dispersion (PMD) constitutes a form of modal dispersion wherein two distinct polarizations of light within a waveguide traverse at varying speeds due to irregularities and asymmetries, causing a stochastic widening of optical pulses. In fiber optics, three dispersion types exist: modal dispersion (MMF), chromatic dispersion, and polarization mode dispersion. In the case of polarization mode dispersion, each polarization component reaches the receiver at slightly different times, leading to the broadening of the received pulse.

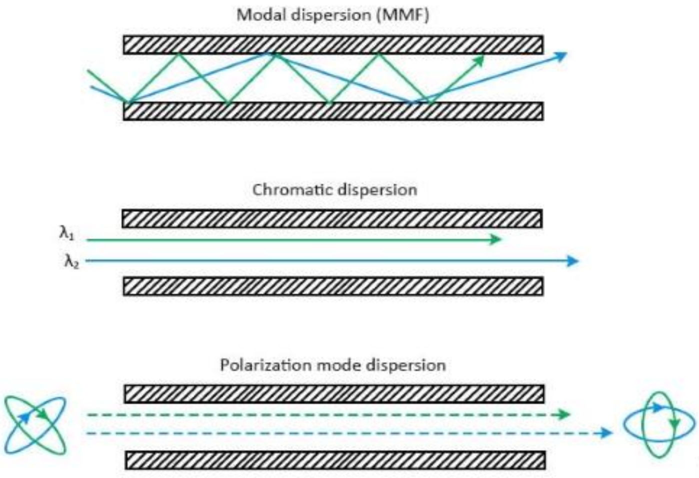

Figure 3.26 : Three types of dispersion in fiber optics

3.6 Summary

Overall, the flowchart guides all the activities and tasks that must be completed in this chapter. The steps for preparing the optical loop fibers under test, preparing various dehumidification percentages, and taking optical power readings will be covered later. This chapter also explains how to take readings with precision and minor mistake and how to clean the sensor element with soft tissue soaked in alcohol to remove any residual residue or particle.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter details the outcomes and data analysis pertaining to the development of an optical microfiber single loop resonator designed for a liquid sensor. Various tests have been conducted to showcase the project's efficacy. These project encompass criteria such as the sensor's sensitivity and linearity, test outcomes, operational capacities, comparisons between 1310nm and 1550nm wavelengths, and the average power of single loop resonator across different concentration levels for both 1310nm and 1550nm. These evaluations are pivotal in substantiating the sensor's progress and refinement.

4.2 Size of Microfiber Optic Loop Sensor

Figure 4.1 visually presents the updated dimensions of the microfiber optic sensor. The measurement of the sensor's size was conducted employing a microscope. The fabrication process involved the successful creation of the microfiber sensor through controlled combustion during the tapering process. Notably, the initial size of the fiber, originally at 125µm, has been significantly decreased to 8µm, demonstrating the efficacy of the fabrication method in achieving the desired reduction in size for the sensor.

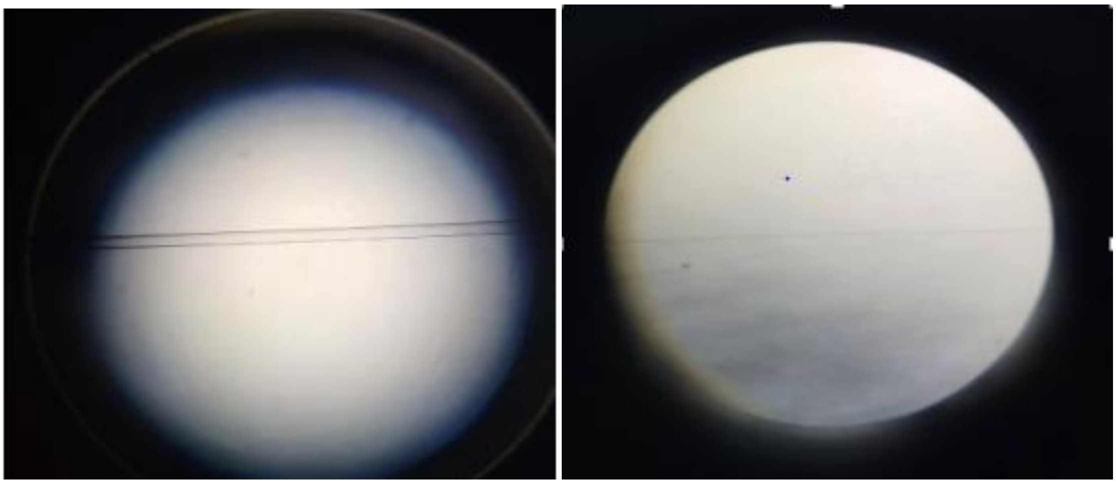

Figure 4.1 : New Size of the Microfiber Optic Sensor

4.3 Result and Analysis for Different Level of Cetirizine Concentration

Figure 4.2 illustrates the experimentation conducted on the fiber optic sensor immersed in cetirizine liquid for a duration of 7 minutes, with data recorded at 1-minute intervals. The experimental setup entails transmitting a modulated light source to an Optical Time Domain Reflectometer (OTDR) using two single-mode fiber pigtails. These pigtails are connected at a splice point, featuring an unclad region positioned in the center of the transmission path, forming a loop. The sensor was subjected to varying concentrations of cetirizine, specifically 0ml, 5ml, and 10ml.Additionally, each concentration was evaluated using two distinct light sources (λ) at wavelengths of 1310nm and 1550nm. The acquired data was analyzed and presented in a line graph format, depicting the relationship between output power (measured in decibel dB) and time over the course of the 7-minute period. This graphical representation aims to elucidate the behavior and performance of the fiber optic sensor under different concentrations of cetirizine and various light wavelengths. Time Domain Reflectometer (OTDR) using two single-mode fiber pigtails. These pigtails are connected.

