MICROFIBER RESONATOR IN SINGLE LOOP FOR OXYGEN GAS SENSOR

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MICRORESONATOR FIBER IN SINGLE LOOP FOR OXYGEN GAS SENSOR

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronics Engineering Technology (Industrial Electronics) with Honours

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DEDICATION

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

ABSTRACT

This project investigates the potential of a single-loop microresonator fiber as an oxygen gas sensor. The study utilizes light sources with wavelengths of 1550 nm and 1310 nm, both within the acceptable wavelength range for the sensor. The design involves tapering the fiber to create a microfiber, which is then formed into a single loop. The transmission of light through the sensor is affected by total internal reflection, which varies with the transmitted spectral wavelength. Oxygen levels ranging from 10% to 50% are analyzed to evaluate the sensor's performance. The sensitivity and linearity of the microresonator fiber are assessed through transmitted power analysis. The findings demonstrate that the sensor performs exceptionally well in detecting gas, making it a promising candidate for concentration measurement applications.

ABSTRAK

Projek ini menyiasat potensi gentian mikroresonator gelung tunggal sebagai penderia gas oksigen. Kajian ini menggunakan sumber cahaya dengan panjang gelombang 1550 nm dan 1310 nm, kedua-duanya dalam julat panjang gelombang yang boleh diterima untuk sensor. Reka bentuk ini melibatkan meruncing gentian untuk menghasilkan mikrofiber, yang kemudiannya dibentuk menjadi gelung tunggal. Penghantaran cahaya melalui sensor dipengaruhi oleh jumlah pantulan dalaman, yang berbeza dengan panjang gelombang spektrum yang dihantar. Tahap oksigen antara 0 mg/L hingga 10 mg/L dianalisis untuk menilai prestasi sensor. Kepekaan dan kelinearan gentian mikroresonator dinilai melalui analisis kuasa dihantar. Penemuan menunjukkan bahawa sensor berfungsi dengan baik dalam mengesan gas, menjadikannya calon yang menjanjikan untuk aplikasi pengukuran kepekatan

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LIST OF SYMBOLS

δ	-	Voltage angle
λ_B	-	Bragg wavelength
Λ	-	Grating Period
n_{eff}	-	Effective Refractive Index
dB	-	Bandwidth
θ_C	-	Critical Angle
n_1	-	Refractive index of the medium around the fiber
n_2	-	Refractive index of the cladding

LIST OF ABBREVIATIONS

V	-	Voltage
RI	-	Reflective Index
µ	-	Micro
k	-	Kilo
M	-	Mega
LAN	-	Local Area Network
FGB	-	Fibre Bragg Gratings
MZI	-	Mach-Zehnder Interference
SI	-	Sagnac Interference
FSR	-	Free Spectral Range
PMF	-	Polarisatoin-Maintaining Fibre
ASE	-	Amplified Spontaneous Emission
OC	-	Optical Coupler
OSA	-	Spectrum Analyzer
EW	-	Ephemeral Wave Fibre
POF	-	Polymethyl Methacrylate Core
LED EMI	-	Light Emitting Diode
RFI	-	Electromagnetic Interference
ASE		Radio Frequency Interference
OTDR NA	-	Amplified Spontaneous Emitter
	-	Optical Time Division Mirror
	-	Numerical Aperture

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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, oxygen gas sensing plays a crucial role in fields such as environmental monitoring, industrial safety, and biomedical diagnostics. The ability to accurately detect and analyze oxygen levels is of great importance in ensuring the safety and quality of various environments and processes.

The microfiber single loop resonator represents an innovative approach to oxygen gas sensing, leveraging the unique properties of microfiber structures to achieve high-performance detection and characterization of gases. 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 processes and interactions along the resonator.

The key principle behind the operation of a microfiber single loop resonator for oxygen gas sensing is the strong evanescent field interaction between the guided light and the surrounding gas medium. As light propagates through the microfiber, a portion of its power extends beyond the fiber boundary, interacting with the gas 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 gas under investigation.

The design and fabrication of microfiber single loop resonators for oxygen gas 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 gas 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 gas sensing applications. They exhibit excellent sensitivity, allowing for the detection of minute changes in the refractive index or concentration of oxygen in a gas 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 an oxygen gas sensor can contribute to addressing global issues in several ways, such as environmental monitoring, health and safety, and industrial applications. Microfiber single loop resonators represent a promising technology for gas sensing applications. Their ability to exploit the evanescent field interaction with the surrounding gas medium offers high sensitivity and enables precise characterization of different gas samples. As further advancements in fabrication techniques and system integration are made, microfiber single loop resonators hold great potential for revolutionizing gas sensing in fields ranging from environmental monitoring to biomedical diagnostics.

1.2 Problem Statement

The problem statement for this project is as follows:

a) There is a scarcity of oxygen gas 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 oxygen gas sensing applications.

1.3 Project Objective

The main goal of this project is to develop an effective and appropriate approach for evaluating system-wide oxygen gas 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 Oxygen Gas Sensor.

b) To develop the microfiber single loop resonator for oxygen gas sensing.

c) To optimize the performance of the oxygen gas sensor using the Microfiber Single Loop Resonator with different concentration levels.

1.4 Scope of Project

The scope of this project are as follows:

a) Designing by tapering the fiber into a microfiber and forming it into a single loop.
b) Testing the sensor with varying levels of oxygen gas concentration.
c) Comparing the results across different concentration levels.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The development of high-performance oxygen gas sensors is crucial in various fields, such as environmental monitoring, biomedical diagnostics, and industrial processes. Recently, microfiber single loop resonators have gained attention as a promising platform for gas sensing applications. These resonators provide advantages including high sensitivity, compact size, and compatibility with microfluidic systems. The literature on the use of microfiber single loop resonators for gas sensors has expanded significantly, with researchers examining their fundamental principles, fabrication techniques, and potential applications.

This literature review aims to offer a comprehensive overview of research on microfiber single loop resonator-based oxygen gas sensors. By analyzing the existing body of knowledge, the review seeks to identify key findings, advancements, and challenges in this field. It will cover studies focused on the design and optimization of microfiber single loop resonator structures, the fabrication techniques employed, and the characterization of their sensing capabilities. Additionally, this review will explore the various types of gas analytes investigated using these resonators, along with the reported sensing mechanisms and detection methods.

Through systematic analysis and synthesis of relevant literature, this review aims to illuminate the current state-of-the-art in microfiber single loop resonator-based gas sensing and provide valuable insights for researchers and practitioners. Furthermore, it will identify potential areas for future research and highlight opportunities and challenges in fully utilizing these resonators for gas 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 oxygen gas sensing. By consolidating existing knowledge and highlighting research gaps, this review will contribute to advancing the field and inspiring further innovation in the design and utilization of these resonators for gas sensing purposes.

2.2 Fiber Optic

Fiber optics is a technology that uses thin strands of glass or plastic, known as optical fibers, to transmit light signals over long distances at high speeds [1]. These fibers are designed to carry optical signals in the form of light pulses, enabling the transmission of large amounts of data over significant distances with minimal loss and interference [2]. A typical fiber optic cable comprises three main components:

Core: The core is the central part of the optical fiber where light signals travel. It is usually made of high-purity glass or plastic and has a very small diameter, typically ranging from 9 to 125 micrometers [3]. Some glass cores can be as small as 3.7 micrometers or as large as 200 micrometers [4]. The core guides and transmits light signals along its length through a process called total internal reflection [1].

Cladding: Surrounding the core is the cladding, made of a material with a lower refractive index than the core. The cladding confines the light within the core by reflecting it back into the core through total internal reflection [2]. This ensures the light does not escape or get absorbed, maintaining signal integrity [3].

Buffer/Coating: The outermost layer of the fiber optic cable is the buffer or coating, which protects 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 [2]. The fundamental principle of fiber optics is based on total internal reflection. When light enters the core of the optical fiber at a specific angle, it undergoes multiple internal reflections within the core, bouncing off the cladding [1]. This continuous reflection allows the light to travel through the fiber with minimal loss and without significant degradation [3]. Glass fiber offers several benefits as a tiny tube, including superior performance in signal transmission

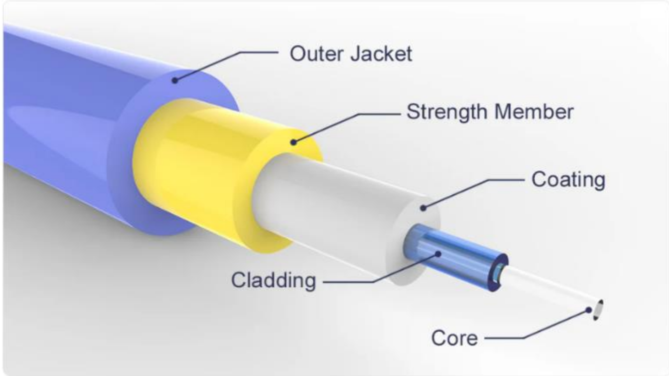

Figure 2.1: Structure of Fiber Optic

Single Mode

Single-mode fiber optic on the other hand refers to the optical fiber depicting the ability to transport a single mode or path of light. While multimode fiber can handle multiple light modes according to their wavelengths, single-mode fibers are constructed with a smaller cable diameter to support only a single mode of light that can transmit information with high levels of accuracy over very long distances without losing quality [2].

Single mode fiber on the other hand, has the core diameter of approximately 8 to 10 micrometers, making it much smaller than the core diameter of multimode fiber. The small core size also helps the light to travel in only one mode, which helps dissuade modal dispersion, or in modem parlance, permits high multiplication rates and longerreaching distances.

As with multimode fiber, single-mode transmission utilizes an optical fiber in which all light signals are confined to a single mode. On the other hand, the core size of the single-mode fiber is smaller when compared to multimode fiber; this limits the light propagation within a confined and defined beam width leading to a linear light transmission path. This reduces the spread of the transmitted light pulses and reduces the amount of signal attenuation, which means that single-mode fiber has the potential of carrying more bandwidth and transmitting signals further as compared to multimode fibre [3].

Advantages and Applications of Single-Mode Fiber Optics: Advantages and Applications of Single-Mode Fiber Optics:

- Longer Transmission Distances: This is possible due to the difference in the number of modes with single-mode fiber being able to transmit signals over a much longer distance than multi-mode fibers. Single-mode fiber eliminates the beam wander associated with up to fourteen exponentials in modal dispersion that are available in multimode fiber allowing for upgraded transmission speeds and signal attenuation required in telecommunication networks and undersea cables[4].

- Higher Bandwidth: Single-mode fiber offer more data transferring capacity as comparing to multimode fiber. This shields higher datarate and it is applied in high speed operations such as long haul data communication, television broadcasts, backbone transmission among others [5].

- Enhanced Signal Quality: Compared to multimode fibers where light travels along a bundles of pathways with varying degrees of intensity, SMF's strict and confined light pathway enhances signal integrity. It therefore contributes to reduced attenuation and dispersion as needed to support the reliable and high quality of the signal transmitting [3].

- Compatibility with Wavelength-Division Multiplexing (WDM): Single-mode fiber also operate with wavelength division multiplexing or WDM that employed to send more than one wavelength of light signals within a single fiber. This essentially allows the simultaneous transport of multiple, independent data signals, which greatly enhances the total capacity of the fibre [5].

- Cost-Effectiveness for Long-Term Use: Multimode fiber is cheaper than single-mode and easier to install but single-mode requires better alignment, special equipment, and comes at a much higher outlay initially, but is cheaper in terms of cost per bit per kilometer compared with multimode fiber in the long run for applications with high bandwidth and longer transmission distances. With the decreased reliance of analogue signal transmission on lengthening physical cables, there are lowered costs of continuing signal replication and booster such as repeaters and amplifiers in the long standing network [6].

There are, however, some differences when comparing both types of fibers: single-mode fiber demands more accurate alignment and professional tools in terms of installation and connection as opposed to multimode fiber. This makes it a little more expensive and with a higher degree of difficulty when it comes to using it. Nonetheless, given the fact that the single-mode fiber offers the 'longer reach as well as high bandwidth, the latter is ideal for use in long haul communication as well as in high-capacity data transfer.

