Faculty of Electronics and Computer Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEVELOPMENT OF OPTICAL MICROFIBER SENSOR FOR ACETONE FOR DIFFERENT CONCENTRATIONS USING A TAPERING METHOD

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Bachelor of Electronics Engineering Technology with Honours

DEVELOPMENT OF OPTICAL MICROFIBER SENSOR FOR ACETONE FOR DIFFERENT CONCENTRATIONS USING A TAPERING METHOD

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APPROVAL

I approve that this Bachelor Degree Project 1 (PSM1) report entitled "Development Of Optical Microfiber Sensor For Aceone For Different Concentration Using a Tapering Method" is sufficient for submission.

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DEDICATION

I would like to express my gratitude and appreciation to all those who gave me the possibility to complete this report. A special thanks to our final year project supervisor, Dr Aminah Bt Ahmad, whose help, stimulating suggestions and encouragement. Helped me to coordinate my project, especially in writing this report.

To my dear family, your tolerance, support, and understanding gave me the groundwork to pursue my education. Your love was a source of strength during difficult times.

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My mother is watching from a distance, and my father is no longer physically there, but their spirits guide me through every page, every discovery, and every victory. This thesis serves as proof of the love and knowledge they gave me.

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ABSTRACT

Development of an optical microfiber sensor for acetone for different concentrations using a tapering method Fiber optics, commonly referred to as optical fiber, is a medium and system for transmitting information as light pulses over a glass or plastic strand. When light signals are transmitted through fiber optic cable, they bounce off the core and cladding in a sequence of zig-zag bounces, a phenomenon known as total internal reflection. Recently, optical microfiber sensors have received considerable research efforts due to their high sensitivity, detection speed, and ability to use harsh environments. This project aimed to use microfiber optics as a liquid sensor to detect different acetone concentrations using a tapering method. The single-mode fiber will be tapered using the tapering method, and the best size of microfiber optics will be used for further investigation as a liquid sensor. Furthermore, there will be three samples of different concentrations of acetone tested. Before each test, the fiber would be dipped in the samples and measured. In a line graph, each measurement would have different results. The experiment's findings will be described in terms of sensitivity, correlation, and coefficient of determination of the graph, all of completely dependent on the acetone concentration and light source.

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ABSTRAK

Pembangunan penderia mikrofiber optik untuk aseton untuk kepekatan yang berbeza menggunakan kaedah tirus Optik gentian, biasanya dirujuk sebagai gentian optik, ialah medium dan sistem untuk menghantar maklumat sebagai denyutan cahaya ke atas helai kaca atau plastik. Apabila isyarat cahaya dihantar melalui kabel gentian optik, ia melantun dari teras dan pelapisan dalam urutan lantunan zig-zag, fenomena yang dikenali sebagai pantulan dalaman total. Baru-baru ini, penderia mikrofiber optik telah menerima banyak usaha penyelidikan kerana kepekaan yang tinggi, kelajuan pengesanan dan keupayaan untuk menggunakan persekitaran yang keras. Projek ini bertujuan untuk menggunakan optik microfiber sebagai sensor cecair untuk mengesan kepekatan aseton yang berbeza menggunakan kaedah tirus. Gentian mod tunggal akan ditiruskan menggunakan kaedah tirus, dan saiz optik mikrofiber terbaik akan digunakan untuk penyiasatan lanjut sebagai penderia cecair. Tambahan pula, terdapat tiga sampel kepekatan berbeza aseton yang diuji. Sebelum setiap ujian, gentian akan dicelup ke dalam sampel dan diukur. Dalam graf garis, setiap ukuran akan mempunyai hasil yang berbeza. Penemuan eksperimen akan diterangkan dari segi kepekaan, korelasi, dan pekali penentuan graf, semuanya bergantung sepenuhnya pada kepekatan aseton dan sumber cahaya.

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TABLE OF CONTENTS

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF TABLES

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF FIGURES

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF SYMBOLS

µm	-	micrometer
θ_1	-	The incident angle between the light beam and the normal
θ_2	-	The refractive angle between the light ray and the normal
n_1	-	The refractive index of the medium the light is leaving
n_2	-	Refractive index of the material the light is entering
nm	-	Nanometer
dBm	-	Decibels per miliwattt
Ho	-	Make a decisson to reject or fail to reject the Ho

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LIST OF ABBREVIATIONS

SMF	-	Single Mode Fiber
MMF	-	Multimode FIber
RIU	-	Refractive Index Unit
OTDR	-	Optical Time Domain Reflectometer
NA	-	Numerical Aperture
OMR	-	Optical Microfiber Resonator
TIR	-	Total Internal Reflection

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF APPENDICES

اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 1

INTRODUCTION

1.1 Background

Fiber optics is a medium and system for transmitting data as light pulses through a glass and plastic strand. The method that sends information as light pulses along a glass or plastic fiber optic, often known as optical fiber. Glass or plastic is the two materials used to create optical fiber. Most can be miles long and have a human hair diameter . Light travels via the fiber centre from one end to another, and a signal may be enforced. In many applications, fiber optic technologies outperform metallic conductors. Their biggest perk is bandwidth. Since light has a longer wavelength than metal conductors, even coaxial ones.

Next, fiber optics refers to the technology that uses thin, flexible strands of glass or plastic to transmit information in the form of light signals over long distances. It is a crucial part of modern telecommunications and has revolutionized the way we communicate and access information. The technology is based on the principles of total internal reflection, where light waves are bounced back and forth within the core of the fiber optic cable, enabling them to travel long distances without significant signal loss or interference. These glass fibers can range in quantity from a few to several hundred in a fiber optic cable. Then, the glass fiber core is encircled by a second glass layer known as cladding. The buffer tube layer shields the cladding , and the jacket layer is the last line of defence for each stand.

Fiber optics has numerous advantages over traditional copper wire-based communication systems. The high bandwidth and low signal attenuation of fiber optic cables make them ideal for transmitting large amounts of data over long distances. They are also immune to electromagnetic interference and can operate in harsh environments without degradation in performance. Fiber optic technology is widely used in various applications such as telecommunications, internet connectivity, medical imaging, defence systems, and sensing applications. The technology continues to evolve, with ongoing research and development efforts to improve fiber optic systems' perfomance, realibility, and cost -effectiveeness. Overall, fiber optics has transformed the way we communicate and is an essential technology for modern society.

This project aimed to use microfiber optics as a liquid sensor to detect acetone for different concentrations using a tapering method. Several sample size of tapered microfiber will develop, and the best size will be selected for further investigation. There will be three different size of microfiber and three samples of different concentrations of acetone tested. The experiment's outcome will be described in terms of correlation, sensitivity, and graph coefficient of determination, all completely dependent on the three-difference size microfiber, acetone concentration and light source.

1.2 Problem Statement

Diabetes is a chronic medical disease that has an impact on how the body converts food into energy. Most of the human body's food is converted into sugar and released into circulation. Their pancreas is told to produce insulin when their blood sugar levels rise.Insulin functions like a key for blood sugar to entry body's cell and be used as energy. Diabetes is a condition in which the body either produces insufficient insulin or uses it improperly. Too much blood sugar remains in circulation when insufficient insulin or cells cease reacting to insulin. That can eventually lead to serious health issues like kidney disease, vision loss, and heart disease.

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Acetone in diabetes-affected breath increases the likelihood of effective therapy and upholds the need for an affordable, non-invasive, and quantitative diagnosis of diabetes mellitus. This study aims to analyse different acetone concentrations using an optical microfiber sensor by the tapering method.

Next, acetone is a commonly used organic solvent in industries such as pharmaceuticals, cosmetics, and chemical manufacturing. Its detection and measurement are important for process control and environmental monitoring. The proposed optical microfiber sensor aims to provide a highly sensitive and accurate means of detecting acetone in different concentrations. The tapering method will be employed to increase the sensitivity of the microfiber sensor by reducing its diameter and increasing the evanescent field, which can interact with the acetone molecules. The project aim to design, fabricate, and test the optical microfiber sensor for its sensitivity, selectivity, and repeatability. The successful development of this sensor can lead to a reliable and cost-effective solution for acetone detection and measurement in various industrial and environmental applications.

1.3 Project Objective

The objectives are stated below:

a) To study microfiber optics as a liquid sensor using the tapering method.
b) To develop the microfiber optics as a liquid sensor to detect Acetone at different concentrations using the tapering method.
c) To analyse the performance of microfiber optics as a liquid sensor in detecting Acetone for different concentrations using the tapering method.

1.4 Scope of Project

The project's aim is to investigate optical microfiber sensors and use liquid sensors made of microfiber optics to detect acetone at various concentrations. Additionally, the effectiveness of the developed sensors will be assessed. Before the sensors are spliced, the fibers are cleaned with alcohol to remove dust and then cleaved to produce a clean end-uncoated fiber and a smooth cleavage surface. Several sample sizes of tapered microfiber will develop, and the best size will be selected for further investigation. During testing, a 1550nm optical power source was used to gather the input wavelength, and an optical power metre was used to measure the output signal in (dBm) units.

Subsequently, the splicer join the sensors to form a connection between the two-fiber optics. Then, to detect and analyse various acetone concentrations, an optical power supply and an optical power metre are connected to each fiber optic sensor. Finally, the optical microfiber sensors developed for this project are used to measure the acetone sensitivity at different concentrations.

As a result, the experiment's result , will be reported in terms of sensitivity, correlation, and coefficient of determination of the graph. An optical power meter converts the findings to watts (dBm).

Table 1 Equipment used during this project.

Equipment	**Experiment Details**
Fiber optic	Single-mode fiber and fiber optic pigtail.
Size	125nm cladding glass
Liquid	Acetone
Hardware	Tapering Machine Optical Power Level/Source (1550nm) Mini OTDR power meter Commercial Splicer Fujikura FSM-18R Fujikura CT-30 Fiber Cleaver Spectrophotometer

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Microfiber refers to a type of material composed of ultrafine fibers, typically made of synthetic materials such as polyester or nylon. These fibers are much finer than human hair, with a diameter of less than 1 denier, and are densely packed to create a soft, lightweight, and highly absorbent material[6]. Microfiber has a wide range of applications in various industries, including textiles, cleaning products, and electronics. Its ability to absorb moisture and trap dirt and dust particles makes it an ideal material for cleaning cloths and towels. In the textile industry, microfiber is used to create high-performance clothing, such as sportswear and outdoor gear, due to its moisture-wicking and quick-drying properties. In recent years, microfiber has also been utilized in the field of optics to create ultra-thin optical fibers[4]. These microfibers, also known as optical microfibers, have a diameter of a few micrometers and are used to transmit light signals over long distances with minimal signal loss or distortion[10]. They have applications in various fields, such as telecommunications, sensing, and biomedical imaging. Overall, microfiber is a versatile material with numerous applications across various industries. Its unique properties, such as high absorbency, softness, and durability, have made it an essential material in many consumer and industrial products, and ongoing research and development are exploring new applications for this innovative material.

2.2 Optical Microfiber

A dielectric optical waveguide with a diameter of the order of 1 micron that has been drawn is what is referred to as an optical microfiber[4]. Due to its intriguing optical characteristics, which can be exploited to construct inexpensive, miniature, and fiber-based optical devices for a variety of applications, it has recently gained considerable interest[6]. For instance, a great deal of research has gone into creating microfiber-based optical

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resonators that can act as optical filters and have a wide range of potential uses in optical communication and sensing. Numerous microfiber structures, including the reef knot microfiber resonator as an add/drop filter, the microfiber loop resonator (MLR), the microfiber coil resonator (MCR), and others, have recently been discovered[5][1]. A wide evanescent field, high optical confinement, customizability, flexibility, and strong optical confinement are just a few of the distinctive qualities of microfiber optics. They are appropriate for physical sensing applications such highly sensitive surface absorption spectroscopy, hydrogen detection, chemical sensors, and refractive index sensors[1]. Therefore, high fractional evanescent fields enable a strong sensory response. The refractive index, core diameter, and operational wavelength of a fiber can all have an impact on the kind and quantity of modes that can travel through it. On the other hand, the majority of the light energy is maintained inside the fiber, with some going into the clothed. The tiny portion dissipates rapidly into the core-cladding's edge[2]. Common single mode fibers (SMF) can have their low amplitude evanescent fields enhanced by tapering to boost interaction with transmitted light at the taper area.

2.2.1 Single Mode Fiber

Single-mode fiber (SMF) is a type of optical fiber designed to carry a single mode of light. It is commonly used in telecommunications and data communication applications where high-speed, long-distance transmission is required.