Figure 4.2 : Executing the experiment

4.4 Results of Single loop resonator for 1310nm and 1550nm

This part shows the data recorded from 1 to 7 minutes on single loop resonator by using 0ml, 5ml and 10ml levels of cetirizine concentration on 1310nm and 1550nm.

4.4.1 0 ml Level Cetirizine Concentration Tested on 1310nm and 1550nm Wavelength

Time(mins)	Output Power(-dBm)	
	1310nm	1550nm
1	37.43	36.24
2	37.79	36.62
3	37.88	36.62
4	37.93	36.67
5	37.97	36.73
6	37.98	36.73
7	38.01	36.74

Table 4.1 : Recorded Data for 0ml

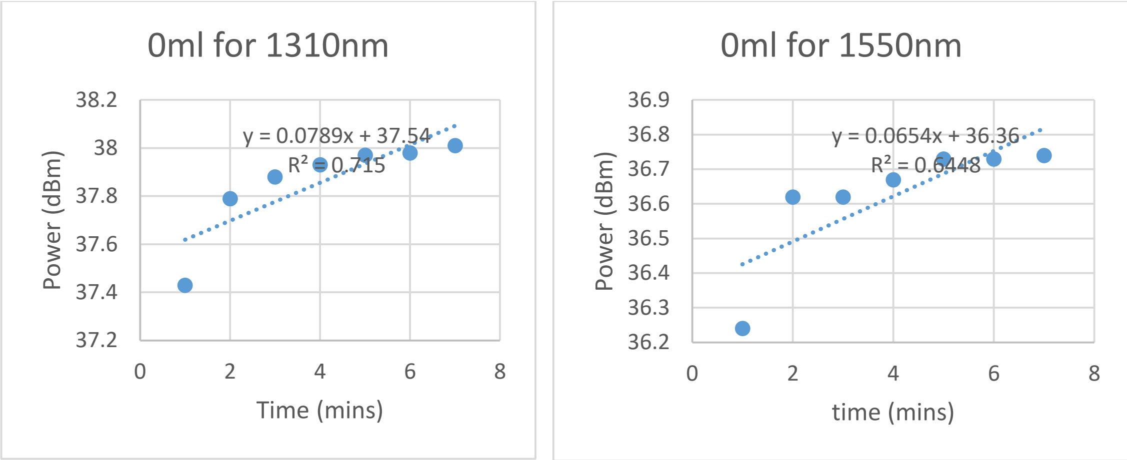

Figure 4.3 : Microfiber optic single loop sensor response at 0ml

Based on the table and the two graphs above, the data shows that power increases linearly with time. For 1310nm, the sensitivity is 0.0789 whereas for 1550nm, the sensitivity is 0.0654. By comparing both graphs, it is concluded that for 0ml of cetirizine concentration, 1310nm is more sensitive than 1550nm.

4.4.2 5 ml Level Cetirizine Concentration Tested on 1310nm and 1550nm Wavelength

Time(mins)	Output Power(-dBm)	
	1310nm	1550nm
1	38.94	34.1
2	39.48	36.23
3	39.61	36.48
4	39.67	36.54
5	39.71	36.59
6	39.73	36.62
7	39.76	36.63

Table 4.2 : Recorded data for 5ml

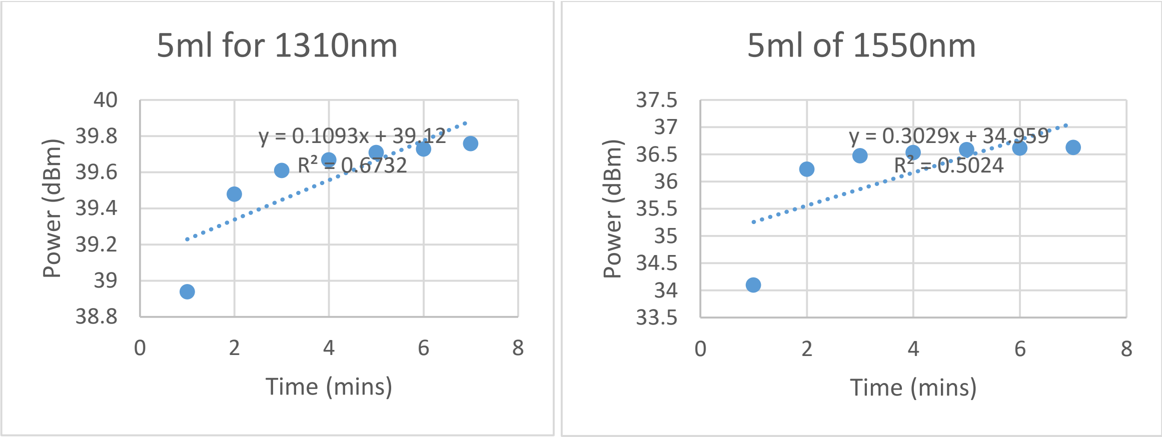

Figure 4.4 : Microfiber optic single loop sensor response at 5ml

Based on the table and the two graphs above, the data shows that power increases linearly with time. For 1310nm, the sensitivity is 0.1093 whereas for 1550nm, the sensitivity is 03029. By comparing both graphs, it is concluded that for 5ml of cetirizine concentration, 1550nm is more sensitive than 1310nm.