Single-mode fiber and multimode fiber are fiber optic cables with dissimilar characteristics, and the selection between them depends on the certain parameters, cost, and performance of the system. Single-mode fiber is employed where data rates are required to be high, transmission distance is relatively larger and signal quality has to be good.
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

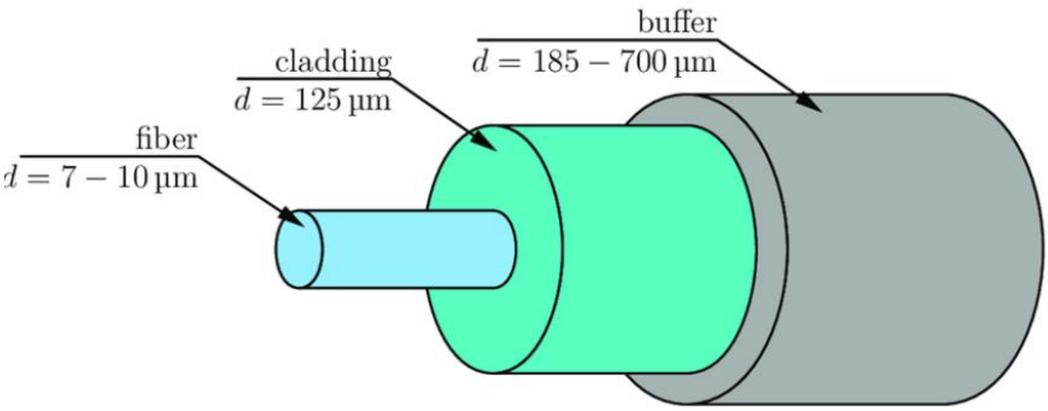

Figure 2.2 Single Mode Fiber

Multimode

Multimode fibers were the first fiber optic technologies purchased and offered to consumers, literally meaning its capacity to guide multiple beams or modes of light through a waveguide at a given time [9]. Multimode fiber optic on the other hand, describes an optical fiber designed to encompass more than one light mode or path at the same time. Compared to Single mode fiber, the core diameter of multimode fiber is much bigger and is between 50 to 62 micrometer(s). 5 micrometers [10]. This larger core size enables the propagation of multiple light mode, in other words, the material can support other modes apart from the fundamental mode.

The concept of multimode transmission is built on the idea of a scenario where various light paths or modes carrying data travel through the fibre core with a slightly different angle. Of them, only those modes which are numbered greater than 1 can reflect off the walls of the core and the cladding, and thus experience what is known as modal dispersion [11]. Modal dispersion results from the spreading out of light pulses through the fiber and is a key factor in affecting distances and data rates possible with multimode fiber versus single mode. There are two main types of multimode fiber:There are two main types of multimode fiber:

Step-Index Multimode Fiber: In SI-MMF, the refractive index is flat across the core diameter and is specific to the core only. This also implies that the refractive index experiences a steep variation at the core-cladding interface [12]. On the other hand, the graded-index multimode consists of a core with a varying dopant density, and it is suitable for applications that require limited reaches, such as LANs and data centres.

Graded-Index Multimode Fiber: Graded-index multimode fiber has a core of defined refractive index that is graded, starting from the center all the way to the outer edges. This refractive index profile assists to minimize modal dispersion by the method of letting the light wave propagate at various velocities with regards to the position of the core [14]. It is graded-index, multimode fiber, and is typically designated for medium range applications, such as in campus networks or video distribution. Advantages and Applications of Multimode Fiber Optics:

- Cost-effectiveness: Multimode fiber has overall cost advantage over single mode fiber and is less expensive. This makes it ideal for lower bandwidth applications such as those within a datasite or a small campus where the increased data transmission rates of single-mode fiber are not needed [15].
- Ease of Installation: One of the differences of operation between both types of fibers is that because of the larger core size, multimode fibers are easier to manage during installation and splicing than single-mode ones. It makes it possible to have a wider alignment tolerance, bringing easiness in connectorization[16].
- Shorter Reach: Multimode fibers are mostly applicable at shorter distances and almost limited to few kilometers at most. Its use is most often in LANs, building backbones, and data center interconnection [17].
- Data Transmission: Multimode fiber also contains the capability to provide data transfer rates that are from the Gigabit Ethernet, 10-Gigabit Ethernet and other. Yet, both the maximum attainable data rates and transmission distance do not exceed the corresponding values of SMOF while there are still sufficient bandwidths available for many applications [12].

This, however must be understood as a disadvantage of multimode when compared to singlemode over lengths of distance and maximum attainable data rates. Hence, for longer distances or where higher data rate transmission is warranted, single-mode fiber is employed. Several factors dictate the decision of when to use MMF and SMF such as the intended usage, the cost, and the level of performance that is desired for the particular application.

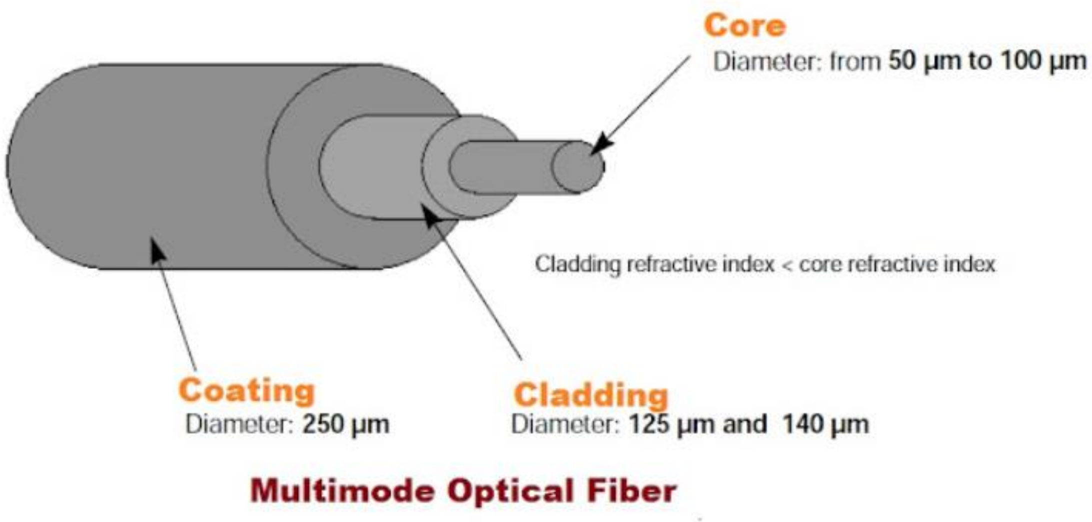

Figure 2.3 Multimode Optical Fiber

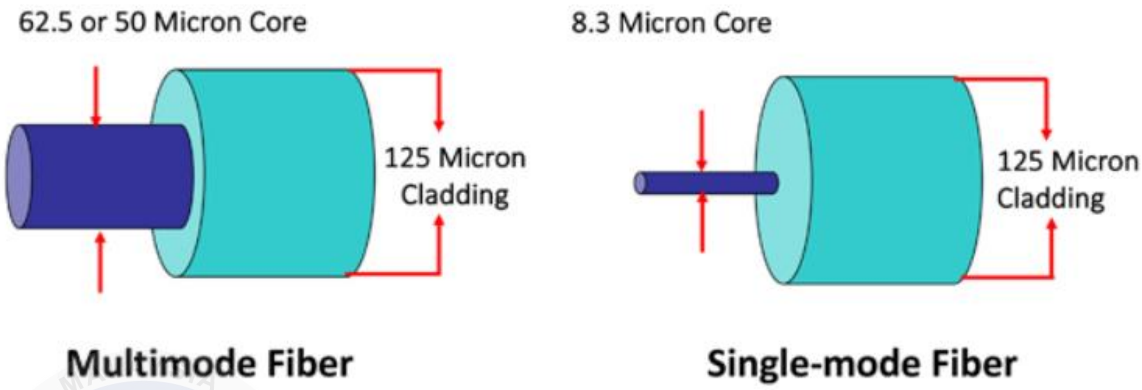

Figure 2.4: Difference between Multimode and Single-mode Fiber

Propagation of Light among a fiber

The process through which light disseminates in the fiber optic cable is generally referred as signal transmission again, through the core of the fiber but is enabled by the fact that it bounces or reflects off the internal walls of the cladding layer. In fiber optics the information carrier is light in the form of a light beam which moves at a speed of 3×10^8ms vastly superior to electronic devices or when dealing with an electric current. The middle lamella of the fiber is dominated by silica usually constructed using glass or plastic, has greater index of refraction than the rest of the solution.
cladding, whereby light can be trapped and transmitted for long distances due to the special design of the layer having a lower refractive index than the core [9] Here is some step-by-step explanation of how light propagates through a fiber optic cable:

- Injection of Light: it then means light signals are introduced into one end of the fiber optic cable which unveils the page by shining on it either by a laser or LED source of light. In the context of the thought experiment, the light indeed moves through the core of the fiber through the total internal reflection made by the help of difference between refractive indices of core and cladding.
- Total Internal Reflection: In the interior of the core, the light meets the core-cladding boundary interface. Because the refractive index of the core region is greater than that for the cladding, the light propagating in the waveguide is subjected to total. It

means that it bounces back inward to the heart or center and is not refracted out into the cladding. This reflection happens because the light interacts with the interface at an angle larger than a specific size referred to as the critical angle depending on refracting index for the difference in the dimensions of the core and cladding.

- Multiple Total Internal Reflections: It will be observed that the light is still reflected through the core-cladding interface as it is transmitted through the length of the fiber. Each reflection helps to confine the light within the core so that the attenuation can be minimized or dispersion.
- Single-Mode or Multimode Propagation: Depending on the type of fiber optic cable used, there are different specifications and tolerance levels available depending on the type of fiber (cable) used – single-mode or multimode it can travel in several forms. Single mode fiber is capable of transmitting light beams through a narrow core diameter which is large enough to allow only the single mode fiber to pass through the system geometry of light, to create a compact diffraction source that shines through the fibers with minimal spreading of the rays. In multimode fiber, the bigger diameter in the core can accommodate a range of light wavelengths used for data transmission. These modes are wider in comparison with other modes and the broader beam might get dispersed over a long distance.
- Signal Attenuation: The power in the fiber is slightly reduced due to other losses that come as the light travels through the fiber interference which includes attenuation where signal strength fades over a certain distance due to various factors such as absorption scattering and bending losses. However, optical fibers are designed to minimize the effect of these losses on their performance, hence they are preferred for delivering signals over long distances at high speed. They also cause a reduction of signal strength and enable propaganda of light signals over a considerable distance.
- Reception of Light: At the other side of the fiber optic cable a photo detector or an optical receiver

The receiver can analyze these electrical signals and can go further and perform some other tasks such as in data sales, telecommunication or sensing among other uses[17].Light transmission in a fiber optic cable makes it easy and guaranteed to convey information from one end to another utilization of guided waves to carry data, voice or video signals to a considerable distance. The principle of total light may leak or escape from the core due to reflection, ensuring the light bounces within the core

reducing signal distortion, noise and inter-symbol interference that need to be controlled to ensure signal integrity is maintained during transmission. Air within the context of the model refers to the use of fiber optics
have changed the face of modern telecommunications, internet connectivity, and almost every other sector. This enables the provision of high-speed, high-bandwidth as well as low-loss transmission capabilities.

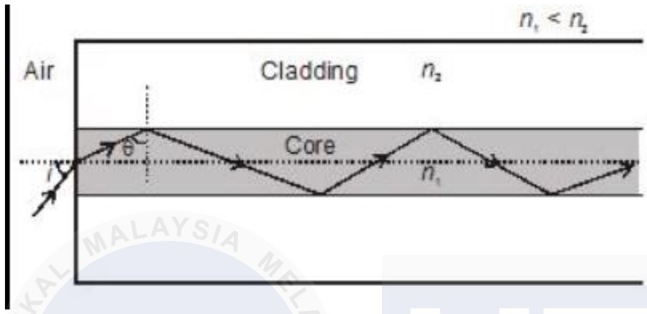

Figure 2.5 Light propagation in Optical Fiber

Reflective and Refractive

The concept of total internal reflection is employed with fibers transmitted within fiber optics to aggregate them light and confining it to the fiber's core is the main idea of an optical fiber. To determine the transition loss for a certain number of materials, it is necessary to know the time it takes for light to travel from one material to other alterations which makes the light turn to the other side [18]. The refractive index measurement is one of the important steps into the investigation of physical, chemical and biological properties. The amount of light reflected from a surface to another can be known by the use of the following parameters; texture of the surface or the planar distance of the surface and the source of light. The refractive index or any other optical material of a given thickness is a measure of the speed of light through the material, and the change in the refractive index is the main reason as to why light is bent. By looking at Snell's law, as light passes through boundaries between different media there are a number of effects transmitted from one medium to another, the degree of reflection is defined by three substrate properties. narrow space between the two materials where a refractive index of the core and cladding is essential.