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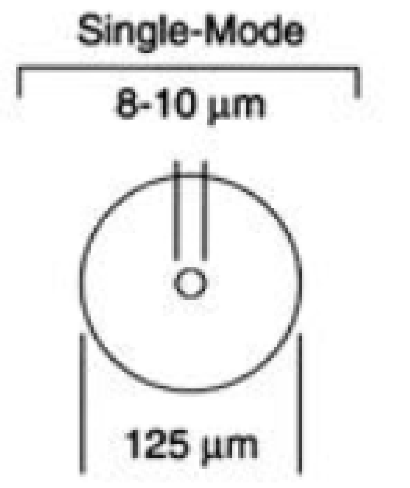

Figure 1 Single mode core and cladding measurement[25]

SMF optic cable has a small core diameter of 8-10 µm and a coating diameter of 125 µm as shown in Figure 1. The accurate small core diameter is 9 µm[25]. . Therefore, the ratio of the core to the cladding is typically 9:125. Only one light scattering band is permitted due to the tiny core design, as seen in Figure 2 below.

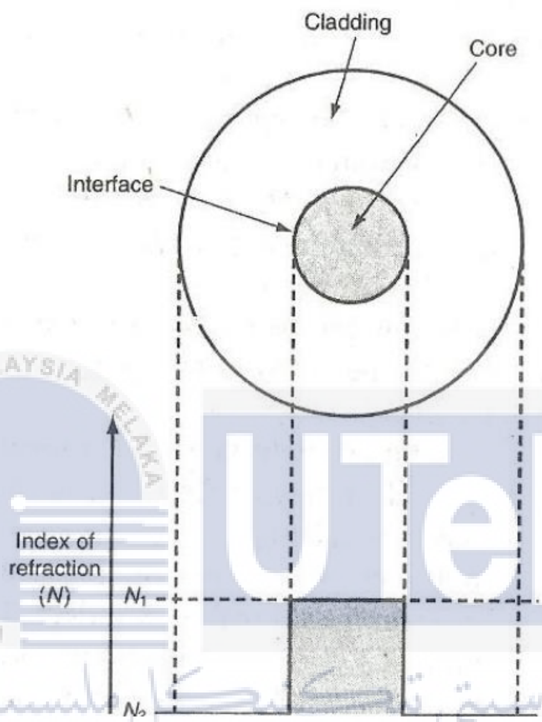

Figure 2 Single mode step index[24]

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The benefit of having a narrow diameter is that light may go further with little dampening since there is little light reflection as it moves through the core. As a result, it can transmit data more effectively and with less data loss, making it a good choice for communication[25]. It has a reduced data loss rate and is faster than multimode fiber at transmitting up to 40 GB of data over distances of hundreds of km.

The narrow multimer core, however, makes it challenging to insert the light because of the constrained mechanical tolerances of the connection with the connector[9]. As a result, building it is more challenging. Its price is therefore higher than that of multimode fiber.

2.3 Properties Of Optical Microfiber

Microfiber has a significant evanescent field, among other intriguing optical characteristics. At the small radii microfiber's external physical boundary, fractional power disperses in the evanescent field[2][3]. Making high quality factor (Q) resonators and beaming light into high Q microresonators both require this feature. Strong near-field interactions between microfiber and its surroundings are another characteristic. Microfiber and other waveguides like substrates, semiconductors, and planar waveguides have good evanescent coupling with each other. Many optical devices, including resonators, sensors, and lasers, were created as a result. For microfiber, propagation loss is a crucial characteristic as well. There are a number of causes for the propagation loss, including cracks, surface flaws, and contaminants in contact with the micro- or nanofiber surface[1]. It increases as the microfiber radii decreases.

To determine the smallest microfiber waist diameter at which a signal can propagate, theoretical research on non-adiabatic intermodal transitions were established. When the value is less than the radiation wavelength, the transmission mode would vanish at a threshold rate[1]. Furthermore, it has been discovered that small size microfibers deteriorate more quickly in air when water absorption causes facet cracks to form. Additionally, given to the small mass of microfiber, it is extremely sensitive to changes in photon momentum caused by mechanical displacement or vibration. Compact opto-mechanical component/device development is made possible by this. When light is travelling through acute bends, it also permits a minimal loss[2]. As a result, microfiber might produce small, power-efficient, responsive, and space-saving devices.

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To create microfiber, optical fibers are stretched until they have the necessary waist diameter while maintaining the original fiber sizes at their input and output ends[4][5]. This makes it simpler for a low loss splicing to interface with other optical fibers of a standard size. To create tiny devices, it can also be bent with a short bending radius. Additionally, the little waist fiber transmits a significant amount of power outside the microfiber and overlaps with the environment[2]. As depicted in Figure 3, any modifications to the properties nearby have an impact on the outcome.

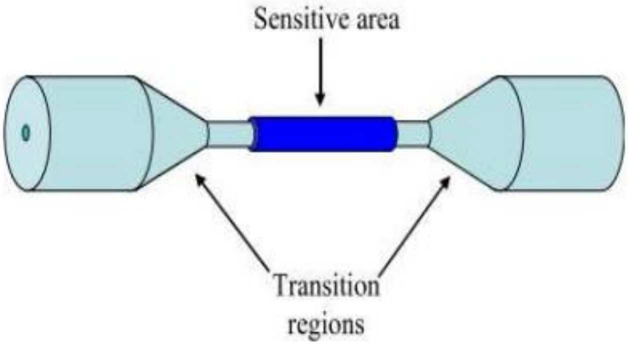

Figure 3 A significant portion of power is propagating through sensitive areas to interact with their surroundings[5].

2.4 Fabrication of Microfiber by using a Tapering Method

The production of fiber couplers and tapered fibers frequently use the flame brushing technique. It was also chosen for this study due to its high degree of flexibility in regulating the movement of the flame and the length and speed of the fiber stretching. Fabrication of the tapered fiber's or microfiber's dimensions can be done with reasonable accuracy and reproducibility[9]. The production of biconical tapered fibers with both ends attached to single-mode fiber (SMF) is made possible most importantly by this method. Low-loss microfiber-based devices can be made using these biconical tapered fibers[8].

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A schematic representation of the production of tapered fiber using the flame brushing technique is shown in Figure 4. Before creating the tapered fiber, the SMF has a coating length of several cm removed, as seen in Figure 4[6]. The SMF is then supported by two fibre holders and positioned horizontally on the translation stage. The uncoated fibre segment is stretched while the torch moves and warms it during the tapering process. The fiber is heated uniformly by the moving torch, and the tapered fiber is created along the heat region with good consistency. An amplified spontaneous emission (ASE) source from an erbium-doped fiber amplifier (EDFA) is injected into one end of the SMF while the other end is attached to the optical spectrum analyzer (OSA) in order to monitor the transmission spectrum of the microfiber during manufacturing[6][8].

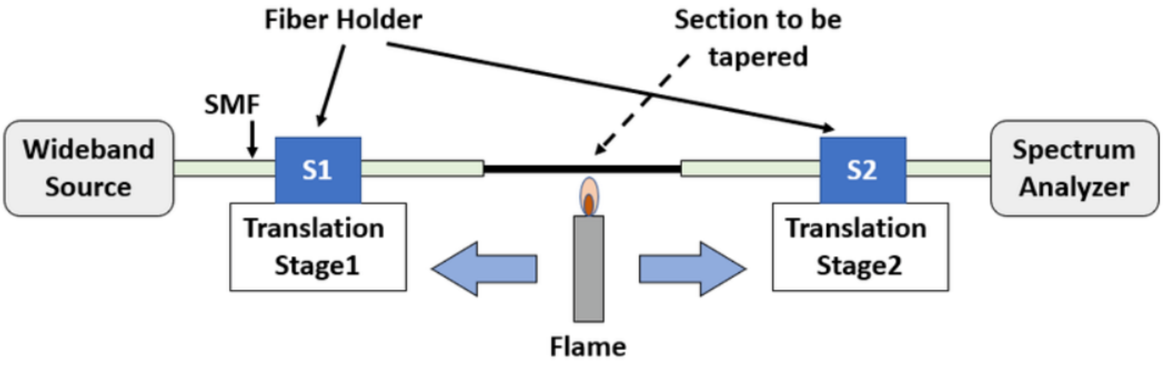

Figure 4 Fabrication of tapered fiber using the flame brushing technique[6]

2.5 Adiabaticity

One of the most important factors in the production of premium tapered fibers is adiabaticity. Furthermore, it is generally known that some tapered fibers lose power when the fundamental mode couples to higher order modes. As the tapered fiber propagates, some of the power from higher order modes will combine again and interfere with the fundamental mode[6]. It can be demonstrated by adding a slight taper angle to the relative local change of the taper radius. During the process of tapering, the fiber's radius decreases as it is drawn, and light spreads across the tapers region as it extrudes from the core to the cladding. The mode would therefore be affected by the core, cladding, and air[7]. Mode evolution inside the tapered fiber or microfiber is significantly influenced by the taper's form. If the taper is too high and the gearbox is low, a non-adiabaticity will develop. As the tapering angle is decreased, the mode propagation will consequently become more adiabatic.

2.5.1 Adiabaticity Criteria

Tapered fiber is fabricated by stretching a heated conventional single-mode fiber (SMF) to form a structure of reducing core diameter. The waist refers to the portion of the tapered fiber with the least diameter, as seen in Figure 5. The transition areas, whose cladding and core diameters are decreasing from the rated size of SMF down to the order of micrometre or even nanoscale, are located between the uniform unstretched SMF and waist[6][11]. The field distribution changes when the wave travels through the transitional areas as the core and cladding diameters change. The rate of diameter change of any local cross section for the propagating wave may be connected with the rate of energy transfer from the basic mode to the nearby few higher order modes, which are most likely to be lost[4]. The buildup of this energy transfer along the tapered fiber could result in a significant decrease in throughput. The excess loss can be minimised if the manufacturing of the tapered fiber complies with the adiabaticity criterion along the whole length of the tapered fiber.

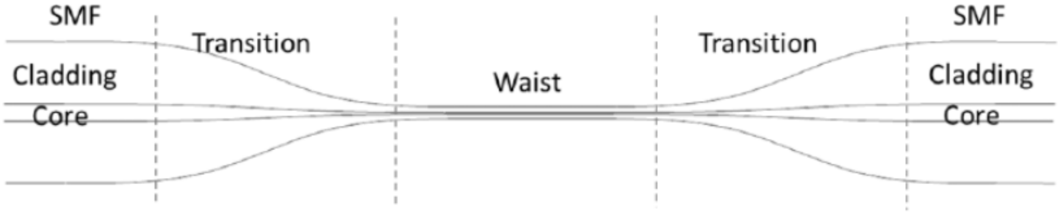

Figure 5 Typical diameter profile of a tapered fiber[6].

2.6 Optical Microfiber Devices

Optical microfiber devices have sparked a lot of interest due to their simple fabrication methods. The special optical characteristics of the device can be leveraged to create low-cost, miniaturized, all-fiber optical devices for a range of applications[1]. As a result, some researchers have concentrated on creating microfiber-based optical resonators, which can function as optical filters and have a variety of applications in optical communication, laser systems, and sensors. A wide range of photonic devices, lithographic planar waveguides being the most popular, can be constructed using microfibers. Microfiber Loop Resonator (MLR), Microfiber Coil Resonator (MCR), and Microfiber Knot Resonator (MKR) are just a few of the current microfiber devices that have been identified[5]. These microfiber-based devices are like lithographic planar waveguides in terms of capabilities, characteristics, and possibly miniaturization.

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2.6.1 Straight Optical Fiber.

An optical fiber that remains linear and straight over its whole length is referred to as a straight optical fiber. Straight optical fiber is purposefully made to have a hard and straight form, in contrast to ordinary fiber optic cables that can be flexible and readily bent[29]. Applications requiring exact alignment, stability, and little to no signal loss require straight optical fiber. It is frequently used in optical components or systems that need precise and dependable light transmission, such as optical switches, couplers, interferometers, and other optical components or systems[30].

A sensor that measures physical or environmental characteristics use a straight optical fiber. It functions by sensing changes in light as it engages with its environment. Because of the sensor's straight fiber, measurements are reliable and precise. It can keep an eye on things like humidity, pressure, strain, and temperature[30]. The sensors are incredibly sensitive, resistant to electromagnetic interference, and ideal for severe settings. They have uses in the automotive, healthcare, aerospace, and environmental monitoring industries. For different sensing needs, several approaches may be used[30].

2.6.2 D shaped Optical Fiber.

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D-shaped optical fiber is a specialized type of optical fiber that is designed with a flat or D-shaped cross-section instead of the traditional circular cross-section found in most fiber optic cables. This fiber's D-shaped profile enables special applications and advantages in some circumstances[26]. A classic D-shaped design has a flat side and a curved side that resemble the letter "D." While the curved side aids in maintaining the fiber's vital alignment, the flat side offers a surface for simpler coupling with other optical components, such as photodiodes or light sources[26][27].