4.4.3 10ml Level Cetirizine Concentration Tested on 1310nm and 1550nm Wavelength.

Time(mins)	Output Power(-dBm)	
	1310nm	1550nm
1	37.97	34.32
2	38.37	36.37
3	38.45	36.6
4	38.52	36.67
5	38.56	36.71
6	38.58	36.73
7	38.61	36.75

Table 4.3 : Recorded data for 10ml

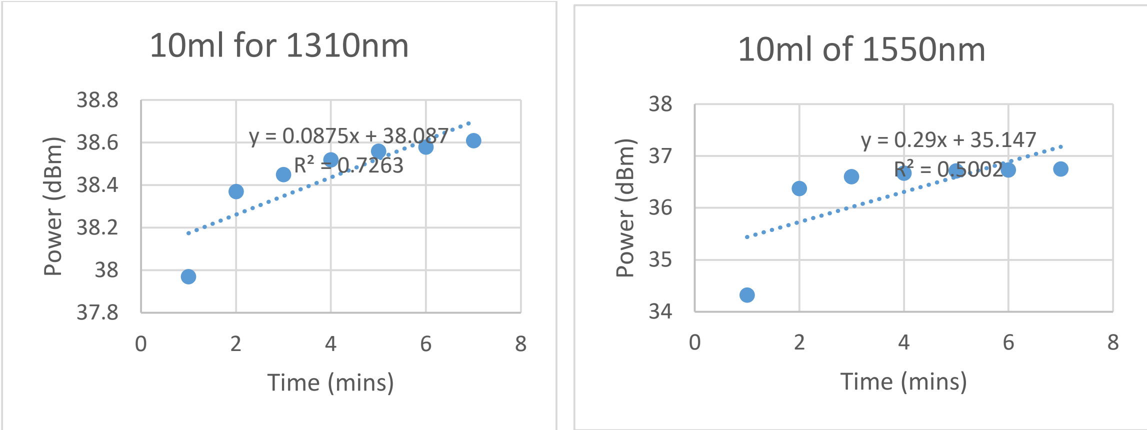

Figure 4.5 : Microfiber optic single loop sensor response at 10ml

Based on the table and the two graphs above, the data shows that power increases linearly with time. For 1310nm, the sensitivity is 0.0875 whereas for 1550nm, the sensitivity is 0.29. By comparing both graphs, it is concluded that for 10ml of cetirizine concentration, 1550nm is more sensitive than 1310nm.

4.4.4 Comparison between 1310nm and 1550nm for Single Loop

Level of Concentration(ml)	1310nm		1550nm	
	Sensitivity(dBm)	Linearity(%)	Sensitivity(dBm)	Linearity(%)
0	0.0789	84.56	0.0654	80.29
5	0.1093	82.05	0.3029	70.88
10	0.0875	85.22	0.29	70.72

Table 4.4 : Recorded data for comparison for different level of concentration (ml) and different wavelength (nm)