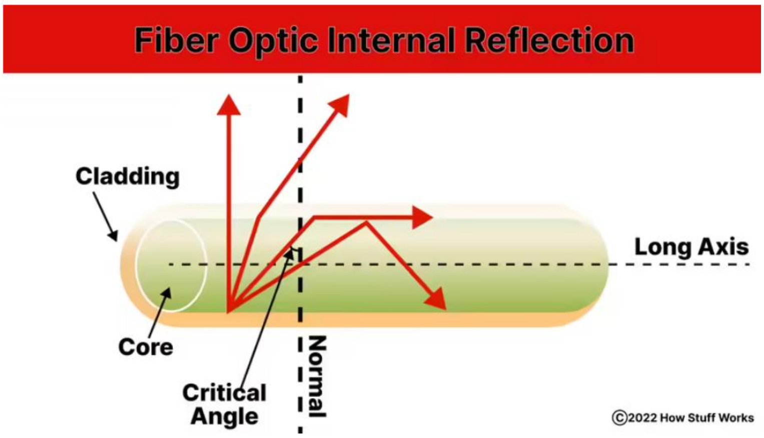

Figure 2.6: Fiber Optic Internal Reflection

Numerical Aperture

The light ray phenomenon that takes place at the core of the optic fiber has been described earlier. It is now the time to comprehend the significance of the number of photons that could be accepted in the optical fiber of intrusion into or through the core before it can enter the core. The acceptance angle, or also known as a meaning of this word, the maximum is the angle at which something is accepted. We calculate the pinhole, using the numerical aperture (NA) which is the sine of the acceptance angle, a, of the system light acceptance. Based on the above formula, the progressive variation in the refractive index of the samples is given by the concentration of NA is therefore defined by the core and cladding in this case [19].

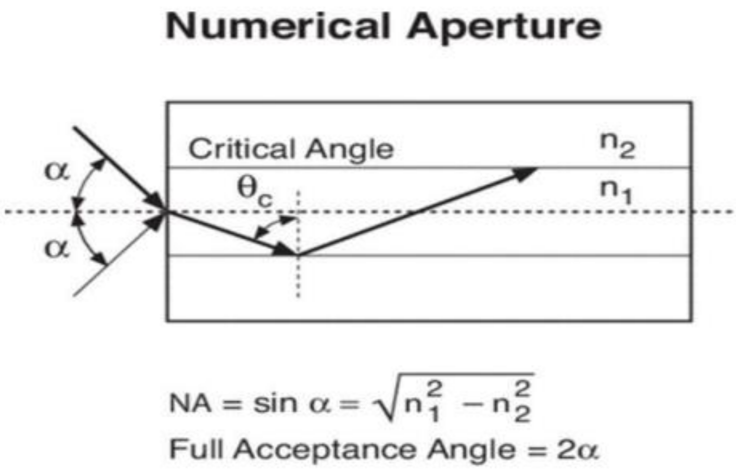

Figure 2.7: Numerical Aperture

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.

2.3 Related Previous Project

Fiber-optic sensor for liquid level measurement

The research article Fiber-optic sensor for liquid level measurement by J. E. Antonio-Lopez et al discuss the employment of MMI effects in a no-core fiber, an unclad type of multimode fiber, to come up with a novel liquid level sensor. It is clearly illustrated in the study that through applying the new length of the no-core fiber, the sensor can exhibit a highly linear response to alterations of the liquid levels d // dt , making it highly flexible for different applications. Besides, the amount of light reflected in the sensor peaks can be used to determine the refractive index of the liquid.

The no-core fiber sensor does not demand much fabrication complexity and intricate machinery needed to construct the full and inner cladding, thus making it efficient for real-world applications. These studies established that the utility of the sensor stems from such features as tunability of the sensing range, together with multiplexing properties in the measurement process – areas such as environmental monitoring, industrial processes, and diagnostics in biomedical applications. This shows that the capacity of the sensor to allow high accuracy and repeatability across various conditions of the field is one of the most exciting features to have a lot of potential in terms of future developments and applications.[20]

On balance, this perspective of how fiber-optic sensors are employed to perform liquid level measurement serves as a model of how advanced optical sensing could potentially offer improved outcomes within a multitude of practical applications while at the same time proving to be cost-effective.

ZnO nanorods coated microfiber loop resonator for relative humidity sensing

In journal article, Donghui Wang, Liuxia Wei, Tao Ju, and Libo Yuan work to outline the novel fiber-optic sensor using a multicore fiber for the simultaneous measurement of strain and temperature. As for this sensor, it is aimed for the possibility of measuring several values at the same time, for instance, strain, as well as temperature. The MCF sensor integrates three channels: One is for surface plasmon resonance (SPR) to determine salinity, the second one is for Fabryo–Pérot inference (FPI) pressure & temperature and the third one is for fiber Bragg grating (FBG) temperature compensation.

This new approach takes advantage of a symmetrical core reflection (SCR) of 45° and a step-like inner diameter capillary (SIDC) made of polydimethylsiloxane (PDMS) on the fiber facet. The various measurements are controlled by the varying modes of the sensor and the technology of space division multiplexing (SDM) that reduces crosstalk between the channels making the demodulation of the signals easy. Experimental results provided in the work show that the sensor can be operated on an incredibly low level offering sensitivities of 0. 0.36 nm/‰ for Salinity, -2.10. At high pressure 62 nm/MPa, below this pressure there is no visible movement the displacement is reduced and finally the movement is stopped and it becomes −0. 19 nm/°C for temperature. This high level of integration and demodulation makes the sensor ideal for multi-parameter applications especially where customization of the sensor for use in different frequencies is readily achievable [20].

This is illustrated in the ocean where the joint characterization of several properties using a single instrument such as the sensor is of significant importance. By integrating multiple functionalities to the sensors, P-SENSE offers an invaluable tool in improving the current state of oceanographic and other research where accurate and simultaneous multi-parametric measurements are fundamental.

Design and fabrication of a compact gas sensor integrating a polymer micro resonator and a 850nm VCSEL source

Among the most remarkable works, one should mention "Development and characterization of a compact optical fiber hydrogen sensor for harsh environments" by F Abdelkader, which is a qualitative contribution dedicated to the creation of a hydrogen sensor based on optical fiber technology. This sensor is built with portability and robustness, high sensitivity and selectivity for hydrogen detection is due to its high efficiency. The work conducted focuses on how the sensor needs to be built and from materials that have to be used, as well as the processes which have to be followed. It also explains the methodologies applied in the experimental part of the develop sensor, including the calibration procedures and the conditions that were imitated during the experimenting.[21]

The practical benefits of the sensor for widespread industrial applications are demonstrated, as the structure design allows maintaining high accuracy and reliability in identifying hydrogen in adverse conditions. It underlines the role of such sensors in creating safe and efficient conditions in case with presence of hydrogen in chemical works, refineries and plenty of other production areas. Several difficulties are mentioned in the document related to the concern of the development of the sensor, of the ability to detect substances, to the response time of the sensor, and the influence of external factors on its performance.

The research is strength by presenting a rich characterization of the sensor that includes its response at various hydrogen concentrations as well as temporal stability, which would help to beef up understanding of the real-world uses and opportunities of the optical fiber hydrogen sensors. Based on the study, it is established that the developed sensor holds much promise in improving the hydrogen detection in unfriendly setting hence can go along way in helping to increase safety and efficiency.

Optical Microfiber Sensor : A Review

The document "Optical Microfiber Sensor: In the paper titled "Optical Microfiber Sensors for Refractive Index and Temperature Sensing: Principle and Applications – A Review," by Mohd Hafiz Jali, Rosziah Omar, Norsuhaili Muhamad Amin, Nurul Amziana Amir Hashim, Rashmi Ravinder, Abdullah Asiri, Jianping Chen, and Kamal Anuar Kassim, the authors discuss OMFS with a focus These kinds of the sensors which despite of their lower sensitivity as compared with electronic sensors have other advantages such as non-susceptibility for electromagnetic interference and possibility of signal transmission over long distances, are described in detail with references. Among the examined fabrication techniques, tapering techniques are further divided into flame-tapering, fusion-splicer, CO 2 laser beam and micro-furnace tapering. Besides the discussion of the elements of the microfiber sensors, the features of the evanescent waves and their using in resonant structures, including micro-loops, micro-knots and micro coils are described.[22]

The document points regarding the optical characteristics such as large optical confinement, which can be configured, flexible, strong optical confinement, and large evanescent field which makes microfibers suitable for physical sensing. The review also discussed new developments in humidity sensing, and demonstrate the wide range of materials and techniques used to improve the sensitivity and response of the sense including, optical absorption, fiber bragg gratings, interferometers and micro-resonators. The adaptability of these sensors is best articulated by the different uses which include; cultural relic preservation, maintenance of products mainly in the warehouses, control of manufacturing processes, semiconductors use, agricultural use, food production & storage, environmental uses, general health industries, and chemical industries.

It is therefore seen that optical microfiber sensors hold a greater promise for satellite enablement in practical scenarios due to continuous improvements in the fields of material science and fabrication technology. Particular emphasis is placed with the potential that describes the ability to develop the sensors that can preserve their efficiency when operating in conditions that are considerably severe; at the same time, they have to possess high sensitivity and accuracy. Thus, the review arrives at the objective recognizing that the evolution and fine-tuning of these sensors will only lead to the increased usage and effectiveness across a broad spectrum of industries.[22]

Advances in Tapered Optical Fiber Sensor Structures: From Conventional to Novel and Emerging

The journal article titled "Advances in Tapered Optical Fiber Sensor Structures: The article titled, “A Review of Tapered Optical Fibre (TOF) Sensors: Techniques from Conventional to Novel and Emerging” by Alexander Ingham in Biosensors, Volume 13, Issue 6, 2023 provides substantial on the advancement of TOF sensors. These sensors have been widely used due to their easy fabrication process, high stability and versatility of the structure which has made them to be valuable in the various fields like physics, chemistry and biological sciences.

The present paper is a short article of recent advances in TOF sensors and a brief description of the different structural features of the TOF based sensors that provide higher order sensitivity and response rate as compared to the typical optical fibers for different application. It will present a comprehensive review on the working mechanism of TOF sensors, the different approaches of structuring them, and newly designed TOF structures in the past few years. Furthermore, it identifies novel directions of TOF sensor usage and their perspectives as well as discusses the tendencies and difficulties of TOF sensor creation in details.[23]

In light of this, the review aims to provide modern insights and approaches towards enhancing the performance and design of TOF sensors using fiber-optic sensing technologies. This study aims to supporting the use of TOF sensors for improvement of detection performance across different fields including environment, industry and biomedical diagnosis.

Microfiber loop resonator for formaldehyde liquid sensing

The journal article titled "Microfiber loop resonator for formaldehyde liquid sensing" investigates the application of microfiber loop resonators (MLR) using the whispering gallery mode (WGM) for the detection of formaldehyde in liquid. This study showcases the significant sensing response of MLR to varying concentrations of formaldehyde, from 0% to 5%. The results demonstrate that as the formaldehyde concentration increases, the output power of the MLR decreases linearly, with the sensitivity of the MLR increasing by a factor of 2.5 compared to straight microfiber (SmF) sensors. Moreover, the resolution of MLR sensors improved by a factor of 3.28 compared to SmF sensors, highlighting their enhanced performance in formaldehyde detection. This indicates the potential of MLR for precise and sensitive chemical detection applications, making them suitable for various industrial and environmental monitoring purposes.[24]

The study underscores the potential of microfiber loop resonators for applications that require high sensitivity and accuracy in chemical detection. The MLR's improved performance in sensitivity and resolution over traditional straight microfiber sensors makes them an ideal candidate for formaldehyde sensing in various settings, including environmental monitoring and industrial applications where precise detection of chemical concentrations is crucial.