Due to the tunability of the effective index and the energy distribution during optical fiber transmission, D-shaped optical fibers can be used for a variety of sensing applications. By adjusting the effective index, environmental factors can be determined by observing how the optical wavelength shifts[28]. Detecting changes in optical intensity allows for the realisation of energy distribution changes.

In applications where exact alignment and positioning of the fiber are crucial, this type of fiber is frequently employed. It is frequently used in optical couplers, switches, and other components that need precise and dependable optical coupling[26][28]. The efficient transmission and reception of optical communications is made possible by the D-shaped architecture, which provides superior control over the direction and location of the light within the fiber.

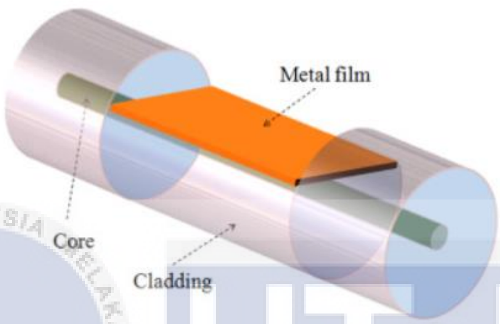

Figure 6 stereogram of structural [28].

It is crucial to examine the structure's arrangement since the D-shaped optical fiber sensor functions by keeping track of how the evanescent wave and surrounding medium interact[28]. The fundamental structure is created by side polishing a single mode fiber, which is made up of a cladding, a core, and a metal film, as illustrated in Figure 6.

2.7 Optical Sensor using Microfiber.

An optical sensor using microfiber is a sensor that detects and measures optical signals by making use of the characteristics of microfibers. Microfibers are incredibly thin fibers having sizes of a few micrometers or less. They are often constructed of materials like glass or polymers[5]. The waveguiding characteristics of these fibers are used by optical sensors based on microfibers to effectively guide and control light[2]. Here is a general explanation of how a microfiber-based optical sensor might function: for light guiding, the microfiber is made to have a high refractive index relative to the material it is placed in, allowing it to direct light through total internal reflection[2]. Light enters the fiber and spreads out throughout its entire length. Microfiber-based optical sensors have found use in a variety of industries, including telecommunications, chemical analysis, biological sensing, and environmental monitoring[14]. High sensitivity, compact size, low cost, and interoperability with fiber optic systems are only a few of their benefits.

2.7.1 Evanescent Wave

The core and cladding are the two primary components of a typical silica fiber. According to Snell law, the core is frequently doped with more refractive index (RI) material to ensure total internal reflection (TIR) under specific circumstances[5]. But there is always a tiny amount of evanescent field, or energy transfer, coupled with the cladding modes. Evanescent waves are electromagnetic field leaks or losses that are represented by a tiny amount of energy that seeps through the cladding and core edges during the TIR. TIR occurs when the incidence angle exceeds the critical angle, which causes light to bounce back from the core to the surface of the cladding[4]. According to studies, as the surrounding refractive index and normalised wavelength increase, the power fraction in the evanescent field also rises.

Smaller microfibers would therefore generate more evanescent wave fractional power. When the diameter of the fiber is equivalent to the wavelength, a little amount of power propagates in the evanescent field[9]. The evanescent field reacts to any environmental change in the immediate area, making sensing applications possible.Total Internal Reflection

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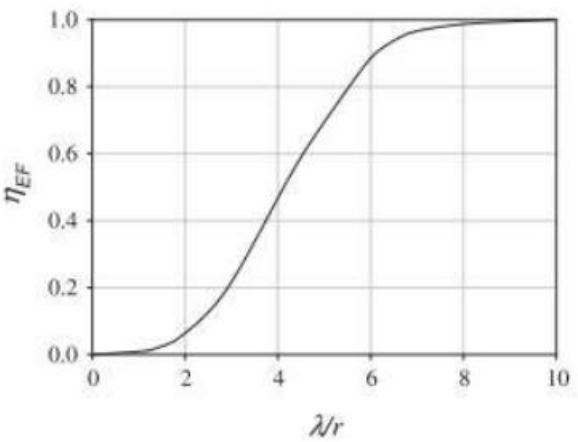

Figure 7 Relationship between fraction of power (ηEF) of the silica microfiber and the normalize wavelength (ƛ/r)[5]

2.7.1.1 Snell's Low Concept

Snell's law, sometimes referred to as the law of refraction, is a cornerstone of optics that defines how light waves alter their direction as they pass through different media[12]. It connects a light ray's incident angle to the refracted angle when it enters another medium. The ratio of phase velocities in the two media is the same as the ratio of incidence and refractive angles, according to Snell's law[4][5]. As a result, it is also equivalent to the refractive index ratio's reciprocal.

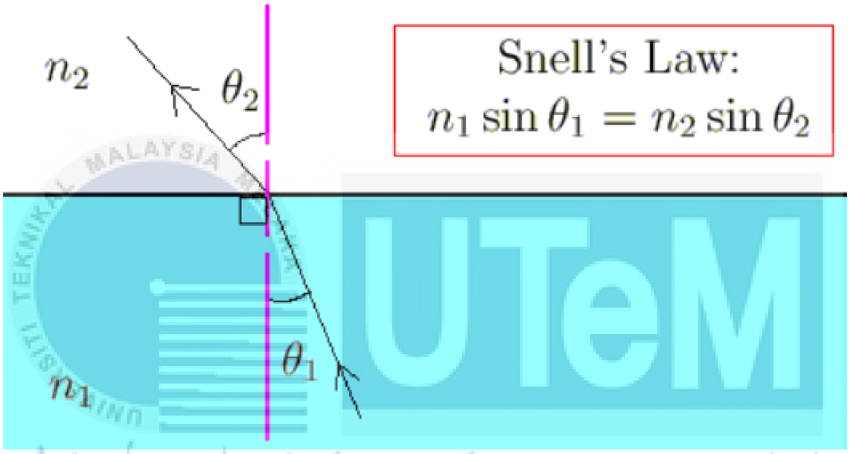

Figure 8 Snell's Law Concept

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Bases on the figure 19, the mathematical expression of Snell's law is as follows:

$n_1 * \sin(\theta_1) = n_2 * \sin(\theta_2)$

where:

- n_1 and n_2 are the refractive indices of the two media through which the light is passing.
- θ_1 is the angle of incidence, which is the angle between the incident light ray and the normal (perpendicular) to the surface separating the two media.
- θ_2 is the angle of refraction, which is the angle between the refracted light ray and the normal to the surface.

2.7.2 Optical Microfiber Resonators (OMRs)

Microfiber is a versatile material that may be used to create resonant structures like micro-loops, micro-knots, and micro-coils as well as to stimulate resonant modes like microspheres, micro-disks, microcapillaries, and micro bottles[11]. In order to create a compact resonator, this would result in modes propagating between two adjacent big evanescent field sections that overlap and pair. The quality factor Q is the most significant resonator parameter. By dividing the wavelength by the bandwidth (FWHM) of a resonance in the transmission spectrum as shown in (1), it can be estimated.

$$Q = \frac{\lambda}{FWHM}$$

Loop and knot resonators have been used by Vienna et al. as refractometric sensors. The sensors work by taking advantage of a substantial portion of the microfiber mode that transmits in the fluidic channel[11]. Any change in the analyte's refractive index would cause a shift in the resonance wavelength, as seen in Figure.

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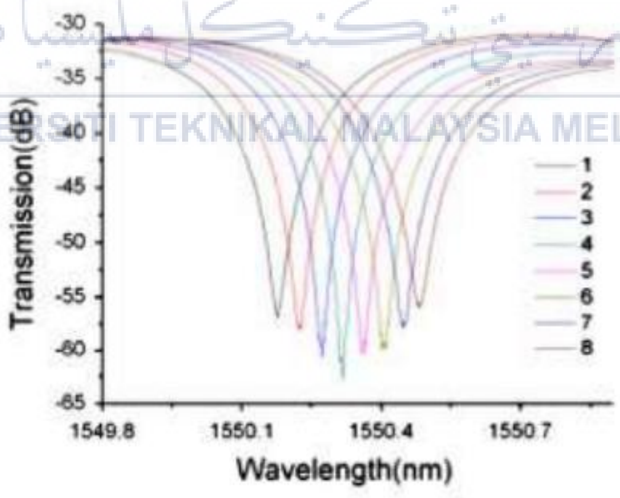

Figure 9 Refractometric sensors based on the wavelength change of the loop and knot resonators during resonance[5].

A refractometric sensor for microfluidic applications was created by Xu et al. by using a micro-coil resonator with an intrinsic channel. The same procedure is applied to a sensor with a refractometric loop resonator[12]. It functions similarly to a sensor with a refractometric loop resonator. The overlapping of the evanescent wave and the analyte during mode propagation in the microfiber is the cause of this. The resonant wavelength alters as the refractive index varies. The resonance wavelength shifts to a longer wavelength when the analyte's refractive index rises. These high-Q resonators are appropriate for evanescent sensing for chemical and biological detection due to their enormous resonator surface[13].

2.8 Fiber Optic Sensor for Acetone Detection

Acetone is a recognized biomarker for diabetes on a qualitative level. However, the quantitative data on the amount of acetone in diabetes breath is lacking, and it is unknown whether acetone levels in the breath correlate with the diabetic diagnostic measures blood glucose (BG) and glycohemoglobin A1C (A1C)[19]. Despite being influenced by degrees of fasting, body mass, and activity level (exercise)[20], some studies have indicated that acetone can also exhibit a non-linear and linear relationship[21].

Fiber optic sensors can also be utilized for acetone detection in the context of diabetes management[16]. When insulin levels are low, as they are in situations of diabetic ketoacidosis (DKA) or uncontrolled diabetes, the body produces a variety of ketone bodies, including acetone[16][17]. The metabolic condition of people with diabetes can be learned a lot by acetone monitoring[18].

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A fiber optic sensor can be used to create a breath analysis system[20]. A diabetic person's exhaled air would be monitored by the sensor, which would be made to measure and identify the amount of acetone present[18][22]. Breath contains acetone molecules that interact with the sensor, changing the light's wavelength or intensity as it travels down the fiber[21]. A non-invasive method of checking ketone levels is provided by the measurement of these variations and their correlation to acetone concentration[20].

Another option is to create a wearable gadget that uses sensors to continuously track the amounts of acetone in diabetic patients' skin or sweat[19][20]. The sensor would be built into a wearable patch or other gadget, enabling real-time acetone level monitoring[22]. Continuous monitoring provided by this strategy enables early identification of metabolic abnormalities and prompt action[16][21].

2.9 Microfiber Optic's Application

Microfibers are exceptional materials that are perfect for functionalizing fiber-optic circuits on a micro or nano scale because of their tight optical confinement, high fractional evanescent fields, and large tunable waveguide dispersion[1]. With its thin and flexible fibers, microfiber optics has a wide range of applications in various sectors of the economy. It is widely used in telecommunications to transmit high-speed data across fiber optic connections[7]. Microfiber optics also have a significant impact on sensing and measurement applications, enabling precise monitoring of physical properties. Microfiber-based endoscopes are revolutionizing less invasive procedures and imaging in the medical field[10]. As a result, they help with environmental monitoring, gas sensing, and medical diagnostics. They are also used for optical sensing and detection of numerous compounds.

2.10 Summary

The methods for creating tapered microfibers are discussed in this chapter. In this section, we'll talk about how to make microfiber by employing the flame brushing method. This chapter has therefore covered three microfiber-based devices, the MLR, MKR, and MCR. The method of production, properties, and uses of an optical microfiber have all been extensively studied up to this point. These tiny fibers have provided a number of advantageous qualities for controlling light on the micro or nanoscale as well as a new platform for both scientific research and technological applications by shrinking optical fiber widths to the wavelength scale. Numerous new applications of optical micro or nano in atom optics have recently been demonstrated, and these may open up new possibilities for using light in ways other than optics and pave the way for a bright future for fiber optics and technology. These applications are based on their ability to waveguide tightly confined evanescent fields with low losses, strong near field interaction, and miniature sizes.

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CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter introduces the design process of microfiber optics as a liquid sensor which includes detailed information on the tools and components used, the sensor manufacturing process, prototypes, and other topics. The proposed study aims to create a sensor that can detect Acetone in different concentrations using a tapering method.