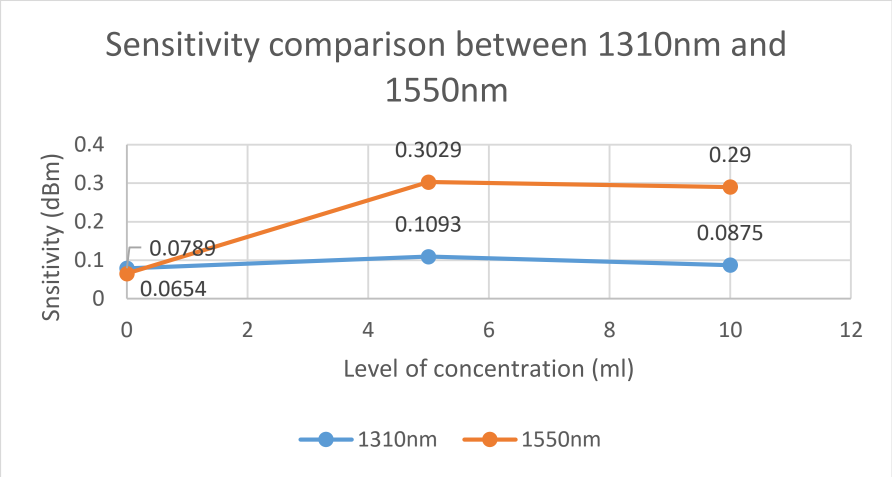

Figure 4.6 : Comparison of Sensitivity between 1310nm and 1550nm

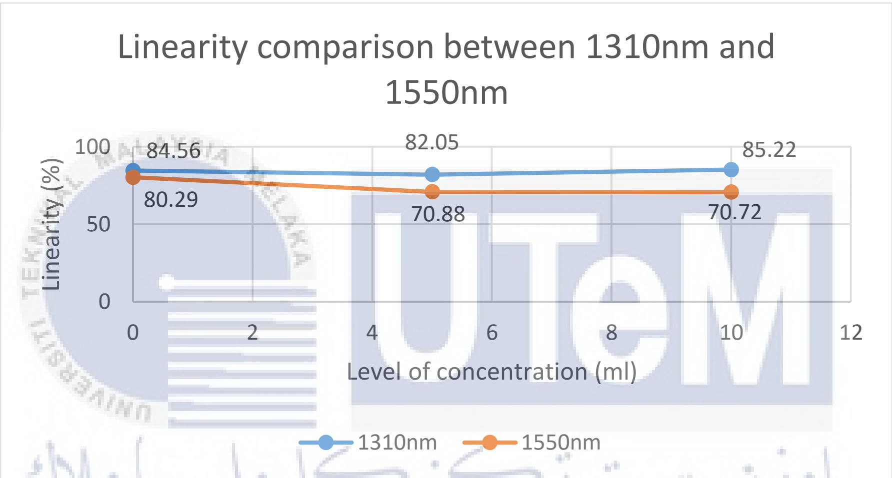

Figure 4.7 : Comparison of Linearity between 1310nm and 1550nm

For both wavelengths which is 1310nm and 1550nm, as the concentration increases from 0 ml to 5 ml, the sensitivity generally increases. At a concentration of 10 ml, the sensitivity decreases slightly for both wavelengths compared to 5 ml, but it's still higher than at 0 ml concentration. At 1310nm wavelength, the linearity generally increases as the concentration increases from 0 ml to 10 ml. However, at 1550nm wavelength, the linearity decreases as the concentration increases from 0 ml to 10 ml. At 0 ml concentration, the sensitivity at 1550nm is slightly lower than at 1310nm, while the linearity is also lower at 1550nm. At 5 ml concentration, the sensitivity at 1550nm surpasses that of 1310nm, but the linearity is notably lower at 1550nm. At 10 ml concentration, sensitivity at 1550nm is higher than 1310nm, but again, the linearity at 1550nm is significantly lower than at

1310nm. The overall observation from the result of 0ml, 5ml and 10ml level Cetirizine Concentration Tested on 1310nm and 1550nm Wavelength is the sensitivity tends to increase with higher concentrations for both wavelengths, with 1550nm showing higher sensitivity at higher concentrations. However, for linearity it behaves differently between the two wavelengths. At 1310nm, linearity generally improves with increasing concentration, while at 1550nm, linearity deteriorates as the concentration increases.

4.5 Analysis and Result for Microfiber Interaction with Different Level of Cetirizine Concentration over Time

This section contains data collected at various times, ranging from one minute to seven minutes, with one-minute intervals at varying level of Cetirizine concentration.

4.6 Result for Single Loop Resonator of 1310nm and 1550nm over time

This part shows the data recorded by using 0ml, 5ml and 10ml of Cetirizine concentration on 1310nm and 1550nm from 1 minutes to 7 minutes in a single loop resonator.

4.6.1 1 Minutes Tested on 1310nm and 1550nm Wavelength.

Level of Cetirizine Concentration(ml)	Output power of 1 minutes (dBm)	
	1310nm	1550nm
0	37.43	36.24
5	38.94	34.1
10	37.97	34.32

Table 4.5 : Recorded data for 1 minute

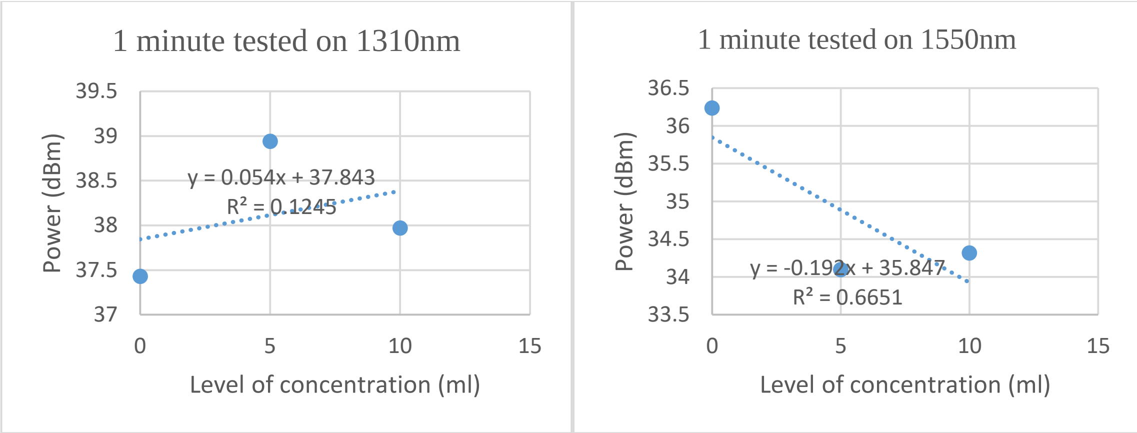

Figure 4.8 : Microfiber Single Loop Sensor response at 1 minute

Table 4.5 presents the data recorded for the output power value (dBm) at the 1st minute for both optical light sources with different wavelengths. The two graphs above shows, that power increases for 1310nm and decreases for 1550nm with time. For 1310nm, the sensitivity is 0.054 whereas for 1550nm, the sensitivity is -0.192. By comparing both graphs, it is concluded that at the 1st minute for both optical light sources with different wavelengths, 1310nm is more sensitive than 1550nm.

4.6.2 2 Minutes Tested on 1310nm and 1550nm Wavelength.