Micro-/Nanofiber Optics: Merging Photonics and Material Science on Nanoscale for Advanced Sensing Technology

The journal article titled "Development of a Smart Fiber Optic Sensor for Monitoring Hydrogen Peroxide Concentration in Aqueous Solutions" explores the design and application of a fiber optic sensor system specifically engineered for detecting and monitoring hydrogen peroxide concentrations in aqueous solutions. This study is crucial for various industrial and environmental applications where hydrogen peroxide is used or monitored, such as in the food industry, wastewater treatment, and medical applications.

The research focuses on the integration of fiber optic technology with specific sensing materials that react with hydrogen peroxide, resulting in a measurable optical signal change. This innovative approach enhances the sensor's sensitivity and accuracy, enabling real-time monitoring of hydrogen peroxide levels. The study also delves into the sensor's calibration, response time, and the effects of various environmental factors on its performance.[25]

Overall, this development represents a significant advancement in the field of chemical sensing, providing a reliable, efficient, and accurate method for hydrogen peroxide monitoring, which can be extended to other chemical sensing applications as well.

Research on a Fiber Optic Oxygen Sensor Based on All-Phase Fast Fourier Transform (apFFT) Phase Detection

The article under discussion is titled "Research on a Fiber Optic Oxygen Sensor Based on All-Phase Fast Fourier Transform (apFFT) Phase Detection" and it aims to reveal the prospective of designing and enhancing a fiber optic sensor for oxygen measurement. employing apFFT, the sensor provides accurately phase detecting and improving the precision and the resolution of oxygen measuring. The study shows that through the calibration of the sensor to the NIST standards it has shown high stability and accuracy especially in the low oxygen concentrations and due to that the sensor is well suited for use in critical and sensitive applications such as in hazardous environments, in medical fields and in industrial processes.

To achieve the desired performances, the paper describes the steps to build the sensor and include the apFFT algorithm into the firmware. Wherein, the experimental validation reveals the credibility as well as the reliability of the sensor measurements and it aptly signifies possible field application. This paper also outlines the benefits of utilizing the apFFT algorithm as compared to conventional approaches in that has given contribution to sensor optimization.

Also, the study provides the methods used in calibrating this sensor and the environment under which its given to test its operational stability. In light of the above findings, the authors assert that fiber optic oxygen sensor, which differs in high sensitivity, reliability, is a major step forward in the classification of optical sensing technologies.

2.3.9 Advantage and Disadvantage of Fiber Optic

Advantages of Fiber Optic

Advantages	Explaination
High Bandwidth	Most notably, fiber optic cables are capable of transmitting far larger volumes of data at much faster rates in comparison to copper cables, making them supreme for communications and Internet Service Provisioning.
Long Distance Transmission	It is worth asserting that fiber optic cables can transmit information over much larger distances with relatively little attention on signal loss since the features of optical signals are superior as opposed to electrical signals.
Immunity to Electromagnetic Interference	Fiber optics cables themselves are resistant to electromagnetic interferences (EMI) and radio frequency interferences (RFI), hence providing an optimal solution for places with excessive electrical noise, which confines the electronic signals.
High Security	Fiber optic communications are even more secure than wire line communications since they do not emit signals to the surrounding environment, and it can also be hard to intercept data without the sender being aware of it, making it suitable for secure information networks.
Lightweight and Durable	Fibre optic cables is that they are made of glass which is lighter than copper and can also withstand more pressure than copper cables. For they can endure severe more environmental conditions than miniature fans making them suitable for use in industrial and outdoor settings.
Reduced Signal Degradation	On the note of cable attenuation over length, fiber optic cables are widely preferred due to the small or negligible amount of signal loss in lengthy transmission as well as for the superior quality of the signal that is mandatory for high definition video and sound signals.

Scalability and Future-Proofing	Fiber optic infrastructure is also highly scalable; it is possible to upgrade it to add more bandwidth through simple additions rather than radical changes to the platform. This makes fiber optic systems one of the most cost effective and future ready solutions that are likely to suit growing technology requirements and high bandwidth traffic.

Table 2.3: Advantages of fiber optic

For these reasons the application of fiber optic technology is preferred in many different fields. In the sector of telecommunications and internet services, fiber optics possess the key infrastructure for high data transmission rates that facilitate increased internet speed and better streaming capabilities for video services as well as overall improved communication networks. In the field of industries, the fiber optics play an immense role in providing a reliable and efficient communication between the machines or manufacturing equipments and control systems used in industries thus increasing the productivity of the factories and industries. In the medical field, fiber optic is widely used in technologies used in imaging purposes like in the endoscopy technique and other methods in the diagnosis that requires less invasive process.

Also, fiber optic forms the backbone of development of the smart grid system, where there is the need for the integration of efficient communication technology for management of energy distribution. In aerospace and defense industries, some of the most obvious advantages of fiber optics include their light weight and incredible sturdiness that is useful in areas where weight and strength are key considerations. Moreover, fiber optics are becoming relative widely applied in environmental monitoring systems due to their capabilities to transmit information with minimum signal loss over large distance ensuring accurate and time effective reflection of certain environmental conditions.

In conclusion, the effectiveness and accessibility of fiberglass technology in terms of broadband transmission and minimum susceptibility to interference, strengthen its position as an indispensable component of contemporary communication and industrial advancements, medical devices, and others. With the increasing volumes of information in industries, communication, and technology, fiber optics will have a broad application and importance in different industries, hence improving on efficiency by meeting the growing need for fast and efficient data transfer.

Disadvantages of fiber optic

Disadvantage	Explaination
High Initial Cost	Utilizing the fiber optic systems is that the installation costs are relatively high. To this are added cable or any other special equipment needed and the cost of the time taken in installing. Larger systems may be initiated by larger institutions or organizations and the higher initial investment may be constricted if the organization or area is small.
Complex Installation	Most fiber optic cables come in difficult-to-handle forms, and installation needs highly skilled personnel and tools. These cables are quite delicate, and their installation may require some measures to ensure that they are not damaged. This complexity makes the overall cost and time for the deployment of AVOs higher as compared to using a simple combination of AO and VO.
Fragility	Fiber optic cables are more delicate than copper cables, but they are the most preferred means of transmitting data. The underlying techniques are ‘vulnerable to mechanical stress from bending, twisting or forcible crushing, which can lead to the disruption of the signal or breakage of the link completely
Limited Availability	In some geographic areas, it is admitted that fiber optic networks are not as dense as copper-based ones. This has the disadvantage of limiting the adoption of high-speed fiber optic internet services in areas with low development or no urban areas.

Specialized Equipment	Fiber optic systems involve many fiber joints, connections and some tests that need some special tools to be used. It may also have a high purchase price or may not be as user-friendly and may need to be operated by a specialist.
Power Requirements	While copper cables are able to deliver electrical power to distant devices, equipment or even circuits, aerial fiber optic cables are not able to transmits power. This limitation requires that there might be the need for other power source strings or copper as complementary to fiber optic for some uses.
Signal Loss Over Long Distances	Fiber optics come out as having less signal losses than copper cables, they sometimes need repeaters or amplifiers for very long-distance signals. This can increase the cost and size of the network depending on the type of design implemented.

Table 2.3.1 Disadvantages of Fiber Optic

Hence these disadvantages require careful thought and analysis when planning and conducting fiber optics. The costs of fiber optic networks comprise the cable, space, equipment, installation tools, and the technicians required for fiber optics deployment, they are quite hefty thus present a challenge for small businesses, or communities. Furthermore, the installation procedures are quite technical and small and precise as fibers are very sensitive to bending, twisting, and crushing.

Moreover, the limited physical reach of the fiber optic cables keep high-speed as well as high-bandwidth applications of fiber optics limited by their geographic coverage, especially covering rural and developing territories. This means that even though it has benefits, you can’t always use it everywhere as a method of low-cost organisation. The requirement of subscribing to specialized cables for splicing, joining and testing makes the overall cost prohibitive and the set up also requires extra training for technicians.

This is in contrast to copper cables where fibres optic is unable to supply power to remote equipment as copper cables supply power through it . This requires the use of other power source to augment the fiber optic systems or it requires the use of separate copper cables to augment the fiber optic cables leading to more complicity and expense in the overall network system. In addition, though fiber optics transmit a signal more efficiently over large distances than copper does it is not free of repeaters or amplifiers for very large distances transmissions. It further contributes to the worsening of fiber optic network's cost and difficulty to maintain.

Nevertheless, there are always pros of using fiber optics that outweigh the cons at any given context. The unique feature of high bandwidth and the ability to deliver data securely makes the element a critical part of modern communication applications, industries, and medical technology. These are important in applications which may include high-quality video and audio broadcast, online and interactive gaming, telepresence, and big data centers. The fiber optic connections also have high levels of reliability and stability, thus suitable for use in military operations or even in the aerospace industry or the financial world where the data to be transmitted needs to be very secure and accurate.

The necessity of the higher and more stable data rate keeps increasing, which in turn determines the fibre optics utilization in different fields. Current limitations include the cost of equipment and installation, however, improvements in these areas seem inevitable thus increasing the advantages of using fiber optic for multiple uses. Copper based solutions are yesterday's technologies and fiber optics are the technologies of tomorrow as it boasts of scalability and a potential that can satisfy the increasing needs in the age of the third millennium.

2.4 Journal Comparison from Previous Work Related to the Project

Article Title	References	Main Objectives	Key Findings	Advantages	Disadvantages
ZnO nanorods coated microfiber loop resonator for relative humidity sensing	[20]	Develop a microfiber loop resonator coated with ZnO nanorods for humidity sensing	Achieved high sensitivity to relative humidity with a linear response	High sensitivity, compact design, and potential for industrial applications	Requires precise fabrication techniques and may be sensitive to environmental factors
Design and fabrication of a compact gas sensor integrating a polymer micro resonator and a 850nm Vcsel source	[21]	Design a compact gas sensor using a polymer micro resonator and an 850nm VCSEL source	Demonstrated effective gas detection with high accuracy	Compact design, high accuracy, and suitable for various gas sensing applications	May require complex integration and calibration for different gases
Optical microfiber sensor: A Review	[22]	Review the development and	Highlighted advancements in	High sensitivity, broad applicati	Fragility and potential for damage

			applications of optical microfiber sensors	sensitivity and application versatility	on range, and low noise	during installation
	Advances in tapered optical fiber sensor structures: From conventional to novel and emerging	[23]	Discuss advancements in tapered optical fiber sensor structures	Identified novel structures that enhance sensitivity and response time	Enhanced sensitivity and response time, suitable for various sensing applications	Potential complexity in fabrication and maintenance
	Microfiber loop resonator for formaldehyde liquid sensing	[24]	Develop a microfiber loop resonator for detecting formaldehyde in liquid	Demonstrated high sensitivity to formaldehyde concentration	High sensitivity and specificity, suitable for chemical sensing	Limited to specific chemical detection, requires careful calibration
	Micro-/Nanofiber optics: Merging photonics and	[25]	Explore the integration of photonic	Achieved significant advance	High precision and integration	High cost and complexity of fabrication

Material Science on nanoscale for Advanced Sensing Technology		s and material science for advanced sensing	ments in nano-scale sensing technology	capabilities, suitable for advanced sensing applications	
Research on a Fiber Optic Oxygen Sensor Based on All-Phase Fast Fourier Transform (apFFT) Phase Detection	[26]	Develop fiber optic oxygen sensor	Utilizing the apFFT algorithm for phase detection	High sensitivity and precision	Complex implementation process

Table 2.4: Comparison for previous research

2.5 Summary

Varying forms of analysis about optical loop fiber oxygen gas sensor were considered in this chapter. According to the findings made in the course of the study, there are several methods used in the creation of fiber optic sensors. Fiber optic technology can handle larger amounts of data and transfer them at significantly higher rates compared to other technologies over larger distances. Therefore, this review ends here summarizing the essential discussion of different optical fiber sensing techniques applied in the study of gases. It is useful to look at the number of extrinsic and intrinsic methods published in this regard over the years most of which were considered outcome in terms of sensory attributes which were attained in a controlled environment of the laboratory.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The life cycle of a project refers to the entire range of guidelines that outline the general plan of a project which details the process in completion of the project. In accordance with the earlier-stated objectives of the chapter, procedures on stripping, cleaning, cleaving, splicing, tapering and looping of the optical fiber cable have been discussed. These steps are quite important since they are a preparation process towards connecting the fiber optic cable to the microresonator fiber in a reduced turn manner. Every process is designed in detail so as to give a perfect structure and finishes to the fiber it produced. Stripping has to do with the removal of the outer layer or coating, cleaning involves putting the fiber through a process that ensures all the outer dirt is eliminated and cleaving involves slicing the fiber to the right length with so much care. Splicing is a process through which two fiber ends are connected to retain the path against light while tapering is a process through which fiber diameter is made smaller to increase its sensitivity. Finally, when the fiber is wound to position it in a single loop, it becomes effective in detecting oxygen gas. This makes it possible for the development as well as the operation of the oxygen gas sensor since it is a very comprehensive methodology.