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3.2 Project Flowchart

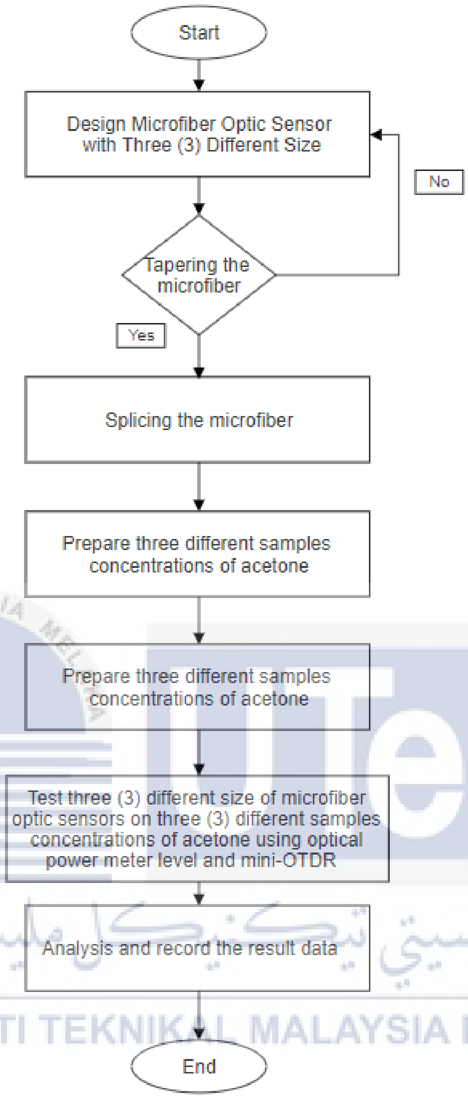

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Figure 10 Process flow of project.

From Figure 10, the project started with the design of microfiber optics as a sensor to Acetone using a tapering method. There will be three different size of fiber optic for different concentrations of Acetone tested. Each measurement would yield a different result in a first line graph. The125nm single-mode fibre was first cut to the same length to minimise losses throughtout the experiment. The following stage involved getting ready three samples of various fibre optic sizes and three samples of various acetone concentration.

Each fiber will be analysed and monitored when the setup is complete in order to derive an average measurement. The experiment's outcomes will be discussed in terms of the graph's sensitivity, correlation, and coefficient of determination, all of which are entirely dependent on the amount of acetone and the light source.

3.3 Method of Project

During each step of project development, complementary models, facilities-specific techniques, and equipment-specific techniques must be applied in accordance with the approach. A methodology is composed of numerous methods, each of which is employed to deal with a distinct component of the methodology as a whole. Several methods can be used to increase the sens or structure. To complete these, follow the steps given below.

3.3.1 Splicing Process

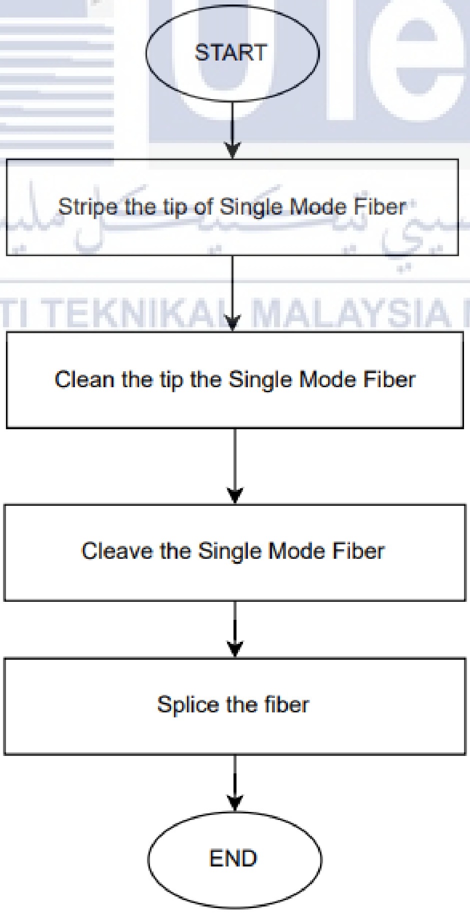

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Figure 11 Flowchart of Splicing Process

Firstly, a fiber optic cable stripper is used to remove the coating layer of a Single Mode Fiber. After that, alcohol cleans the fiberss and removes any leftover coating or dust. The fiber is then cut off using a high-quality cleaver like the Fujikura CT-30 to produce flat faces.

The joining of two fibers after they have been cleansed and stripped of their cladding is accomplished using the Fujikura FSM-18R splicing tool. The fiber will then be mounted on the splicer with the fibres positioned parallel to one another. Table 2 illustrates the entire connection process.

Table 2 Detailed instructions for using the Fujikura FSM-18R to splice.

No	Procedure	Description
1		List of the apparatus that used in stripping and splicing.
2		Press the "ON" button to switch on the Fujikura FSM-18R.

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3		Remove the second layer (cladding) on the optical cable.
5		Remove the dust using alcohol and tissue.
6		Cut the optical cable using a high precision cutter.
7		Place the cable on the separator, and make sure the cable is in the same position.

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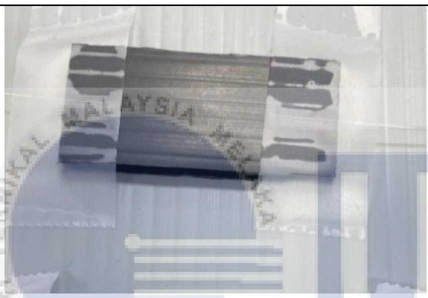
8		Press start and wait until the connection is complete.
9		The connecting cable is ready to be laid on the stage.

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3.3.2 Measured concentrations acetone process

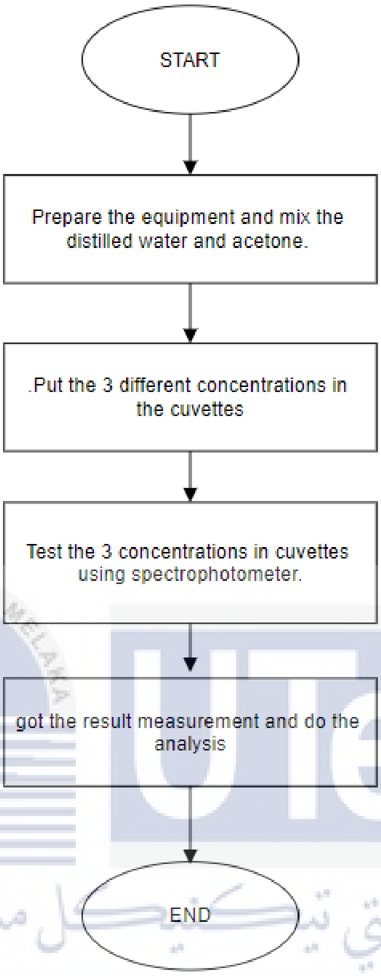

Figure 12 Flowchart of concentration measurement

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The wavelength concentration set to determine the concentration of acetone is 550nm. This spectrophotometer will provide values in transmittance, absorption, factor, and concentration. By having that value, the acetone concentration can be distinguished and determined through this method. Before using this spectrophotometer, acetone must be measured and mixed with distilled water to make various desired differences such as 100% concentration, 70% concentration, and 50% concentration.

Table 3 Completed step of measurement concentrations of acetone

1. Prepare the equipment for mix the distilled water and acetone.	
2. First, put the 30 ml acetone and 30 ml distilled water in a beaker to get the 50% concentrations. Then repeat the same step by putting 30 ml acetone and 5 ml distilled water to get the 70%concentrations. For 100% concentrations, only acetone for 30ml.	
3. Put the three different concentrations in the cuvettes.	

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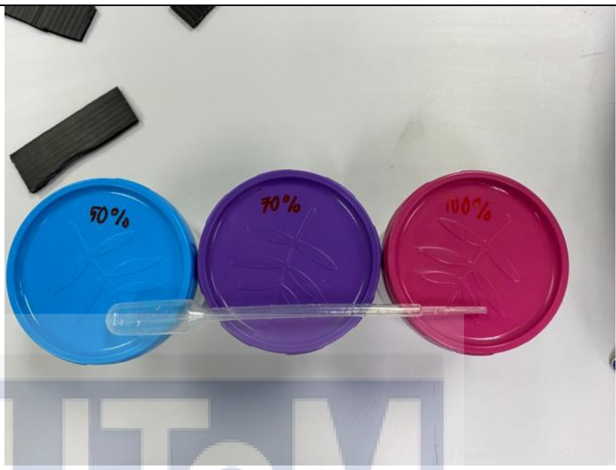
4. Test the three concentrations in the cuvettes using a spectrophotometer to get the result.	
5. The three different concentrations will be transferred in the container.	

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3.3.3 Tapered Fiber of Fabrication Prcoess

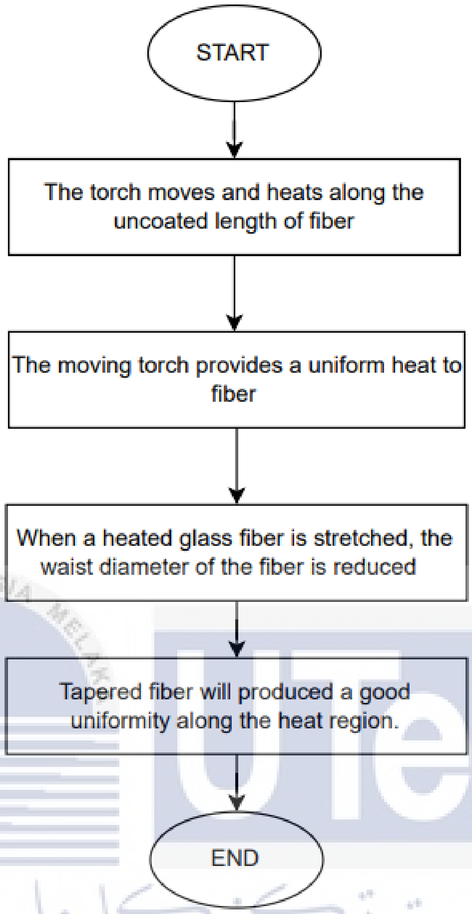

Figure 13 Flowchart of tapered fiber fabrication.

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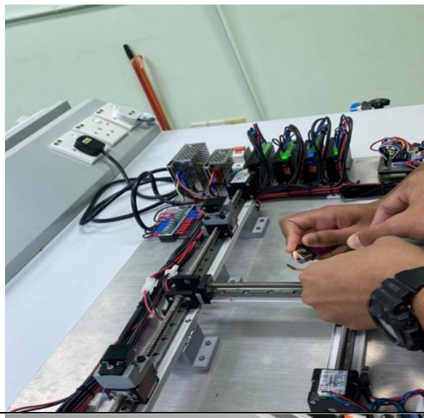
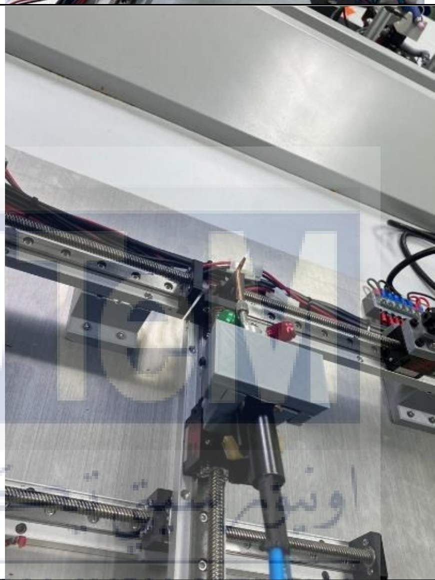
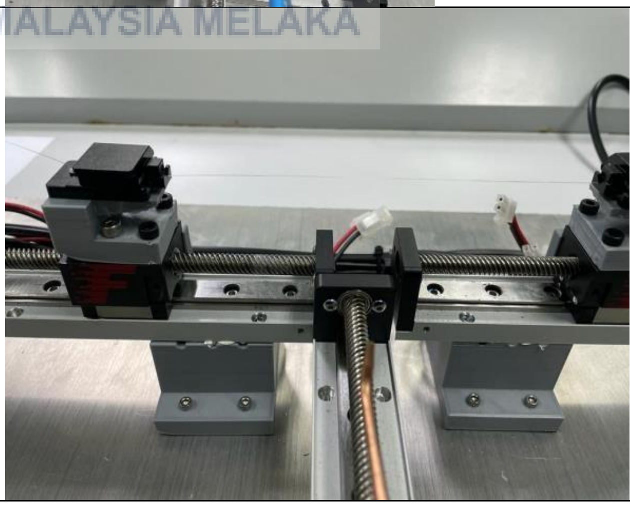
First, to create tapered fiber, a coating length of several cm from the SMF is removed. The SMF is then placed horizontally on the translation stage while being held by two fiber holders. Then, as the fiber is being tapered, the torch moves forward and warms up throughout the length of the uncoated fiber. The heat source is an oxy-butane torch flame with a width of 1mm. Two internal stepper motors control the translation stage and torch motions. The moving torch then evenly heats the fiber. The waist diameter of a stretched heated glass fiber shrinks. Along the heat region, the tapered fiber is produced with good homogeneity.