Level of Cetirizine Concentration(ml)	Output power of 2 minutes (dBm)	
	1310nm	1550nm
0	37.79	36.62
5	39.48	36.23
10	38.37	36.37

Table 4.6 : Recorded data for 2 minutes

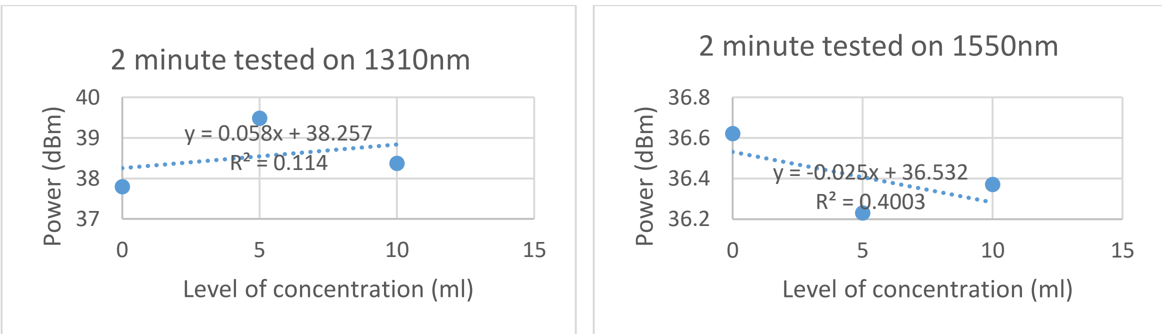

Figure 4.9 : Microfiber Single Loop Sensor response at 2 minute

Table 4.6 presents the data recorded for the output power value (dBm) at the 2nd minute for both optical light sources with different wavelengths. The two graphs above shows, that power increases for 1310nm and decreases for 1550nm with time. For 1310nm, the sensitivity is 0.058 whereas for 1550nm, the sensitivity is -0.025. By comparing both graphs, it is concluded that at the 2nd minute for both optical light sources with different wavelengths, 1310nm is more sensitive than 1550nm.

4.6.3 3 Minutes Tested on 1310nm and 1550nm Wavelength.

Level of Cetirizine Concentration(ml)	Output power of 3 minutes (dBm)	
	1310nm	1550nm
0	37.88	36.62
5	39.61	36.48
10	38.45	36.6

Table 4.7 : Recorded data for 3 minutes

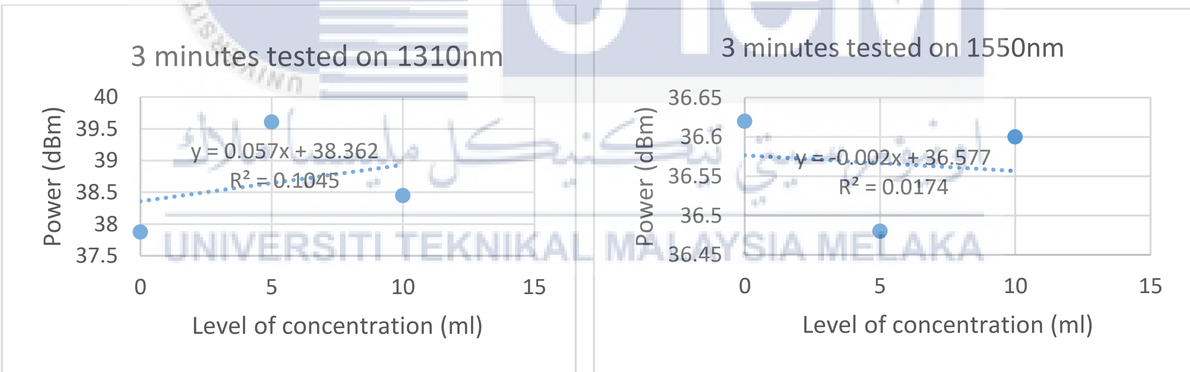

Figure 4.10 : Microfiber Single Loop Sensor response at 3 minutes

Table 4.7 presents the data recorded for the output power value (dBm) at the 3rd minute for both optical light sources with different wavelengths. The two graphs above shows, that power increases for 1310nm and decreases for 1550nm with time. For 1310nm, the sensitivity is 0.057 whereas for 1550nm, the sensitivity is -0.002. By comparing both graphs, it is concluded that at the 1st minute for both optical light sources with different wavelengths, 1310nm is more sensitive than 1550nm.

4.6.4 4 Minutes Tested on 1310nm and 1550nm Wavelength.

Level of Cetirizine Concentration(ml)	Output power of 4 minutes (dBm)	
	1310nm	1550nm
0	37.93	36.67
5	39.67	36.54
10	38.52	36.63

Table 4.8 : Recorded data for 4 minutes

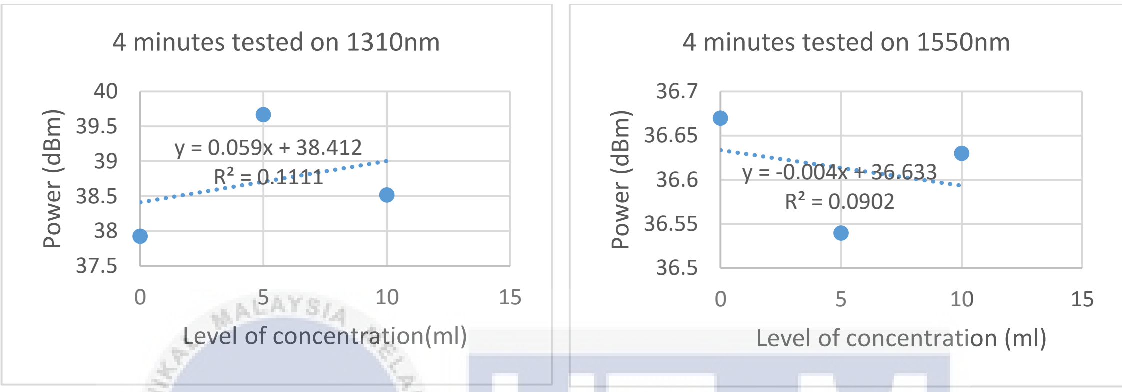

Figure 4.11 : Microfiber Single Loop Sensor response at 4 minutes

Table 4.8 presents the data recorded for the output power value (dBm) at the 4th minute for both optical light sources with different wavelengths. The two graphs above shows, that power increases for 1310nm and decreases for 1550nm with time. For 1310nm, the sensitivity is 0.059 whereas for 1550nm, the sensitivity is -0.004. By comparing both graphs, it is concluded that at the 1st minute for both optical light sources with different wavelengths, 1310nm is more sensitive than 1550nm.