3.2 Hardware Specification

1. Single mode Fiber Pigtails

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

2. Fiber Cutter and Jacker Remover

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

3. Isopropyl Alcohol

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

4. Hand Cleaver

Figure 3.4: Hand cleaver used to cut the fiber tips to the proper length for splicing

5. Fusion Splicer

Figure 3.5 Fusion Splicer machine to splice two fibers together

6. Oxygen Booster

Figure 3.6: Oxygen Booster for fiber optic

7. Amplified Spontaneous Emitter (ASE)

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

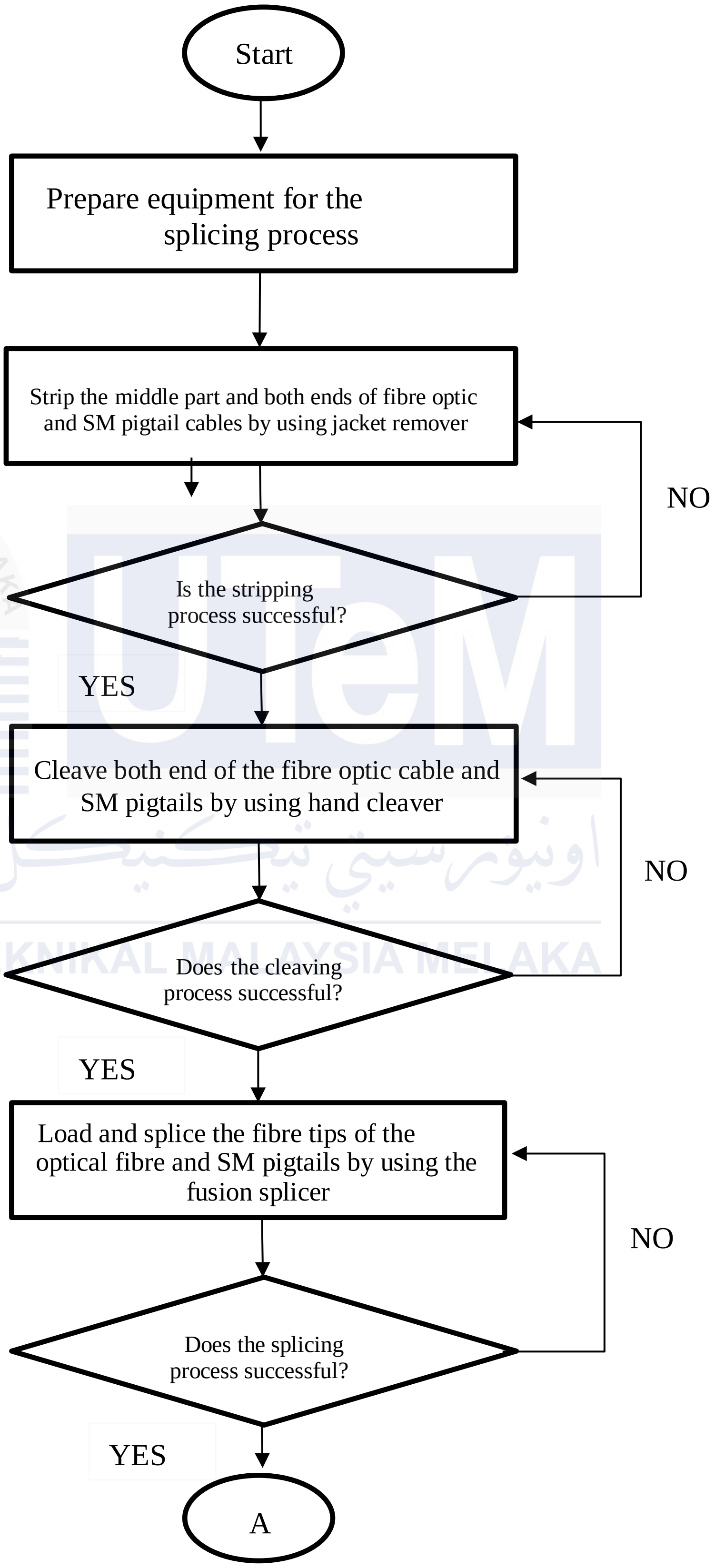

Figure 3.9 The flowchart of splicing fiber optic cable

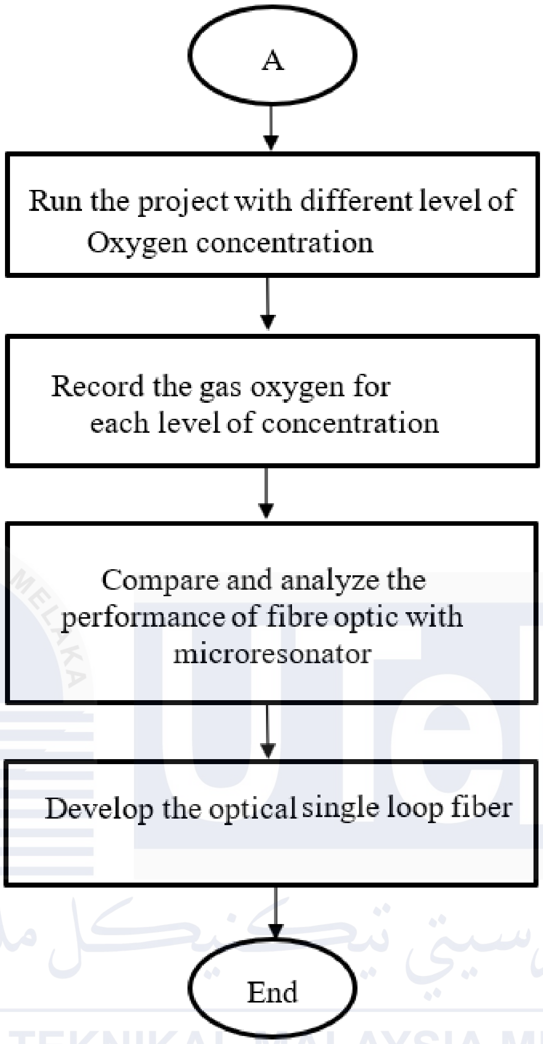

Figure 3.9.1: The flowchart of the experiment in developing fibre optic as a sensor

3.4 Setting up the experiment with Fiber Optic Sensors

Figure 3.11 illustrates the arrangement of the project's test. ASE will therefore act as a transmitter which outputs. This means that for the next experiment, 1550nm light pulse and OTDR will be acted as receiver in order to measure the optical power as shown in the diagram to give the position of the optical loop microfiber under test as mid-position thesis.

Figure 3.10: Design of a microfiber optic sensor experiment setup

3.5 Stripping Process

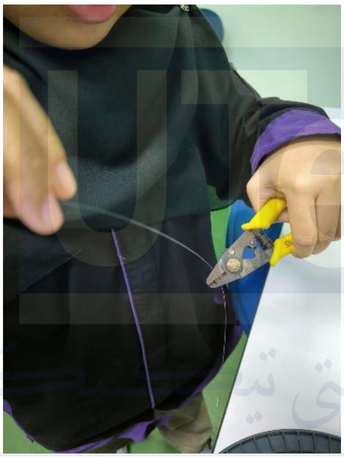

Figure 3.11 Fiber Optic being stripped

Stripping is the process of removing a protective polymer coating around an optical fiber. Figure 3.2 is a stripping tool used to cut the outer layer before sliding it along to strip the coating. Figure 3.12 shows the stripping process, which removing the coating around an optical fiber in preparation for fusion splicing. The hole in the stripper blade is large enough that the stripper can cut without breaking the fiber glass.

3.6 Cleaning Process

The methods of cleaning fiber optics are an essential procedure that determines the effectiveness of the fiber optic system from interruption of the fiber optic telecommunication system and to enhance the reliability of the fiber optic system. Impurities including dirt, oil, dust or any residues substances are potential that may greatly the quality of it. This can cause changes in the quality of the optical signal and can lead to signal loss or signal quality degradation. Therefore, it is essential so as to ensure that the fiber optic connectors are clean and in order in case of any cleaning cables. Here are the general steps involved in the cleaning process of fiber optics. Here are the general steps involved in the cleaning process of fiber optics:

1. Inspection: Prior to cleaning meet all fiber optic connectors, adapters and cables to ascertain that they are free from dust, debris or streaks of other materials before these externalities affect its aesthetic appeal or integrity through evident soiling, spilling, or scratches. The next step is to look for a dust or dirt or finger prints or any other spot on the surface that may distort or prevent effective passing of light towards the bottom areas of a building.
2. Safety Measures: It is also important to make sure to take all the necessary precautions as a measure of protecting yourself, like washing your fingers gloves and increase in wearing clean clothes to avoid touching more surfaces that would spread the bacteria during the cleaning process.
3. Dry Cleaning: With dry cleaning processes to vacuum or brush off any debris or dust from the furniture particles and dust. This can be done using a lint-free cleaning cloth, wipe or a small piece of tissue that has not been subjected to other uses such as washing compressed air. To clean the fabric connectors, do not use a brush to clean the connectors but use your fingers to wipe or blow away any particles that are easily visible or cables.
4. Wet Cleaning: The need for wet cleaning process is therefore crucial in gaining better performance. Wet cleaning is by refers to the process of cleaning by applying a fiber optic cleaning solution or isopropyl alcohol (IPA) on a fuzzy-less cleaning wipe. To clean the connector end face or the end face of the optical fiber, dip the cleaning wipe into the solution and then clean lightly the concerned area the exposed fiber in an anticlockwise or circular direction. The fiber core should not be touched or else any damage to it could occur the connector end.
5. Inspection and Repeated Cleaning: After the cleaning process, the visual check should be conducted or the results obtained by a different person once more to warrant the full elimination of any impurities The second step is also accompanied by agitation to ensure the removal of all contaminants. If necessary, repeat the cleaning steps to clean the affected region from the marks and stains left by dirt and dust achieve the desired cleanliness. There is one thing that must be understood – the cleaning tools are to be proper for cleaning, the cleaning solutions are to be suitable for cleaning, and the

cleaning techniques are to be safe for cleaning have to be adopted with reference to the stipulated measures and policies. Cleaning and maintaining parts of the home, especially the ones that are frequently used, should be a routine. It is wise to maintain the fiber optic system in the right manner, to achieve the required reliability of the system

Figure 3.12: Fiber being cleaned with isophrophyl alcohol

3.7 Cleaving Process

The term cleaving in fiber optic industry is the art of or process of cutting an optical fiber through a specific way. It is to make the fiber both the clad and core ends flat and smooth. The cleaving process involves cutting the fiber optic in order to achieve these specifications as it's the key step in manufacturing the fiber optic cutoff, splice, or connector specifications, as it defines the shape and surface profile of fiber end face and tudying in turn how it impacts the transmission of the optical signal. Here is an overview of the cleaving process:

1. Selecting the Cleaving Tool: The first method in selecting cleaving tool is to make a proper selection. There are various categories of cleavers depending on the method of utilization, cleaver based on scribe, cleaver based on blade, and so on.
2. Prior to cleaving, fiber optic cable with outer sheathing stripped off reduces thickness to its core that after ejecting and stripping process, rub, buffer, and coat layers are applied on the jacket layer.
3. Fiber Fixation: The fiber is then positioned and attached within the vehicle using a fiber holder or fixture to make sure it will not move or get loose. Orientation of the cleaving plane is critical here in order to avoid misalignment and to guarantee the dimension of the fiber.