Table 4 Complete steps on the tapering process

No.	Description	Picture
1	The microfiber tails on both sides will then be placed on the grip so that it cannot move. Then we turn on the fire.	
2	The fiber coating-removed section is exposed to the heat source while the fiber tails are pulled in opposite directions.	
3	After clicking the stop button, we can see that the microfiber is already thin.	

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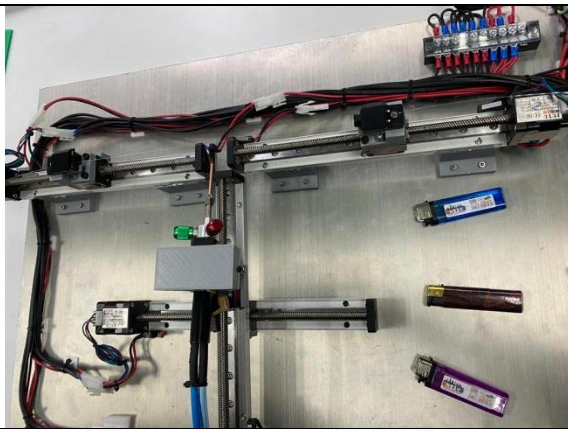
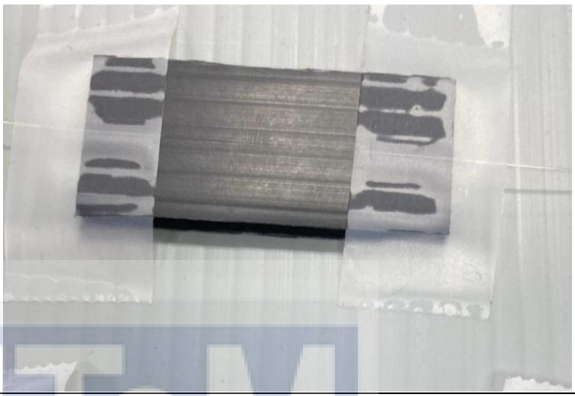
4	Take the fiber optic out from the grip carefully. Then, transfer it to the plastic cardboard.	
5	Placing the microfiber on plastic cardboard	

3.3.4 Experimental Setup Process

This section will proceed with the experiment procedure process to achieve the purpose of this project.

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3.3.4.1 Preparations of the Microfiber Optic Sensor and three different concentrations of acetone.

For the process of preparations, the microfiber optic sensors can be seen in Table 1 and make the three samples microfiber optic sensors for different acetone concentrations, as shown in Figure 13. Then, make three different acetone concentrations: 100%, 70%, and 50%.

Figure 14 Microfiber Optic Pigtail

Prepare three different concentrations of acetone, which are 100% concentrations, 70% concentrations and 50%concentrations. Filling in the small container makes it easier to test the experiment with a small container.

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Figure 15 Three types of concentrations of acetone.

3.3.4.2 Procedure Material and Equipment Setup

Firstly, prepare the Optical Power Level and mini OTDR Optical Power Meter by setting the wavelength to 1550nm and plugging the fiber optic pigtail illustrated in Figure 16. Then, the plastic container containing different acetone concentrations will be tested, and the process will be run by taking the reading of sensitivity, linearity, and repeatability with the Optical Power Level and Optical Power Meter for different acetone concentrations. Finally, each different acetone concentration can be monitored by the Optical Power Level and Optical Power Meter for 30 minutes, with the output measured in decibels (dBm) and taken every 3 minutes at a wavelength of 1550nm.

Figure 16 Optical Power Level and mini OTDR Optical Power Meter

Figure 17 Concentrations of acetone process.

3.4 Tools and materials

All materials and equipment used in the project are shown in Table 3.

Table 5 Materials and equipment utilised in the project.

Material and Equipment	Description
 SimpliFiber® Optical Power Level	- Optical Power level is a source of input connected to the fiber.
 Mini-OTDR Optical Power Meter	- The output to measured and sent to the display. - The device will display the measurement result.
 Commercial Splicer Fujikura FSM-18R	- Splice the fibers together. Its creating connections between two fiber optic cables to ensure the continuity of communication between two slice of fiber optic.
 Cleaver Fujikura CT-30	- Obtain the flat tip of the fiber. Cleaver is the tool that holds the fiber under low tension, scores the surface at the proper location, then applies greater tension until the fiber breaks

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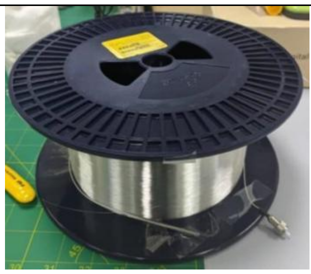
 Fiber optic stripper	- Remove the first and second layer (cladding) on the optical cable.
	- Used in sensor development, The size of fiber optic is 125nm.
 Single mode connector (pigtail)	- Use to connect an optical spectrum analyser to a sensor.
 Rubbing Alcohol	- To remove residue or dust after splitting and before connecting.
 Tissue	- Use with alcohol to clean the fibers.

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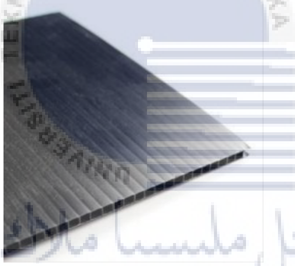
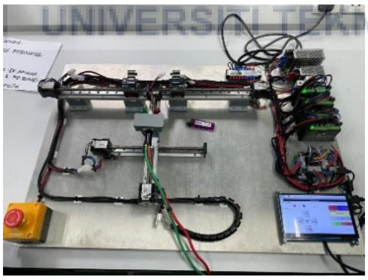
 Acetone	- Acetone is the main liquid in this experimental, acetone was put at the fiber optic.
 Dropper feeder	- Used to transfer acetone into fiber optic
 Impra board	- To lay the fiber after the fiber becomes a splice. - Used as the main supply point for experiments.
 Tappering Machine	- The fibre is stretched during this operation, which reduces the heated section's diameter.
 Spectrophotometer	- Analyse the intensity in relation to the light source's wavelength.

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3.5 Experimental Setup Project

In this section, the microfiber optic sensor setup will show the flow of the connection of components and equipment with its function.

3.5.1 Tapered Fiber Fabrication using a Flame.

Biconical tapered fibers can be created using this method and connected to single-mode fiber (SMF) at both ends. Low-loss microfiber-based devices can also be created using these biconical tapered fibers. A schematic representation of the manufacturing of tapered fibers using the flame-brushing method is shown in Figure 15. In order to create tapered fiber, the SMF had a coating length of several cm removed, as shown in Figure 15. The SMF is then positioned horizontally on the stage and secured with two fiber holders.

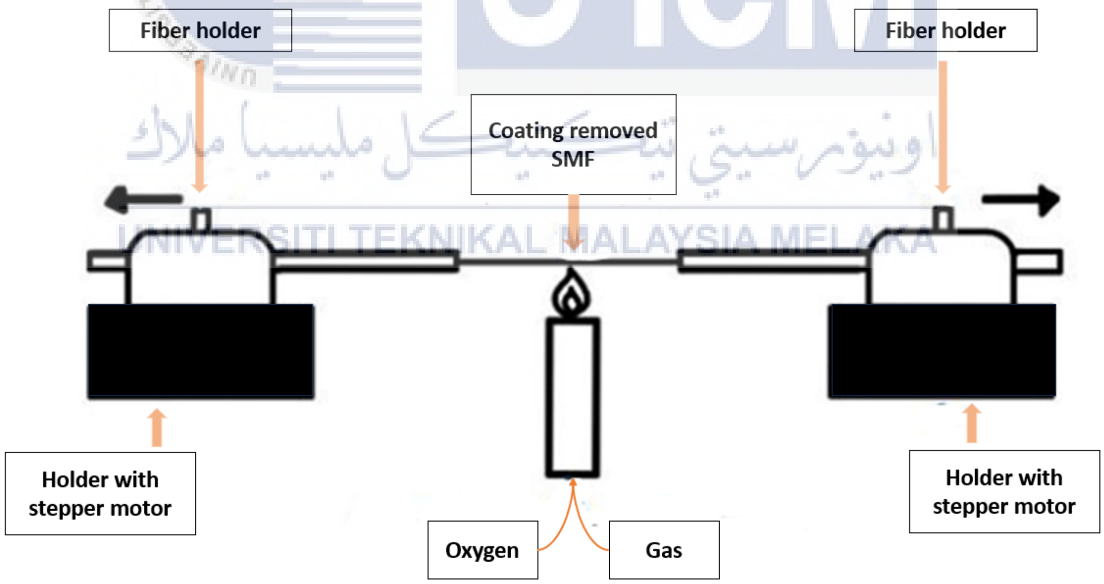

Figure 18 Experimental setup for the production of tapered microfiber using the flame blushing technique.

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3.5.2 Microfiber Optic Sensor to Detect Acetone.

To evaluate the different concentrations of Acetone, single mode fiber optic sensors are connected to an Optical Power Level at the input. The Optical Power Level emits a wavelength of 1550nm to the fiber. The result is then recorded in dBm by the Optical Power Meter, as shown in Figure 16 below.

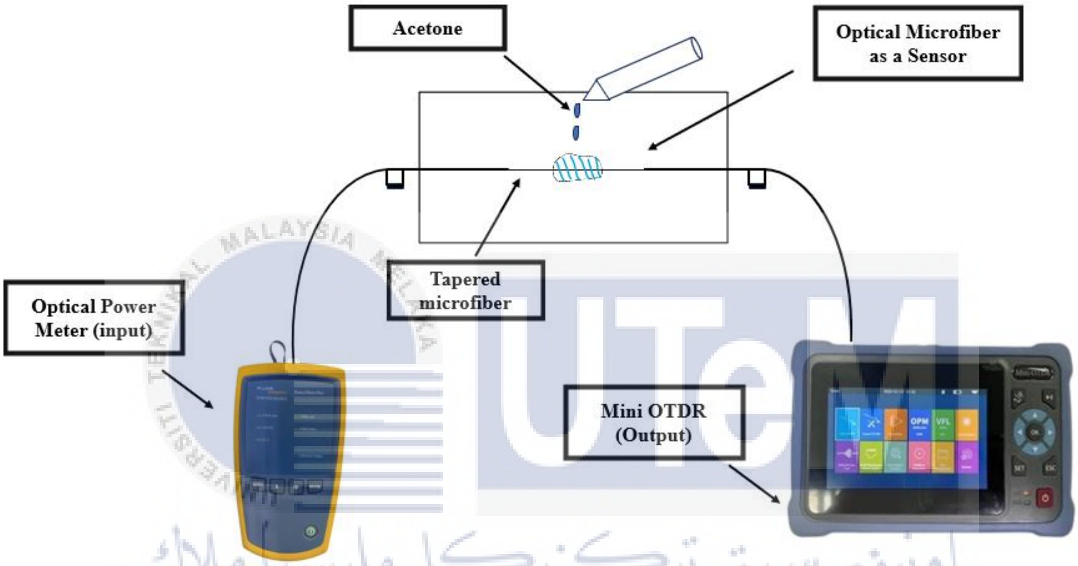

Figure 19 Experiment setup of optical microfiber sensor to acetone in different conce ntrations.

There will be three different sizes of fiber optic, and will choose one the best size fiber optic and three samples of different concentrations of Acetone will be tested. In a line graph, each measurement would have a different result. The optical microfiber will act as a sensor to detect the Acetone in different concentrations. The acetone is put onto the microfiber optic for the first 100% acetone, second at 50% acetone, and lastly at 20% acetone. This will determine the reading value due to the different concentrations of Acetone.

The results were analysed, and the experiment's findings will be described in terms of the graph's sensitivity, correlation, and coefficient of determination, which are all completely dependent on the acetone concentration and light source.

3.6 Summary

This chapter outlines the suggested process for creating an optical microfiber sensor for acetone at various concentrations using a tapering strategy. The primary objective of the suggested methodology is to increase the optical power level and the power meter's waveform output value. Instead of achieving the highest level of accuracy, the technique's ultimate goal is to optimise the effectiveness, simplicity of use and manipulation, and usefulness of microfiber optic sensors.

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CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The results and analyses of the development of a microfiber optic as a liquid to detect acetone using a tapering method are presented in this chapter. Case studies are conducted to demonstrate the sensitivity of microfiber. There will be three different sizes of fiber optic and three samples of different concentrations of acetone tested. Before each test, the fiber would be dipped in the samples and measured. In a line graph, each measurement would have different results. The case study will describe the experiment's findings to determine the graph's sensitivity, linearity, and repeatability, which completely depend on the acetone concentration and light source. Each different size fiber optic and acetone concentrations are subjected to the proposed method, which involves testing three times due to the percentage value.