4.6.5 5 Minutes Tested on 1310nm and 1550nm Wavelength.

Level of Cetirizine Concentration(ml)	Output power of 5 minutes (dBm)	
	1310nm	1550nm
0	37.97	36.73
5	39.71	36.59
10	38.56	36.71

Table 4.9 : Recorded data for 5 minutes

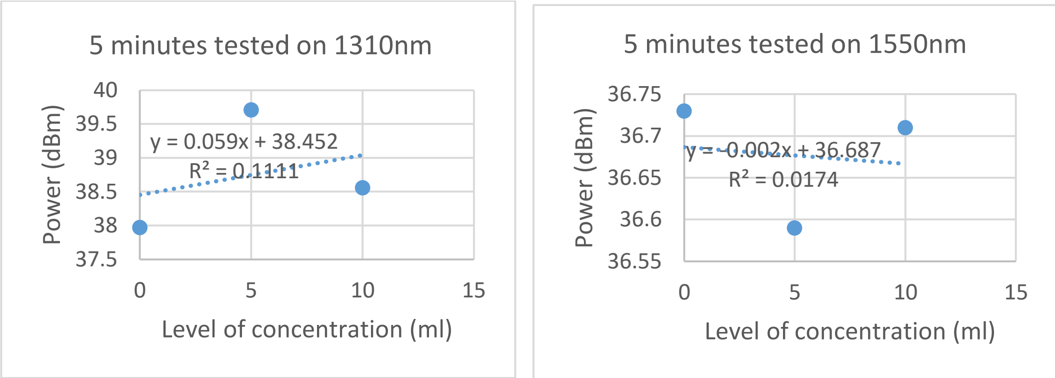

Figure 4.12 : Microfiber Single Loop Sensor response at 5 minutes

Table 4.9 presents the data recorded for the output power value (dBm) at the 5th minute for both optical light sources with different wavelengths. The two graphs above shows, that power increases for 1310nm and decreases for 1550nm with time. For 1310nm, the sensitivity is 0.059 whereas for 1550nm, the sensitivity is -0.002. By comparing both graphs, it is concluded that at the 5th minute for both optical light sources with different wavelengths, 1310nm is more sensitive than 1550nm.

4.6.6 6 Minutes Tested on 1310nm and 1550nm Wavelength.

Level of Cetirizine Concentration(ml)	Output power of 6 minutes (dBm)	
	1310nm	1550nm
0	37.98	36.73
5	39.73	36.62
10	38.58	36.7

Table 4.10 : Recorded data for 6 minutes

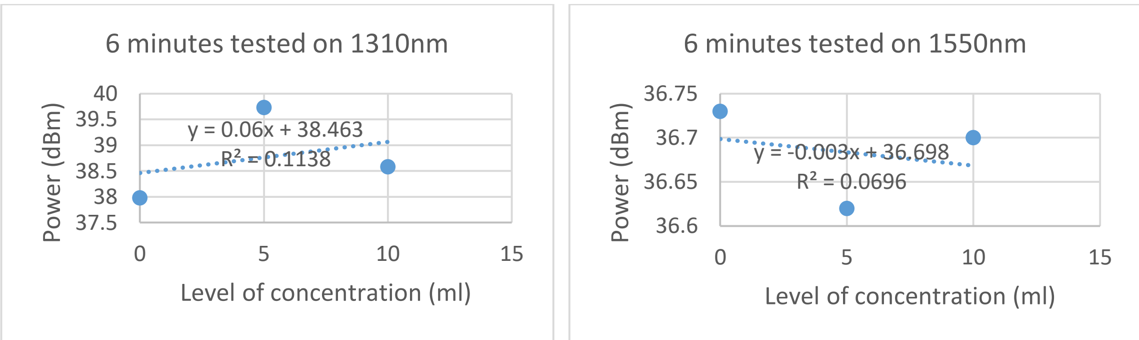

Figure 4.13 : Microfiber Single Loop Sensor response at 6 minutes

Table 4.10 presents the data recorded for the output power value (dBm) at the 6th minute for both optical light sources with different wavelengths. The two graphs above shows, that power increases for 1310nm and decreases for 1550nm with time. For 1310nm, the sensitivity is 0.06 whereas for 1550nm, the sensitivity is -0.003. By comparing both graphs, it is concluded that at the 6th minute for both optical light sources with different wavelengths, 1310nm is more sensitive than 1550nm.

4.6.7 7 Minutes Tested on 1310nm and 1550nm Wavelength.