4. Score Line: When cleaving, there is a relative scratch or groove created on the fiber and this fulfills the option of surface treatment prepares the surface by etching it with diamond or tungsten carbide scribe at a preferred angle. The score line damages the fiber in a way that diminishes the fabric's strength as well as durability them, structural organization and produces cleavage break point in a more controlled manner.
5. Cleaving Operation: According to the different types of cleavers, the cleaving process is actually operation can differ:
    - Scribe-based Cleaving: In scribe-based cleavers, there is a controlled strike that is applied on the ICU to initiate the cleave getting a position of scored line. The fiber is torn manually or by hand or is bent or broken in the present procedure by the investigator a cleaver's lever mechanism. As has been established, it is the competence of the operator, that is, his/her level of experience that plays a criticality in a perfectly clean riser member without any scratches or any rough surface to hinder a clean and smooth cleave.
    - Blade-based Cleaving: There are two primary types of cleavers: blade-based and press-based; blade-based cleavers use a sharp blade or cutting wheel to cleave the fiber.
    - Automated Cleaving Systems: Robotic cutting technologies, also known as automated cleaving systems, depend on the principles of cutting, fracture, and separation which can be then complemented by other cutting techniques like laser cleaving or mechanical scoring along with step and repeat control and alignment mechanisms. These systems work with a high degree of accuracy and the results obtained from these systems tend to be completely accurate. This leads to producing capping and sticky cleaves that are sound and fruitful in nature.
6. Inspection: Subsequently, after cleaving the fiber end face is checked using a fiber optic micro-scope microscope or inspection tool. This end face should appear bright, flat, and free from blemishes that could be seen by the naked eye crossing the fiber axis; P, the Pavement Index, which indicates the relative stiffness of the pavement structure; VA, the Void Angle, which measures the orientation of the void or air

phase of the composite material with respect to the fiber direction; and VF, the Volume Fraction of the fiber phase, or the concentration of the fiber phase in the overall volume of the composite material. Chips or any form of surface defects on the cleaved-end face of the waveguide should be avoided for the same reason that they could interrupt the signal path or be lost altogether.

7. Cleaning: The end face of the fiber should be cleaned with proper cleaning instruments and techniques as discussed. Cleaving is a critical process in which precise methods need to be followed in order to obtain precise and clean cleaves with minimal fiber end face defects. The cleave quality is immediately associated with the later productivity and effectiveness of the fiber optical processes.

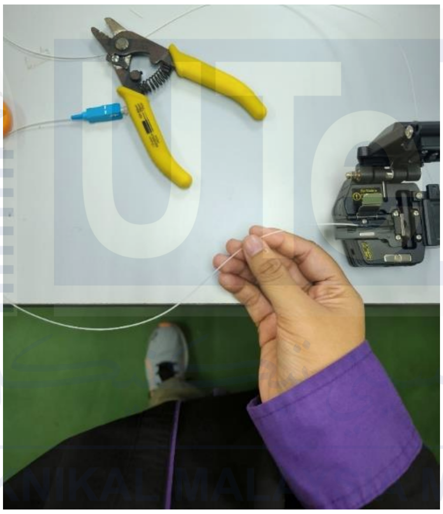

Figure 3.13: Cleaving Process

3.8 Splicing Process

The splicing techniques in fiber optics is essentially the fusion or connection of two cables fibers to form a gradual transmission channel which is also understood as an optical channel for signal transportation. In the process of mRNA synthesis, splicing is amongst the most important procedures in fiber optic network installations, repairs, or expansions that entail delicate and accurate procedures such as alignment and fusion of the fibers ensure that there is minimal signal attenuation and excellent optical characteristics of the fibers. Concisely, here are the details of the following sub-topics; splicing process:

- Fiber Preparation: This preparation involves strimming the fibers before they are spliced, that is, all the fibers that are to be joined should be prepared. This entails the removal of all the outer layers in the fibers ends in the process of demassing them, as recommended by stripping process explained earlier. The bare fibers are cleaned to get rid of anyare sampled and handled to minimize the impact of various contaminants and to achieve the best results in fusion.

- Fiber Cleaving: All the fiber ends are required to be cleaved to ensure that the end face is clean, smooth and conforms perpendicular surface for fusion. Ccleaving is a very important factor which needs to be met if the end product is to be of high quality.The method reduces splice loss and ensures that the integrity of the signal is not compromised in anyway.
- Fiber Alignment: The fems seem and are brought into order, meaning the core- to-core alignment is tightly controlled. This can be done using various alignment techniques, which are among the five tenses of writing: silver, bronze, copper, lead, and gold alignment manual alignment, active alignment or fusion splicing machines for further automated controlled alignment of respective fibers. The alignment process entails a procedural realignment of the fiber's position in such a manner that to yield the best result.
- Fusion Splicing: Fusion splicing, warming over, is the physical act of connected the fiber each and all of them, it then joins them at one end. This is realized by either applying heat to melt the, or by placing the two parts end to end and then applying heat to fuse the joints fiber ends and then linking the fiber ends to flow in a single cable line smoothly.
- Splice Protection: To prevent injuries on the fused area which can be a result of various factors such as pressure vibration, water penetration, or signal interference as their components may be worn, damaged or affected by corrosion. Splice protection can beachieved using various methods, being heat-shrink sleeves, splice trays, or mechanical splicing devices. These protective measures are essential in ensuring that the structure remains strong and stoic against all kinds of vices and negative influences that might jeopardize its integrity stability of the spliced connection The low reliability of the spliced connection means that cane toad's extinction will not restore the ecology back to its pristine condition.

- Splice Testing and Verification: After the splicing is done, one should see the following characteristics of the spliced fiber should be subjected to testing and evaluation to ensure optimal orientation, as well as low splice loss. This is typically performed with an optical-time domain reflectometer (OTDR) or another kind of optical measuring equipment. These tests confirm the optical fiber’s consistency and analyzes its splice loss and such other tests these devices are easy too, to find any defects or anomalies with. modes of fiber connection resulting in high reliability but comes with the drawback of being expensive and would need special tools to be used. Mechanical splicing is quite different and entails the use of assemblies that use some mechanical connectors or devices for positioning and joinery of the fibers while the above, may cause slightly higher losses.

Evidently, there are various methods of splicing which one will depend on some factors such as the application; the budget and other special conditions as outlined in the following sub topic. Among the various splicing techniques there are fusion splicing and mechanical splicing. Fusion splicing offers the least loss and best transmission capabilities among these three

Figure 3.14: Splicing Process

3.9 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 and similar. Figure 3.15 shows the tapered process made.

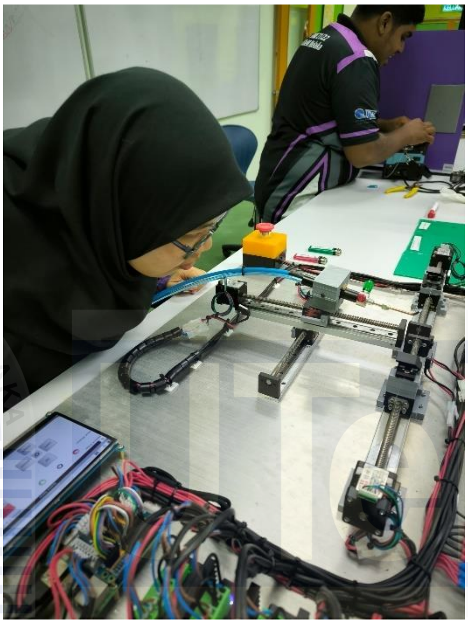

Figure 3.15: Tapering Process

3.10 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.

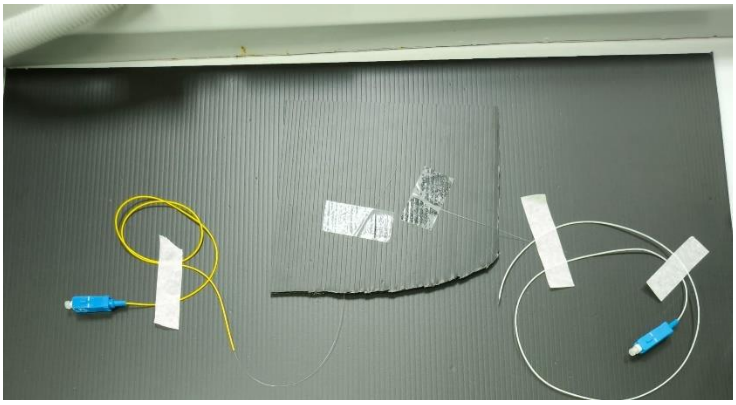

Figure 3.16: The process of looping the fiber optic cable

3.11 Final Check on Fiber

This procedure is adopted in order to validate the authenticity of the fiber that is used in this procedure. This precaution is recommended since there were concerns about the condition of the fiber in case of a break or failure of the laser light to gets to the final position. This potential issue arises during the process of tapering, depending on the manner in which the interest rate is changed is that it ends up in a situation where the fiber core gets damaged, and it metamorphoses into a microfiber. The most critical concern is the looping phase, at which the fiber has a perfect thin and slender structure mostly are likely to be broken. The laser testing protocol is used test the condition of the link to the fiber optic connection

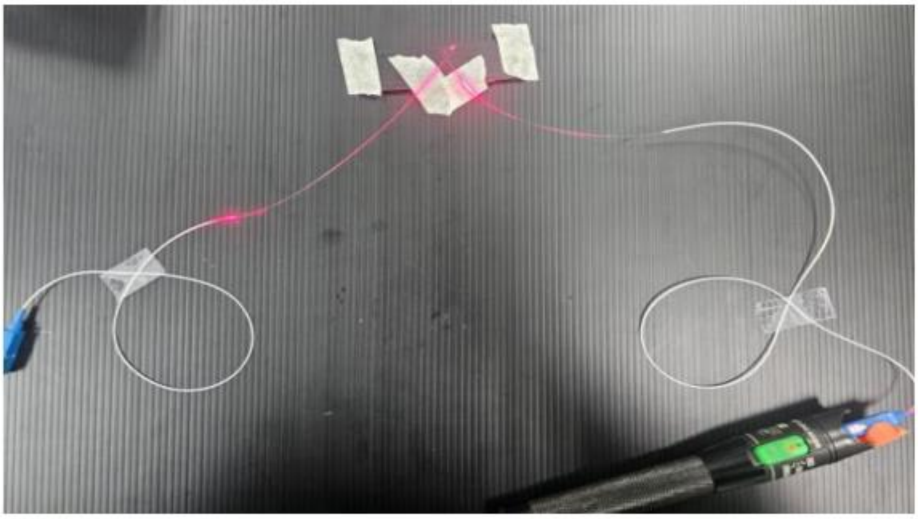

Figure 3.17: Testing Fiber using laser

3.12 Characterization Fiber Optic Loop Sensor

Crucial tests are performed on the experimental setup to determine the performances of the fiber optic loop sensor known as characterization. These include insertion loss, optical return loss, polarisation and dispersion among other features of the connectors. Such assessments help provide the fiber with the ability to transmit data to other ends and can be used for future debugging and troubleshooting. The following detailed characterization captures the sensor's ability and preparedness for field work and physical implementation while giving valuable information on its functionality and viability. evaluations of the experimental setup are performed to assess the capabilities when testing this experiment, known as the characterization of fibre optic loop sensor. Fiber characterization examines insertion loss, optical return loss, polarisation, and dispersion to ensure that the fibre can carry traffic and serve as a reference for further debugging and troubleshooting.

3.13 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.

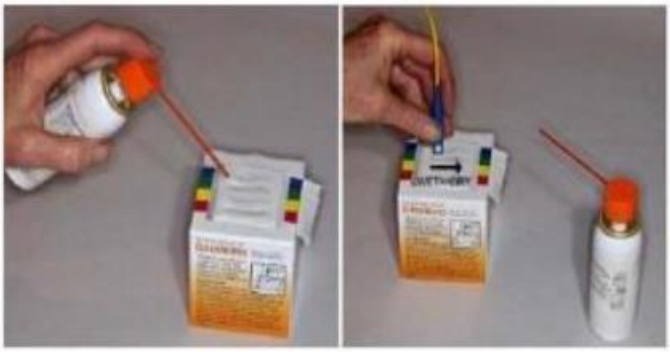

Figure 3.18: Example of wet to dry cleaning

3.14 Insertion Loss Test

Another type of measurement is the insertion loss test, where essential parameters of the fiber line are replicated to reflect actual operating conditions. In this process an optical cable is connected with a test source on one terminal, while the amount of power dissipated at the other terminal is measured in a power meter. The test source and power meter a put in the path between the fiber cable. First the power meter is set for initial zero at zero db then the fiber is connected to the meter. Figures 3.19 and 3.20 demonstrate placement of the 0dB reference on power meter and execution of the insertion loss procedure in turn.