4.2 Results and Analysis

This chapter will analyse the three different sizes of fiber optic and three samples of different acetone test results. These analyses are divided into several pieces of information: number of tests, average time spent each time, and linearity percentage, which indicated a high sensitivity, consistency, repeatability, and stable execution test during the analysis.

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4.2.1 Size of tapered microfiber.

The size of the microfiber is measured using a microscope at the FTKIP lab. It is crucial to ascertain its size to assess the microfiber's sensitivity level. The fiber's diameter at first was 125 µm. After the tapering process, the measured sizes are 51.7 µm, 33.6µm and 21.5µm. The range of axis-y is measured to investigate sizes.

Figure 20 Microfiber size determination using a microscope

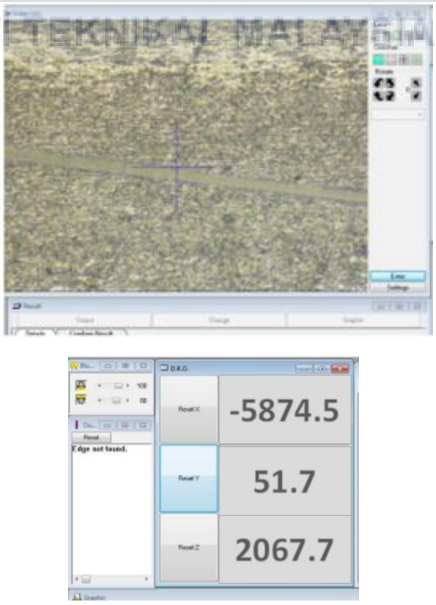

Figure 21 Sample fiber A (51.7µm)

Figure 21 shows the screen of the microscope for sample fiber A. The first sample of microfiber has been tapered about 51.7 µm in diameter. The diameter of axis-Y for the first sample shows the biggest size among the three tapered sample sizes.

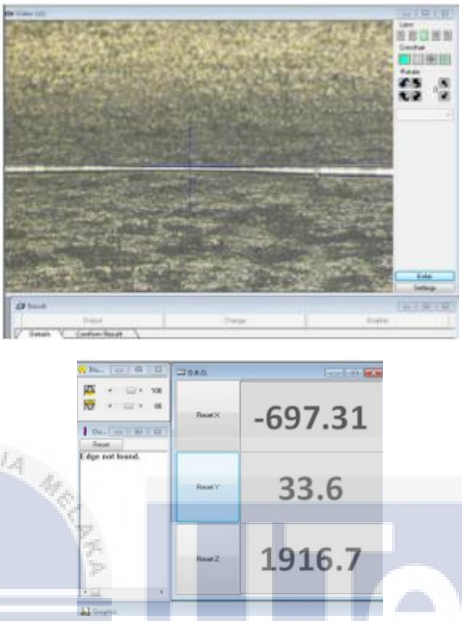

Figure 22 Sample fiber B (33.6µm)

Figure 22 shows the screen of the microscope for fiber B. This sample has been the second smallest in size that has been tapered.

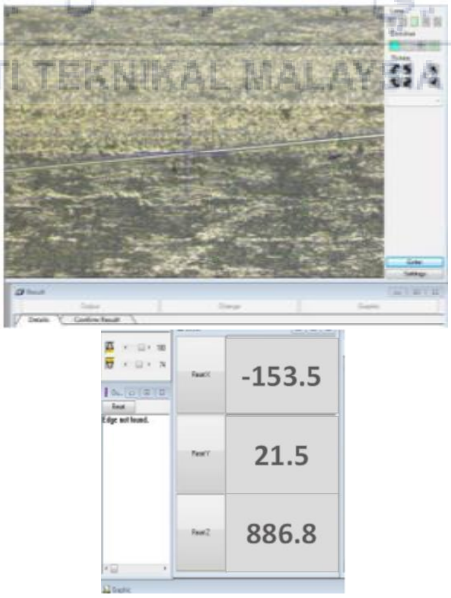

Figure 23 Sample fiber C (21.5µm)

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Figure 23 shows the screen of the microscope for fiber C. This sample has been the smallest in size that has been tapered.

4.2.2 Sizing of microfiber optics sensor on 100% acetone.

The requirements and specific applications dictate the dimensions of the microfibre optic sensor. Microfiber optic sensors are small and flexible by nature, making them useful for various applications such as liquid, temperature, pressure, humidity, and refractive index monitoring. Several factors such as, the intended level of sensitivity, the material to be detected, and the environment in which the sensor will be used, will determine the appropriate size. The analysis is based on the sensitivity and linearity percentage of the performance of different size microfiber optics as a liquid sensor on 100% acetone concentrations to find the best size with the highest sensitivity. Through this analysis, the output power has been observed and recorded for every size of microfiber using 100% acetone concentrations, as shown in Table 6.

Table 6 Data collected from three different size of mircofiber

Concentrations of acetone	Times (minutes)	Fiber A	Fiber B	Fiber C
100%	1	-39.88	-39.72	-38.13
	2	-40.02	-40.01	-38.42
	3	-40.11	-40.07	-39.75
	4	-40.18	-40.09	-39.75
	5	-40.21	-40.11	-39.93
	6	-40.22	-40.12	-39.97

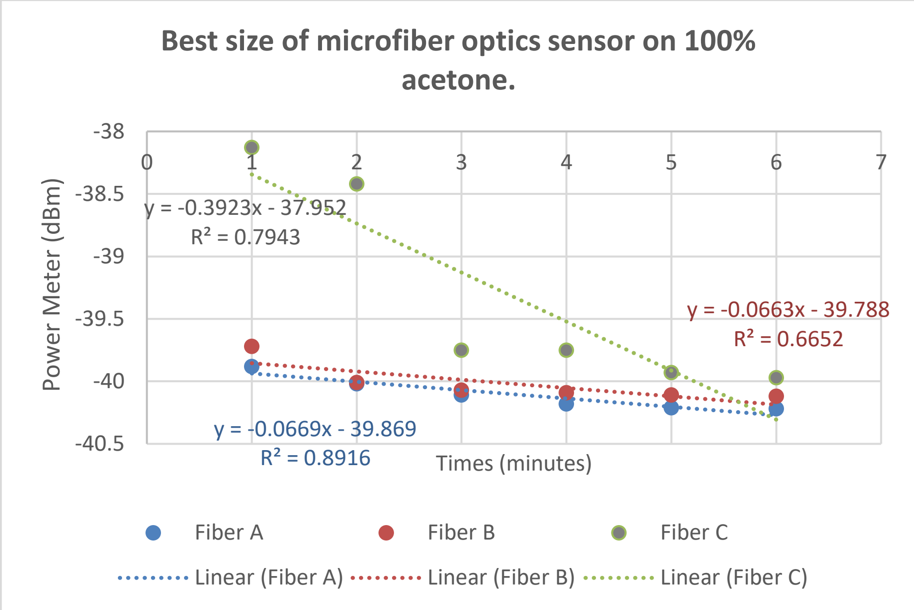

Figure 24 Graph for the sensitivity of three different sizes of microfiber in 100% acetone.

Figure 24 shows the regression line of three different sizes of microfiber at 100% concentrations of acetone (dBm) using a wavelength of 1550nm. In Fiber A and B, the stability of the power meter in dBm is stable from the start value to the initial value. For Fiber C, there is a distinct tendency for the cycle to go down and not return to its initial value. Next, for fiber A whose size is 80.2µm, the sensitivity are 0.0669 was a lowest sensitivity. Then, for the fiber B which size 66.7µm, the sensitivity was 0.0663 are also a lowest sensitivity. For the fiber C which size 40.3µm, the sensitivity are 0.3923 was a highest sensitivity. The sensitivity value of microfiber optic sensor size C is a higher compared to the sensitivity value of microfiber optic sensor size A and B. In other words, the ideal size for monitoring acetone concentration is microfibre optic sensor size C.

Table 7 Sensitivity and Linerity three size microfiber

Fiber	Sizing	Sensitivity	Linearity
A	51.7 µm	0.0669	0.9442
B	33.6µm	0.0663	0.8156
C	21.5µm	0.3923	0.8912

Table 7 shows the sensitivity and linearity values for each microfiber optic sensor at different sizes for acetone concentrations at 100%. The sensitivity values for each type of fiber shown in the table are taken from the slope value of the regression line by omitting the value sign. It is found that fiber C has the highest value compared to other types of fiber, which indicates that fiber C has a higher sensitivity value. The value linearity for three different-size microfiber optic sensors shows the result of 0.9442, 0.8156, and 0.8912 for fibers A, B, and C, respectively. Therefore, the correlation coefficient between the values of three microfiber optic sensors indicates a strong negative linear correlation.

4.2.3 Three samples of different concentrations of acetone test results.

The 550nm wavelength is set to determine the concentration of acetone. This spectrophotometer will provide values in transmittance, absorption, factor, and concentration. By having that value, the acetone concentration can be distinguished and determined through this method. Before using this spectrophotometer, acetone must be measured and mixed with distilled water to make various desired differences, such as 100% concentration, 70% concentration, and 50% concentration. The spectrophotometer from the FTKE laboratory is used to measure the acetone concentrations to get the three samples of acetone concentrations. First, put the 30 ml acetone and 30 ml distilled water in a beaker to get the 50% concentrations. Then, repeat the same step by putting 30 ml acetone and 5 ml distilled water to get the 70% concentrations. Meanwhile, for 100% concentrations, 30 ml acetone is used. Then, the three concentrations in cuvettes were tested using a spectrophotometer, and the result is shown in Table 8.

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Table 8 The result concentrations from the spectrophotometer

Concentrations Acetone	Transmittance	Absorption	Factors	Concentrations
50%	80.5	0.094	1000	94
70%	80.1	0.096	1000	96
100%	79.6	0.0100	1000	100

4.2.4 Result fiber A with 100%, 70% and 50% acetone concentrations.

The analysis is based on the sensitivity and linearity percentage of the performance of different concentrations of microfiber optics A on 100%, 70% and 50% acetone concentrations to observe the concentrations with the highest sensitivity. This analysis shows the output power observed and recorded for every acetone concentration, as shown in Table 9.

Table 9 Data collected from 3 different concentrations of acetone of Fiber A

Fiber	Times (minutes)	100%	70%	50%
A	1	-39.88	-36.63	-36.43
	2	-40.02	-36.97	-36.56
	3	-40.11	-37.01	-36.71
	4	-40.18	-37.02	-36.71
	5	-40.21	-37.03	-36.99
	6	-40.22	-37.04	-36.99

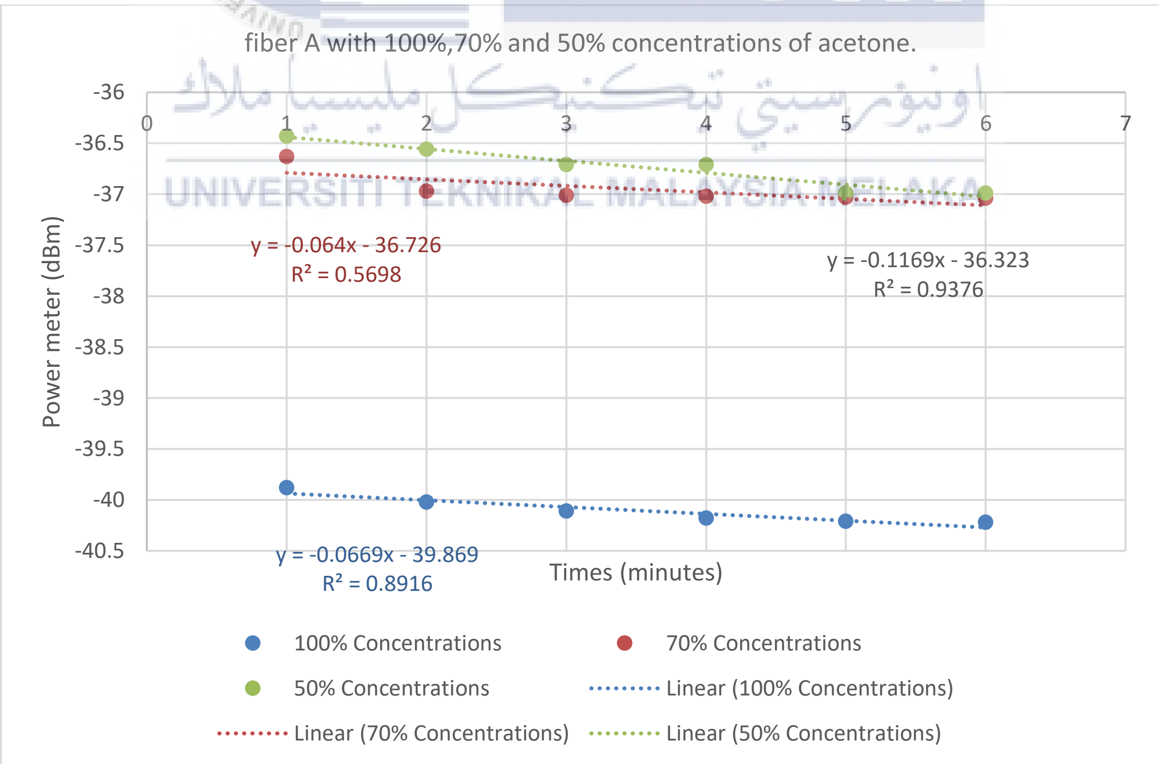

Figure 25 Graph for the sensitivity of different concentrations of acetone of Fiber A

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Based on Figure 25, three regression lines are shown. The reading of the value output power meter of 100%, 70% and 50% concentrations of acetone (dBm) using a wavelength of 1550nm of fiber A.