Level of Cetirizine Concentration(ml)	Output power of 7 minutes (dBm)	
	1310nm	1550nm
0	38.01	36.76
5	39.76	36.63
10	38.61	36.71

Table 4.11 : Recorded data for 7 minutes

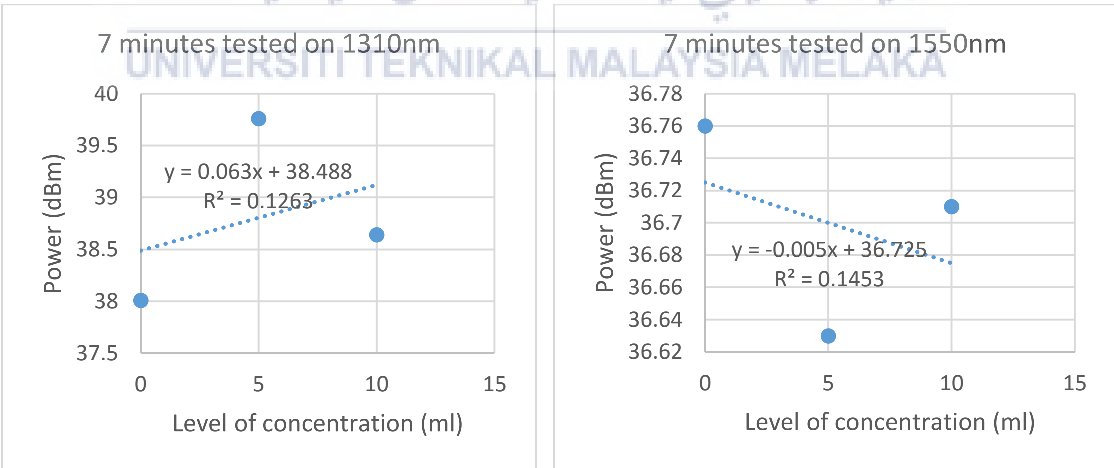

Figure 4.14 : Microfiber Single Loop Sensor response at 7 minutes

Table 4.11 presents the data recorded for the output power value (dBm) at the 7th minute for both optical light sources with different wavelengths. The two graphs above shows, that power increases for 1310nm and decreases for 1550nm with time. For 1310nm, the sensitivity is 0.063 whereas for 1550nm, the sensitivity is -0.005. By comparing both graphs, it is concluded that at the 7th minute for both optical light sources with different wavelengths, 1310nm is more sensitive than 1550nm.

4.6.8 Comparison between 1310nm and 1550nm for Single Loop

Time(mins)	1310nm		1550nm	
	Sensitivity(dBm)	Linearity(%)	Sensitivity(dBm)	Linearity(%)
1	0.054	35.28	0.192	81.55
2	0.058	33.76	-0.025	63.27
3	0.057	32.33	-0.002	13.19
4	0.059	33.33	-0.004	30.03
5	0.059	33.33	-0.002	13.19
6	0.06	24.49	-0.003	26.38
7	0.063	35.53	-0.005	38.12

Table 4.12 : Recorded data for output power (dBm) at 1310nm and 1550nm optical light source with different time (mins)

In conclusion, the analysis of sensitivity underscores significant differences between the two wavelengths. Specifically, at the 1-minute mark, 1550nm displays notably higher sensitivity, registering at 0.192dBm, in comparison to 1310nm, which records 0.054dBm. Interestingly, at the 2-minute mark, there is an unexpected reversal, with 1310nm demonstrating a greater sensitivity of 0.058dBm, whereas 1550nm shows a lower sensitivity of -0.025dBm. Notably, throughout the 3rd to the 7th minute, sensitivity values consistently favor 1310nm over 1550nm. Concerning the Linearity Comparison, at the 1-minute mark, 1550nm displays a markedly higher linearity of 81.55% in contrast to 1310nm, which registers at 35.28%. Throughout the duration of the experiment, linearity experiences fluctuations without exhibiting a consistent trend favoring either wavelength. Noteworthy is the observation at 3 minutes, where 1550nm showcases a lower linearity of 13.19% compared to 1310nm, which records 32.33%. Similarly, at the 7-minute mark, 1550nm's linearity at 38.12% slightly surpasses that of 1310nm, which is 35.53%. Overall, the sensitivity tends to favor 1310nm, while linearity fluctuates without a clear dominance of one wavelength over the other.

4.7 Average 1310nm and 1550nm for Single Loop

Level of Cetirizine Concentration(ml)	Average Power(-dBm)	
	1310nm	1550nm
0	37.86	36.62
5	39.56	36.17
10	38.44	36.31

Table 4.13 : Recorded data for average output power (dBm)