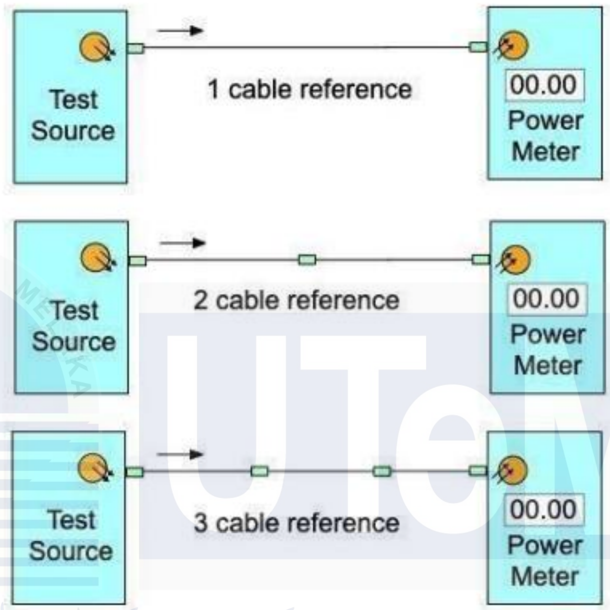

Figure 3.19: Ways to set 0dB references at power meter

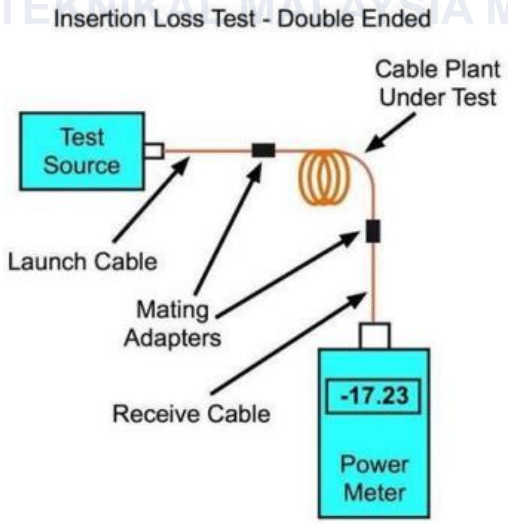

Figure 3.20: Insertion Loss Test

3.15 Reflectance or 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.

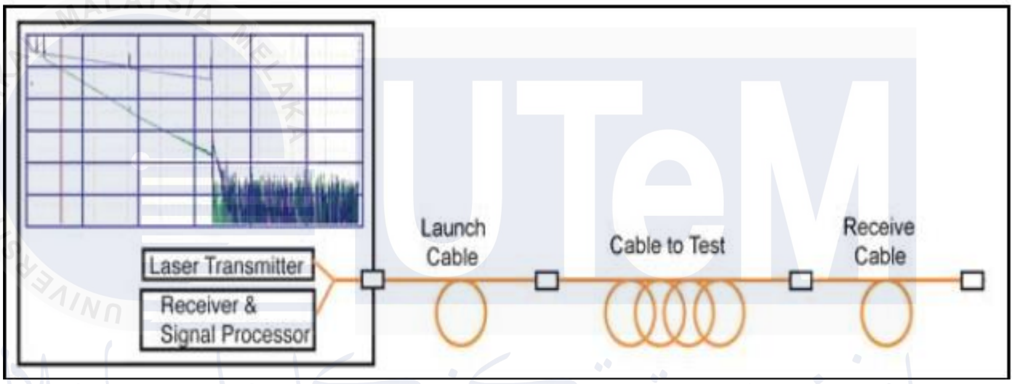

Figure 3.21: OTDR Testing

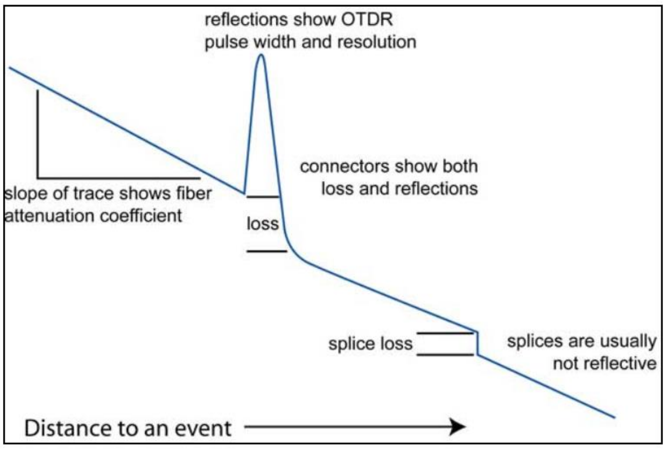

Figure 3.22: Example of OTDR Trace

3.16 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

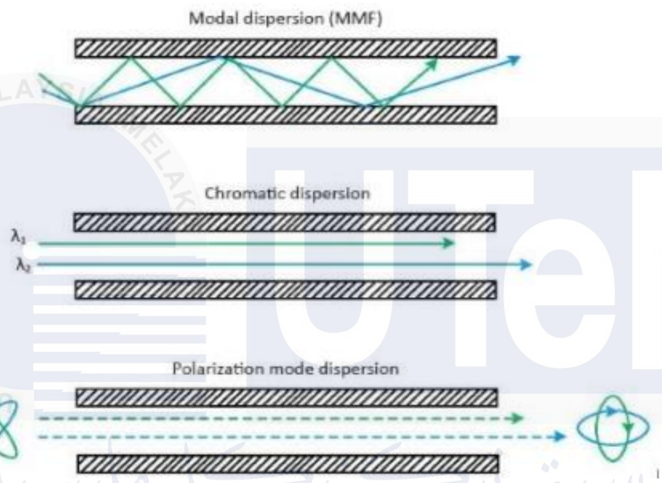

Figure 3.23: Three types of dispersion in fiber optics

3.17 Summary

All the activities and tasks that need to be done in this chapter are described in this flow chart. It also explains how to compensate the OLFT under test in terms of the dehumidification percentage and the OL power readings which must be taken. This chapter also explains how to obtain magnificently clean, accurate and free from error readings with the sensor element and on how to clean it using soft tissue in alcohol to remove any other particles or marks that may remain.

CHAPTER 4

4.1 Introduction

This chapter presents the results and analysis of the development of a microresonator fiber in a single loop designed for an oxygen gas sensor. The system uses advanced optical components, including 1310nm and 1550nm wavelengths, to enhance the detection and measurement of oxygen levels. The sensor's performance is evaluated based on criteria such as sensitivity, linearity, and operational capacities, with data displayed on an integrated LCD screen for real-time monitoring.

Preliminary testing shows that the sensor effectively provides accurate and reliable measurements of oxygen concentration. Initial results indicate high sensitivity and consistent linearity, with immediate feedback displayed to the user. The system's design ensures precise measurement and control, allowing for real-time monitoring of oxygen levels.

The microresonator fiber's fabrication involved a controlled tapering process, reducing the fiber diameter from 125μm to 10μm, which proved crucial in achieving the desired sensitivity and accuracy. The comparison between the 1310nm and 1550nm wavelengths demonstrated distinct advantages in different concentration levels, with the system capable of adapting to various operational environments.

The integration of the microresonator fiber with advanced optical components and real-time data display suggests that the developed sensor offers a highly effective solution for oxygen monitoring. Future work will focus on refining the sensor's components, enhancing its operational range, and improving the overall user experience for practical applications in various fields.

4.2 Size of Microfiber Optic Loop Sensor

Figure 4.1 It is seen from figure 1 that with the new dimensions the microfiber optic sensor is compact. The diameter of the sensor was measured using the other using a microscope. Specifically, in the fabrication process, the formation of the microfiber sensor via the tapering process, where a delicate burning process was used to make the microfiber sensor. Specifically, the examined fiber with an initial diameter of 125µm has been reduced to 30µm, which highlights the use efficiency of the selected fabrication for the sensor fabrication.

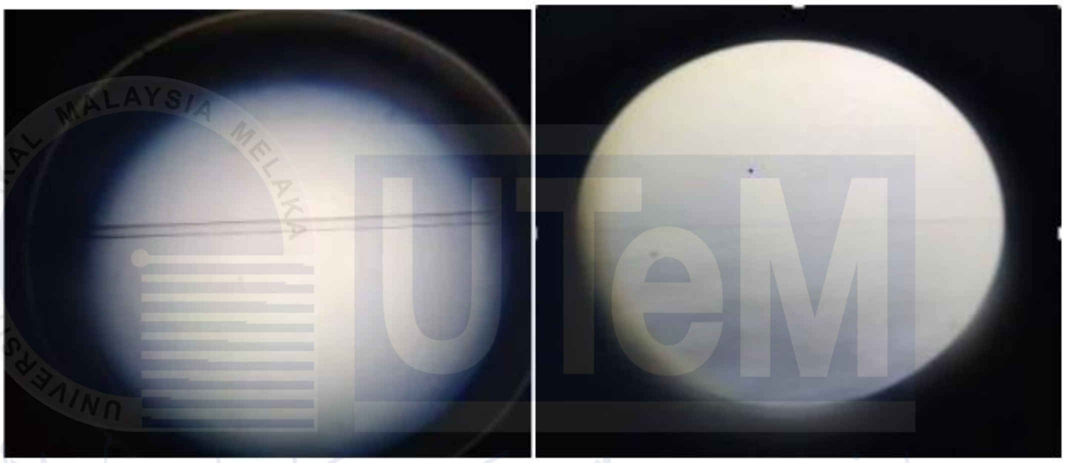

Figure 4.1: New Size of the Microfiber Optic Sensor

4.3 Results and Analysis for Different Level of Concertation

Figure 4.2 illustrates the experimental results obtained from testing the fiber optic sensor in the presence of oxygen gas at concentrations ranging from 10% to 50%. Measurements were taken at 30-second and 1-minute intervals. The experimental setup involved transmitting a modulated light signal through an Optical Time Domain Reflectometer (OTDR) via two single-mode fiber pigtails. These pigtails were connected at a splice point, where an unclad region was centrally located in the transmission path, forming a loop.

The sensor was tested with varying oxygen concentrations (10%, 20%, 30%, 40%, and 50%) using two distinct light wavelengths of 1310 nm and 1550 nm. The recorded data was analyzed and represented as a line graph, depicting the relationship between output power (in decibels, dB) and time (seconds). This graphical representation provides valuable insights into the sensor's behavior and performance under different oxygen gas concentrations and wavelengths, highlighting its sensitivity and response over the course of the experiment.

Figure 4.3: Conducting the experiment

4.4 Single Loop Resonator for 1310nm and 1550nm

This section presents the data recorded over a period of 30 seconds and 1 minutes using a fiber, with oxygen concentrations of 10%, 20%, 30%, 40%, and 50%, evaluated at wavelengths of 1310 nm. There are 3 types of fiber used in this experiment

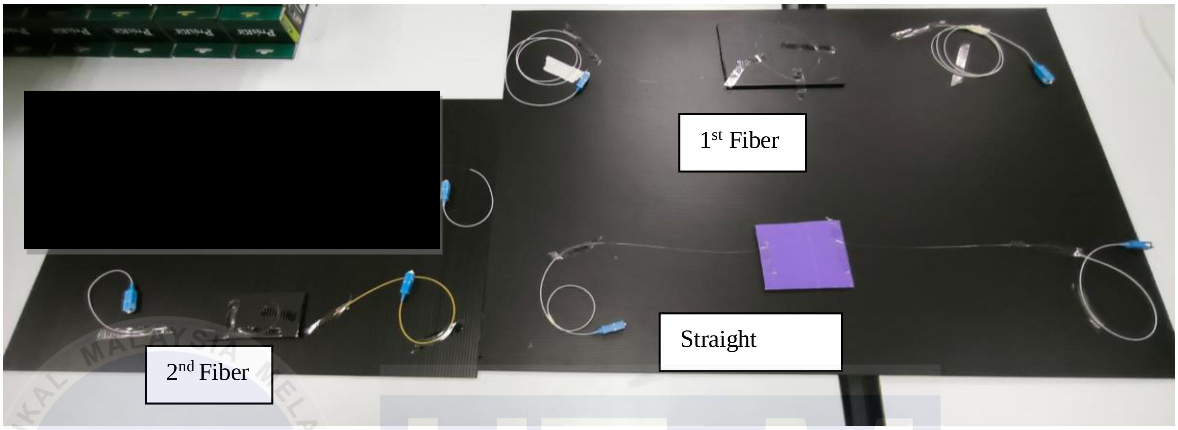

Figure 4.4: Types of fiber used

4.4.1 Results 1310nm wavelength using 10% to 50% of Oxygen Concentration

Type / Concentration Level	10%	20%	30%	40%	50%
1st Fiber (Long Loop)	-35.23	-36.21	-30.46	-38.24	-38.25
2nd Fiber (Small Loop)	-32.20	-32.29	-32.24	-32.27	-32.28
Straight Fiber	-31.64	-32.29	-32.30	-46.15	-32.29