Table 10 Sensitivity and Linearity of different concentrations.

Concentrations Acetone	Sensitivity	Linearity
100%	0.0669	0.9442
70%	0.064	0.2530
50%	0.1169	0.9682

According to Table 10, the 50% acetone concentration had a higher sensitivity value at the tapered microfibre for size A, with a value of 0.9376 dBm. This cycle was repeated five times for each concentration, which lessened random error when observing the results. Furthermore, we can observe that the value linearity at the microfibre optic size A has a strong negative linear correlation at 100% and 50% concentrations, leading to the data fitting in the linear graph. Meanwhile, 70% of concentrations have weak negative correlations, indicating the data is not a good fit. By looking only at 100% and 50% concentration due to nonlinearity for 70% concentration, the result shows that the 50% concentration is more sensitive to light absorption.

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4.2.5 Result fiber B with 100%,70% and 50% concentrations of acetone.

The analysis is based on the sensitivity and linearity percentage of the performance of different concentrations of microfiber optics B on 100%, 70% and 50% acetone concentrations to observe the concentrations with the highest sensitivity. This analysis shows the output power observed and recorded for every acetone concentration, as shown in Table 11.

Table 11 Data collected from 3 different concentrations of acetone of Fiber B

Fiber	Times (minutes)	100%	70%	50%
B	1	-39.72	-38.33	-36.69
	2	-40.01	-39.03	-36.93
	3	-40.07	-39.91	-36.98
	4	-40.09	-40.11	-36.98
	5	-40.11	-40.12	-37.02
	6	-40.12	-40.17	-37.05

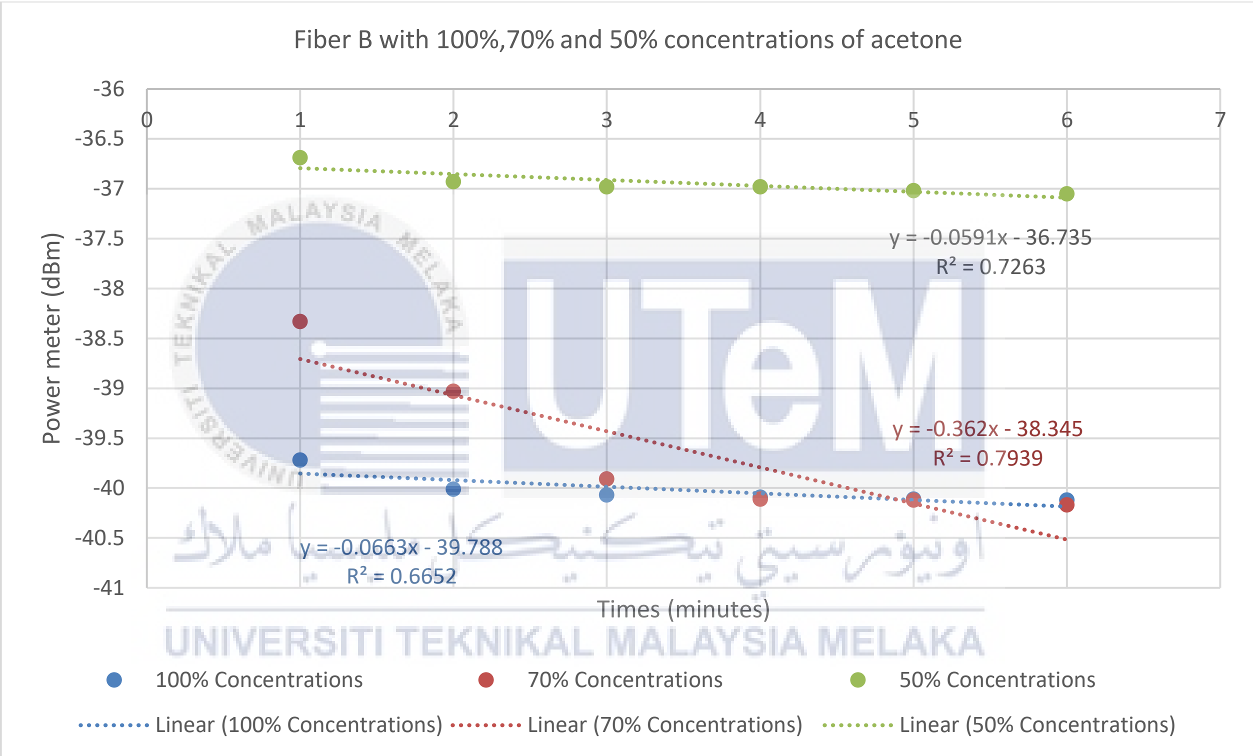

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Figure 26 Graph for the sensitivity of different concentrations of acetone of Fiber B

Based on Figure 26, three regression lines are shown. The reading of the value output power meter of 100%, 70% and 50% concentrations of acetone (dBm) using a wavelength of 1550nm of fiber B.

Table 12 Sensitivity and Linearity of different concentrations.

Concentrations Acetone	Sensitivity	Linearity
100%	0.0663	0.8156
70%	0.362	0.6017
50%	0.7263	0.8522

According to Table 12, the 50% acetone concentration had a higher sensitivity value at the tapered microfibre for size B, with a value of 0.7263 dBm. This cycle was repeated five times for each concentration, which lessened random error when observing the results. Furthermore, we can observe that the value linearity at the microfibre optic size B has a strong negative linear correlation at 100% and 50% concentrations, leading to the data fitting in the linear graph. Meanwhile, 70% of concentrations have moderate negative correlations. By comparing all concentrations, the result shows that the 50% concentration is more sensitive to light absorption.

4.2.6 Result fiber C with 100%,70% and 50% concentrations of acetone.

The analysis is based on the sensitivity and linearity percentage of the performance of different concentrations of microfiber optics C on 100%, 70% and 50% acetone concentrations to observe the concentrations with the highest sensitivity. This analysis shows the output power observed and recorded for every acetone concentration, as shown in Table 13.

Table 13 Data collected from 3 different concentrations of acetone of Fiber C

Fiber	Times (minutes)	100%	70%	50%
C	1	-38.13	-36.39	-36.25
	2	-38.42	-36.61	-36.43
	3	-39.75	-36.63	-36.45
	4	-39.75	-36.66	-36.47
	5	-39.93	-36.67	-36.93
	6	-39.97	-36.67	-36.93

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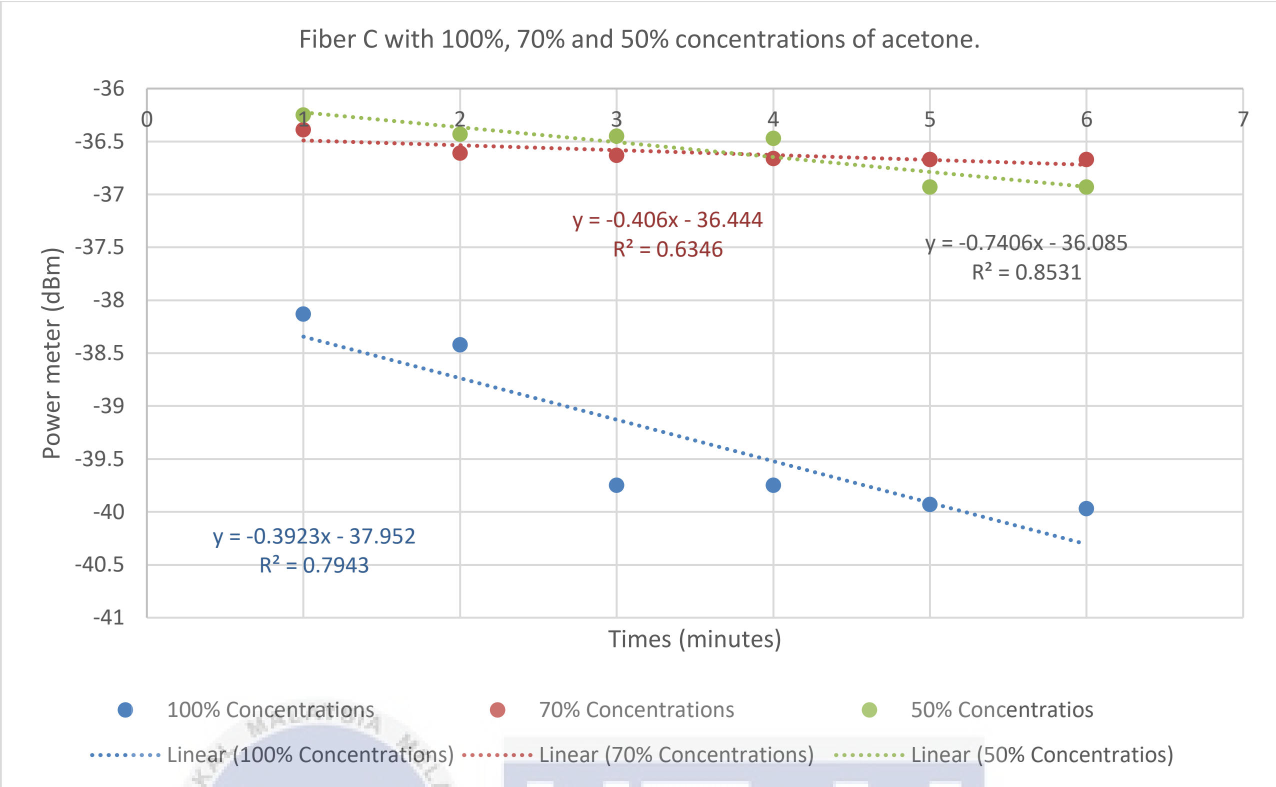

Figure 27 Graph for the sensitivity of different concentrations of acetone of Fiber C

Based on Figure 27, three regression lines are shown. The reading of the value output power meter of 100%, 70% and 50% concentrations of acetone (dBm) using a wavelength of 1550nm of fiber C.

Table 14: Sensitivity and Linearity of different concentrations.

Concentrations Acetone	Sensitivity	Linearity
100%	0.3923	0.8912
70%	0.406	0.2145
50%	0.1406	0.9236

According to Table 14, the 100% acetone concentration had a higher sensitivity value at the tapered microfibre for size C, with a value of 0.3923 dBm. This cycle was repeated five times for each concentration, which lessened random error when observing the results. Furthermore, we can observe that the value linearity at the microfibre optic size A has a strong negative linear correlation at 100% and 50% concentrations, leading to the data fitting in the linear graph. Meanwhile, 70% of concentrations have weak negative correlations, indicating the data is not a good fit. By looking only at 100% and 50% concentration due to nonlinearity for 70% concentration, the result shows that the 100% concentration is more sensitive to light absorption.

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4.2.7 Repeatibility of Fiber C on 50% concentrations.

Further analysis is conducted to observe the repeatability of Fiber C on 50% concentrations. Based on all concentrations' results, the 50% concentrations with fiber C were chosen to prove the repeatability of the results. The analysis of variance (ANOVA) is used as a statistical tool to determine the mean difference each time the experiment is repeated under the same conditions. The main purpose of ANOVA is to compare the differences of more than two population means. The Alpha used 0.05. The experiment was repeated five times, and the average value is observed. Thus, the null and alternative hypothesis should be stated as below :

$H_0 : \mu_1 = \mu_2 = \ldots = \mu_k$

$H_1 : \mu_i \neq \mu_j$

Table 15 data repeatibility five times

take 1	take 2	take 3	take 4	take 5
-36.39	-36.44	-36.67	-36.27	-36.45
-36.61	-36.61	-36.53	-36.45	-36.71
-36.63	-36.64	-36.56	-36.47	-36.71
-36.66	-36.66	-36.58	-36.49	-36.75
-36.67	-36.58	-36.51	-36.75	-36.75
-36.67	-36.58	-36.51	-36.75	-36.75

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Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
take 1	6	-219.63	-36.605	0.01167
take 2	6	-219.51	-36.585	0.00607
take 3	6	-219.36	-36.56	0.00368
take 4	6	-219.18	-36.53	0.0352
take 5	6	-220.12	-36.6867	0.013827

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.084233	4	0.021058	1.49463	0.233909	2.75871
Within Groups	0.352233	25	0.014089			
Total	0.436467	29				

Figure 28 Single factor of ANOVA analysis

Based on Figure 28, the decision failed to reject H_0. It's because the value of F_{test} 1.49463 is smaller than $F_{critical}$ 2.75871. Therefore, in conclusion, there are no differences among the sample means. As the experiment is repeated, the results show no difference in the average due to the data stability.