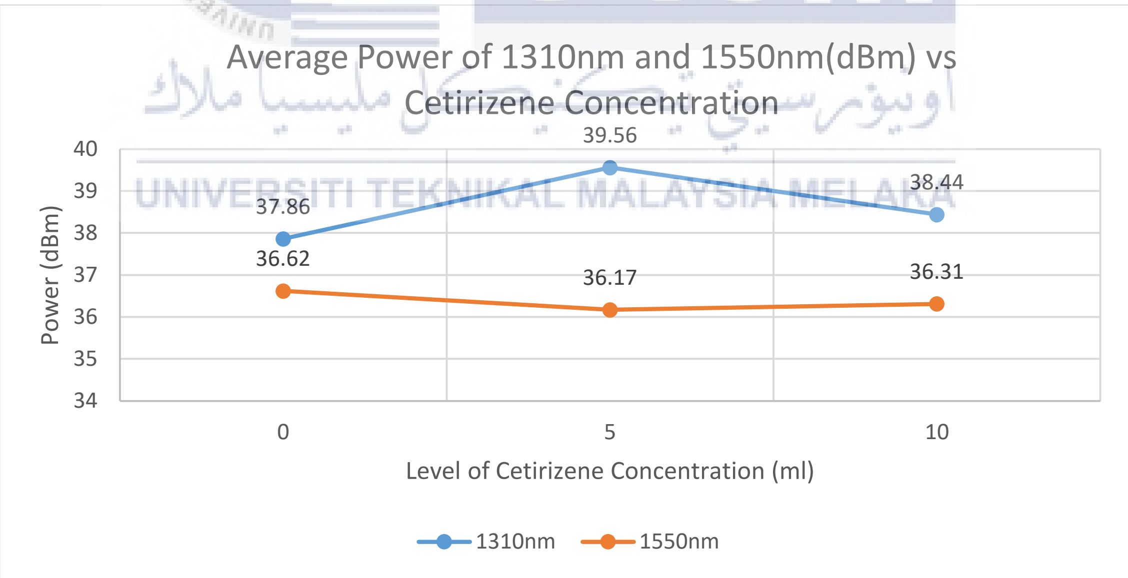

Figure 4.15:Average Power of 1310nm and 1550nm for Cetirizene Concentration

The provided table and graph for the single loop resonator offer valuable insights into the relationship between wavelength and average power across different concentration levels. Notably, the data reveals a consistent pattern wherein the average power for the 1550nm wavelength is consistently lower than that for the 1310nm wavelength across various level of concentrations. This consistent trend implies an inverse correlation between wavelength and average power in the context of the single loop resonator. In other words, as the wavelength increases from 1310nm to 1550nm, there is a corresponding decrease in the average power. This observation suggests that the higher wavelength, in this case, 1550nm, tends to result in lower power levels within the single loop resonator. Understanding and acknowledging this inverse relationship between wavelength and average power is crucial for optimizing the performance of the single loop resonator under various conditions.

4.8 Summary

This chapter presents a comprehensive exploration of the outcomes and data analysis derived from the development of an optical microfiber single loop resonator designed for a liquid sensor. The conducted tests cover critical aspects such as the sensor's sensitivity, linearity, operational capacities, and comparisons between 1310nm and 1550nm wavelengths. Additionally, the chapter delves into the assessment of average power for the single loop resonator across different concentration levels for both wavelengths. The results reveal a consistent pattern, demonstrating that the average power at 1550nm is consistently lower than at 1310nm across various level of concentrations, indicating an inverse correlation between wavelength and average power in the context of the single loop resonator. The observed trend emphasizes the importance of understanding this relationship for optimizing the resonator's performance under diverse conditions. Overall, the findings contribute significantly to substantiating the progress and refinement of the liquid sensor based on the optical microfiber single loop resonator.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the objectives of this project, which aimed to study the operation of a Fiber Optic Liquid Sensor, develop a microfiber single loop resonator for the sensor, and optimize its performance with varying concentrations, have been successfully achieved. The comprehensive exploration detailed in the results chapter highlights key aspects of the sensor's functionality, including sensitivity, linearity, operational capacities, and wavelength comparisons at 1310nm and 1550nm.

The pivotal finding of an inverse correlation between wavelength and average power in the context of the single loop resonator across different concentration levels adds depth to our understanding. Specifically, the consistent pattern of lower average power at 1550nm compared to 1310nm underscores the significance of wavelength selection in optimizing the sensor's performance.

These outcomes contribute significantly to the progress and refinement of the liquid sensor utilizing the optical microfiber single loop resonator. The project's success not only advances the understanding of fiber optic liquid sensors but also provides practical insights for optimizing their performance in real-world scenarios. Future research in this domain can build upon these findings to further enhance the capabilities and applications of microfiber single loop resonators in liquid sensing technologies.

5.2 Future Works

For future improvements, the microfiber single loop resonator for liquid sensor could be enhanced in several ways:

i. Enhanced Sensitivity: Researchers can explore techniques to further enhance the sensitivity of the microfiber single loop resonator. This can involve optimizing the design parameters, such as loop size, diameter, or shape, to maximize the interaction between the liquid and the resonator. Additionally, integrating advanced materials or coatings on the microfiber surface could enhance the sensing performance.

ii. Miniaturization: Further advancements in nanofabrication techniques can lead to the miniaturization of the microfiber single loop resonator, making it even smaller in size. This will allow for easier integration into compact devices or wearable sensors, enabling portable and on-the-go liquid sensing applications.

iii. Integration with Signal Processing: Integrating advanced signal processing techniques and algorithms can improve the accuracy and reliability of the microfiber single loop resonator. This can involve real-time data analysis, noise reduction methods, or machine learning algorithms to enhance the sensor's performance in complex liquid sensing scenarios.

By focusing on these areas of improvement, the microfiber single loop resonator for liquid sensor can further advance its capabilities and find broader applications in various industries, ranging from healthcare and environmental monitoring to chemical analysis and industrial processes.

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APPENDICES

GANTT CHART FOR FINAL YEAR PROJECT 1 AND PROJECT 2

ACTIVITY (FYP 1)	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Meet with supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Research literature review & gather information		■	■	■	■	■								
Submission of logbook progress						■						■		
Proposal writing	■	■												
Report writing		■	■	■	■	■	■	■	■	■	■	■	■	
Submission of draft report													■	
Submission of report													■	
Preparation for presentation														■
ACTIVITY (FYP 2)	**WEEK**													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Meet with supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Planning Experiment	■	■	■	■										
Submission of logbook progress						■						■		
Testing Experiment					■	■		■	■	■	■			
Data Analysis									■	■	■	■	■	
Writing chapter 4 and 5									■	■	■	■	■	
Submission of draft report													■	
Preparation for presentation														■

Appendix 5.1 : Gantt Chart For Final Year Project 1 And Project 2