4.3 Summary

This chapter provides case studies to demonstrate the applicability of the proposed microfiber optic sensor development system employing various concentrations of acetone and different sizes of tapered microfiber. The case study is based on the experimentation of three different sizes of tapered microfiber and three samples of different concentrations of acetone tested. The different acetone concentrations are based on the different values of the percentage of each sample. The experiment uses the setup shown in the methodology to collect data using Mini-OTDR. The result for different sizes and different acetone concentrations shows that size C is more suitable for using microfiber optics as liquid sensors due to the highest sensitivity obtained.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The method for developing microfiber optic sensors for acetone in different concentrations using a tapering method is presented in this thesis. The proposed methodology is effective and strong for obtaining good results with only precise data and minimal network measurement information. The proposed methodology is effective for obtaining good results with only somewhat precise data and minimal network measurement information. The proposed analytical method obtains the correlation for each concentration by combining sensitivity and linearity.

Overall, the research presented in this thesis has helped us comprehend the importance of sensors in microfiber optics. The presented technique generates rapid, compelling, reflective, and correct results while reasonably using a limited set of data and information types, using straightforward mathematical operations, and requiring fewer complex calculations. Additionally, the research concentrated on creating strategies that would facilitate the creation of inexpensive sensors that simply rely on optical microfiber sensing. As a result, it prepares the groundwork for the suggested additional research.

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5.2 Future works

There are several prospects and suggestions for microfibre optical sensing advancements in the future, including :

i) Using a microfiber optic sensor to measure other variables such as temperature, pressure, and humidity. Because the main construction of both sensors is glass, 61 they are resistant to harmful interference such as electromagnetic interference (EMI). They can tolerate harsh conditions such as high temperatures and pressure.

ii) Microfiber optic sensors can be linked to the Internet of Things (IoT) for even greater ease and convenience in monitoring sensor output. IoT enables remote monitoring since authorised users may access the system from anywhere globally. Additionally, extending the detecting zone might boost sensor sensitivity. The sensors may provide a greater resonant output when an optical signal passes through them.

iii) Further exploration into the correlation between acetone levels and different stages of diabetes could lead to the development of diagnostic tools. These tools might help identify prediabetes or monitor the progression of diabetes through acetone level analysis.

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APPENDICES

Datasheet SimpliFiber® Optical Power Level

Ensure smooth, clean fiber connections

Inspect the ends of fiber-optic connectors with Fluke Networks' handheld FiberInspector™ Mini video microscope or FiberViewer™ microscopes. All options ensure your termination is smooth, clean, and ready for optical transmission. The FI-500 FiberInspector Micro can be used in any live fiber installation and provides 200x viewing. The FT120 FiberViewer provides 200x magnification for inspecting multimode fiber end-faces while the FT140 FiberViewer offers 400x viewing for singlemode installations. Both FiberViewer microscopes contain a special safety filter to minimize the risk of eye exposure to harmful infrared rays.

Verify and locate faults

Diagnose and repair simple fiber link problems with Fluke Networks' VisiFault™ Visual Fault Locator (VFL). The laser-powered VisiFault locates fibers, verifies continuity and polarity, and helps find breaks in cables, connectors, and splices. Continuous and flashing modes make for easier identification. Compatible with 2.5 mm and 1.25 mm (with optional adapter) connectors for easy connection.

Reporting made simple

Manage test results, print professional reports, or export data into spreadsheet formats. SimpliFiber Pro can internally store up to 1000 test results which can then be uploaded to your PC using the included LinkWare™ Cable Test Management Software.

Features

- Dual-wavelength testing
- Tests multimode and singlemode fiber
- Measures optical power and loss at 850, 1300, 1310, 1490, 1550, 1625 nm wavelengths
- Offers quick remote identification of cabling runs with FindFiber Remote IDs
- Conduct pre-testing and qualify cabling runs
- Auto-senses source wavelength
- Saves 1000 test results
- Single port testing for simple network connection
- Ruggedly built for demanding field use
- LinkWare™ Cable Test Management Software documents, reports, and manages all test data

FKT1475 Complete Fiber Verification Kit

General Specifications	
Temperature range	Operating: -10 °C to 50 °C Storage: -20 °C to 50 °C
Humidity range	95% (10 °C to 35 °C) non-condensing; 75% (35 °C to 40 °C) non-condensing; uncontrolled <10 °C
Certifications	CE, CSA, N10140, Class 1 laser-safe
Dimensions	Power meter: 6.4 in x 3.2 in x 1.5 in (16.5 cm x 8.0 cm x 3.9 cm) MM/SM sources: 5.6 in x 3.2 in x 1.6 in (14.2 cm x 8.1 cm x 4.1 cm)
Weight	Power meter: 11.5 oz (325 g) MM/SM sources: 9.8 oz (278 g)

Optical Sources	
Optical output connector	Fixed SC
Emitter type	850/1300: LED 1310/1550: FP Laser FindFiber: Laser
Emitter wavelengths	850, 1300, 1310, 1490, 1550, 1625
Power output (minimum)	MM: ≥ -20 dBm; SM: ≥ 8 dBm minimum; -7 dBm nominal
Power output stability (8 hours)	MM: +/- 0.1 dB over 8 hours; SM: +/- 0.25 dB over 8 hours
MM battery life (2 x AA IEC LR6)	40 hours typical
SM battery life (2 x AA IEC LR6)	30 hours typical
FindFiber battery life (2 x AA IEC LR6)	80 hours typical

Optical Power Meter	
Power measurement accuracy	+/-0.25 dB
Optical connector	Removable adapter; SC adapter standard; Optional adapters include LC, ST
Detector type	InGaAs
Calibrated wavelengths	850, 1300, 1310, 1490, 1550, 1625
Power measurement range	850: 10 to -52 dBm 1300, 1310, 1490, 1550, 1625: 10 to -60 dBm
Power measurement linearity	850 nm: +/- 0.2 dB; +/- 0.2 dB for power from 0 dBm to -45 dBm, +/- 0.25 dB for power < -45 dBm; 1300 nm, 1310 nm, 1490 nm, 1550 nm, 1625 nm: +/- 0.1 dB; +/- 0.1 dB for power from 0 dBm to -55 dBm, +/- 0.2 dB for power > 0 dBm and < -55 dBm
Resolution	0.01 dB
Battery life	>50 hours typical
Memory	1000 loss or power measurements
Serial communication physical interface	USB

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Datasheet SimpliFiber® Optical Power Level

Single Fiber Fusion Splicer

Fujikura 70S

Core-to-Core alignment, Dual-axis observation system

SPECIFICATIONS

Applicable fibers	Single / SMF (G.652/657), MMF (G.651), DSF (G.653), NZDSF (G.655)
Cladding dia. / Sheath dia.	80-150µm / 100-3000µm
Cleave length	5mm to 16mm with sheath clamp
Splice mode / heating mode	Total 100 splice modes / 30 heating modes
Splice loss	0.02dB (SM), 0.01dB (MM), 0.04dB (DSF) and 0.04dB (NZDS) Measured by cut-back method relevant to ITU-T and IEC standards.
Attenuation splice function	Intentional high splice loss of 0.1dB to 15dB (0.1dB step) can be made for an in-line fixed attenuator.
Splice time / tube heating time	Typical 7sec with SM / Typical 14sec with FP-03 (60mm) sleeve
Splice result storage	Last 2000 splices
Viewing methods / magnification	2 axis CMOS camera with 4.73" color LCD. X / Y (320X magnification), or both X and Y simultaneously (200X magnification)
Tension test	1.96 to 2.25N
Applicable protection sleeve	60mm, 40mm and Fujikura micro sleeves
No. of splice / heating per battery full charge*1	Typical 200 cycles with BTR-09
Electrode life	3000 splices
Size / weight	146W x 159D x 150H (mm) / 2.7kg (including battery)
Operating condition	Altitude : 0 to 5,000m above sea level, Wind : 15m/sec Temperature : -10 to 50deg C, Humidity : 0 to 95%RH, non-dew
Resistance features*2	Shock : 76cm (30inch) all surface drop Dust : Exposure to dust (0.1 to 500µm dia Alumina Silicate), IP5X Rain : H=10mm/hr for 10min, IPX2
Other features	PC software upgrade / data management
Terminals	USB 2.0 (Mini-B type) connector for PC communication. 6-pin Mini-DIN connector for HJS-02 or HJS-03 power supply.

*1:one(1) splicing and heating cycle per two(2) min. under room temperature condition.
*2:Carried out in Fujikura labs in Japan. The shock, dust and rain resistance test do not guarantee the product will not be damaged under these conditions.

ACCESSORIES

Description	Model No.
High precision single fiber cleaver	CT-05 (for single fiber)
High precision fiber cleaver	CT-30 series (for single to 12 ribbon fibers)
Primary coat stripper	PS-02
Nylon jacket stripper	JS-01
Thermal jacket stripper	HJS-02, HJS-03
Protection sleeve	FP-03 / 03 (L=40) and FPS01series

OPTIONAL ITEMS

Description	Model No.	SET
Fiber holder	FH-60-250 (coating dia. 250µm)	1pair
	FH-60-900 (coating dia. 900µm)	1pair
	FH-60-DC250 (coating dia. of 250µm in drop cable)	1pair
	FH-FC-20 (coating dia. of 900µm in 2.0mm Sheath dia.)	1pc
	FH-FC-30 (coating dia. of 900µm in 3.0mm Sheath dia.)	1pair
	FH-60-LT900 (900µm dia. loose buffer fiber)	1pair
Sheath clamp	CLAMP-S70C (included in standard package)	1pair
	CLAMP-S70D (900µm dia. loose buffer fiber)	1pair
Battery pack	BTR-09 (Li-ion)*3	1pc
Battery charge cord	DCC-18	1pc
DC power cord	DCC-12 (for cigar-socket)	1pc
	DCC-13 (with aligator clamp)	1pc
Electrodes	ELCT2-20A	1pair

*3:all senders must to obey the IATA regulation when transporting Li-ion battery by air.

STANDARD PACKAGE

Description	Model No.	Q'ty
Fusion splicer	70S	1pc
AC adapter	ADC-18	1pc
AC power cord	ACC-XX XX=14 (JP/US),15 (EU),16 (UK),17 (AU)	1pc
Carrying case	CC-30	1pc
Spare electrodes	ELCT2-20A	1pair
Instruction manual CD	M-70 (Manual and PC software)	1pc
Quick reference guide	Q-70S/19S-E (English)	1pc
Warning and cautions	W-70-E	1pc
USB cable	USB-01	1pc
Sleeve loader	SL-01	1pc
Alcohol pot	AP-01	1pc
Screw driver	SD-01	1pc

STANDARD PACKAGE

Specifications and descriptions are subject to change without prior notice.

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Gantt chartt PSM 1

	(BDP 1) SEM 2 2023/2024													
PROGRESS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Tittle selection and BDP 1 briefing by JK PSM, FTKEE														
Background study: Search for papers related to the project														
Evaluate of Work Progress 1														
Completed report for Chapter 1 (Introduction)														
Completed report for Chapter 2 (Literature Review)														
Completed report for Chapter 3 (Methodology)														
Completed report for Chapter 4 (Priliminary Result)														
Evaluate of Work Progress 2														
Submit report to supervisor														
BDP 1 Presentation														
Submission and evaluation of BDP 1 final report on ePSM														

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Gantt chart PSM 2

PROGRESS	(BDP 1) SEM 2 2023/2024													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Continue study while start the project: Search for papers related to the project, stripping and splicing fibe														
Start working on the project: Stripping the fiber, Splicing and Tapering														
Evaluate of Work Progress 1														
Do the experiment concentraions of acetone														
Do the experiment concentrations acetone with mircofiber optic sensor														
Completed report for Chapter 4 (Result)														
Completed report for Chapter 5 (Conclusion)														
Evaluate of Work Progress 2														
Submit report to supervisor														
BDP 2 Presentation														
Submission and evaluation of BDP 2 final report on ePSM														

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