Table 4.4: Results for 1310 nm in 30 seconds

Type/ Concentration Level	10%	20%	30%	40%	50%
1st Fiber (Big Loop)	-32.24	-55	-32.27	-64.93	-64.46
2nd Fiber (Small Loop)	-32.32	-63.23	-57.99	-59.95	-32.29
Straight Fiber	-63.45	-32.28	-63.42	-63.26	-32.24

Table 4.1.1: Results for 1310 in 60 seconds

4.4.2 Results of 3 types of fiber in response to concentration of oxygen (%)

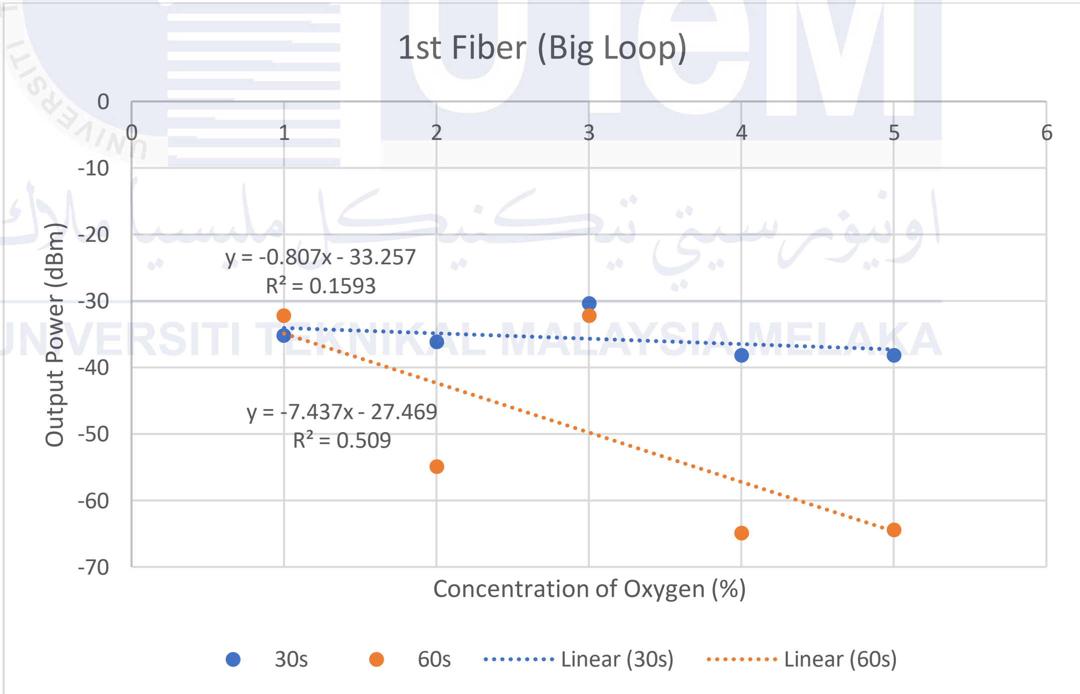

Figure 4.4: Response of 1st Loop Fiber

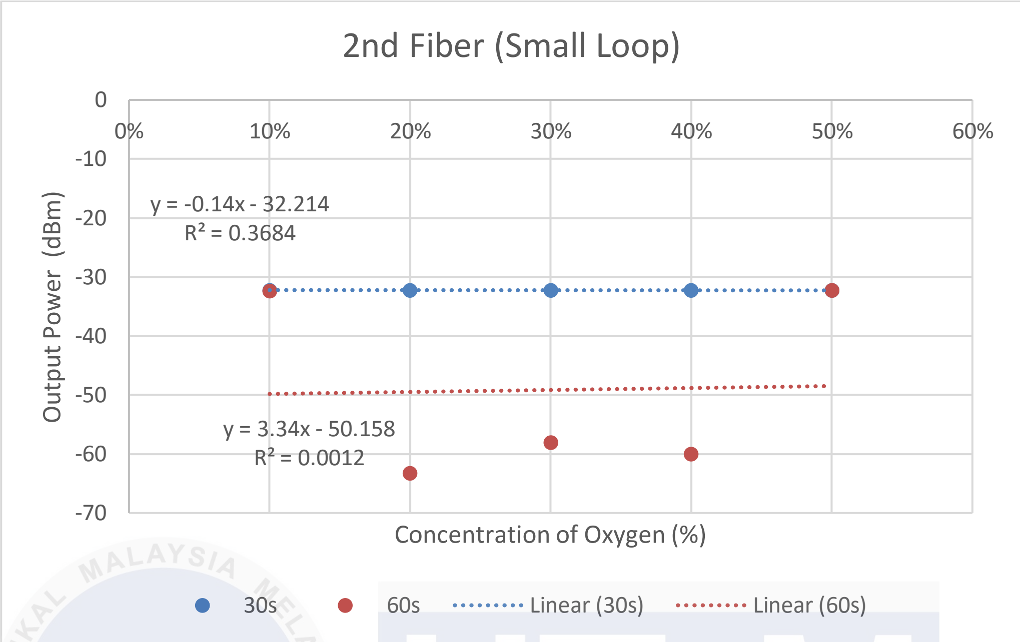

Figure 4.4.1: Response of 2nd Loop Fiber

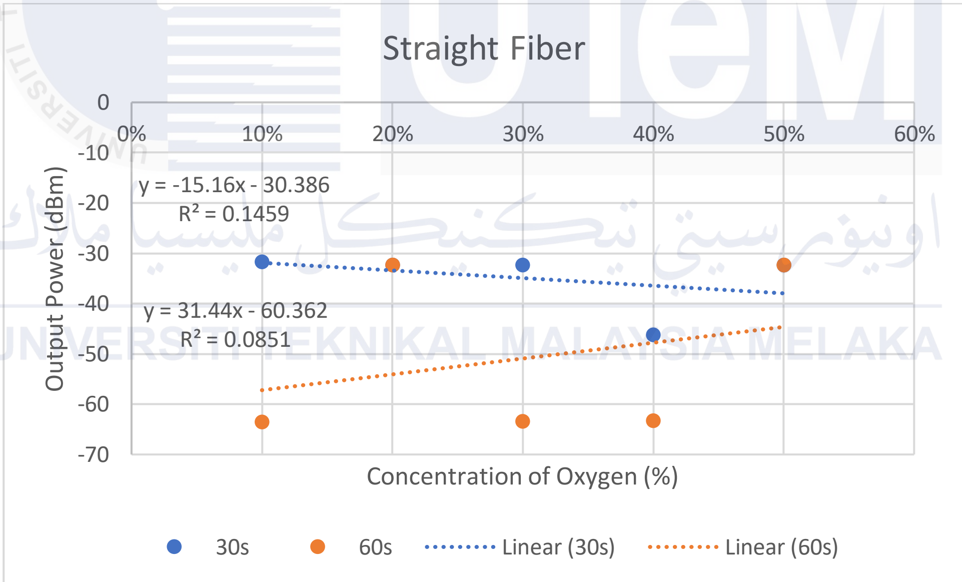

Figure 4.4.1: Response of Straight Fiber

1st Fiber (Big Loop)

The 1st Loop configuration, also referred to as the Big Loop, shows significant variations in output power at different time intervals and oxygen concentration levels. At 30 seconds, the output power ranges from -30.46 dB at 30% concentration to -38.25 dB at 50% concentration. This suggests a moderate level of sensitivity and reliability during shorter measurement intervals. However, at 1 minute, the output power demonstrates notable drops, particularly at 20% (-55 dB) and 40% (-64.93 dB). This indicates that the big loop becomes more sensitive to concentration changes over longer intervals, but it also highlights potential instability at certain concentration levels. The significant drop at 40% may point to a critical threshold where the loop's sensitivity is maximized but may result in less consistent readings.

Straight Loop

The Straight Loop configuration, exhibits more consistent performance during shorter intervals but shows greater variability at longer intervals. At 30 seconds, the output power values are relatively stable, with the exception of a notable dip at 40% concentration (-46.15 dB). This suggests that the configuration is largely unaffected by oxygen concentration changes during shorter intervals, except under specific conditions.

At 1 minute, however, the Straight Loop shows significant drops at 10% (-63.45 dB) and 30% (-63.42 dB). These large variations indicate that the configuration becomes less stable over time, particularly at lower and moderate oxygen concentrations. The consistency at 40% and 50% suggests that the configuration may stabilize at higher concentrations, but the significant drops at other levels highlight its limitations in maintaining uniform performance over extended intervals.

2nd Fiber (Small Loop)

The 2nd Loop configuration, also referred to as the Small Loop, demonstrates the most stable and reliable performance across all time intervals and oxygen concentration levels. At 30 seconds, the output power values show minimal variation, ranging from -32.20 dB to -32.28 dB across all concentrations. This indicates consistent and predictable behavior during shorter intervals. At 1 minute, the Small Loop maintains its stability, with output power values ranging from -32.24 dB to -32.29 dB, except for slight deviations at 40% and 50%.

4.5 Results 1550nm wavelength using 10% to 50% of Oxygen Concentration

This section presents the data recorded over a period of 30 seconds and 1 minutes using three types of fiber with oxygen concentrations of 10%, 20%, 30%, 40%, and 50%, evaluated at wavelengths of 1550 nm.

Type / Concentration Level	10%	20%	30%	40%	50%
1st Loop (Long Loop)	-29.06	-29.05	-29.07	-30.71	-31.26
2nd Loop (Short Loop)	-30.67	-31.21	-32.67	-30.63	-30.68
Straight Fiber	-30.53	-31.2	-30.81	-34.54	-39.01

Table 4.5: Results for 1550 nm in 30 seconds

Type / Concentration Level	10%	20%	30%	40%	50%
1st Loop (Long Loop)	-38.25	-33.83	-29.06	-29.06	-29.05
2nd Loop	-29.03	-30.66	-30.62	-42.45	-40.03
Straight	-30.68	-57.32	-30.66	-39.38	-36.36

Table 4.5.1: Results 1550 nm in 60 seconds

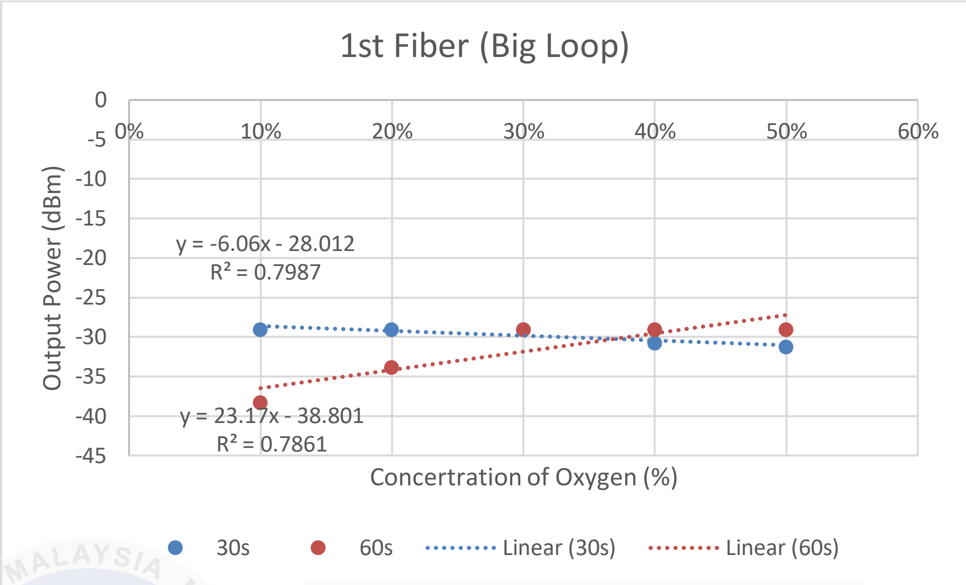

Figure 4.5: Response 1st Fiber

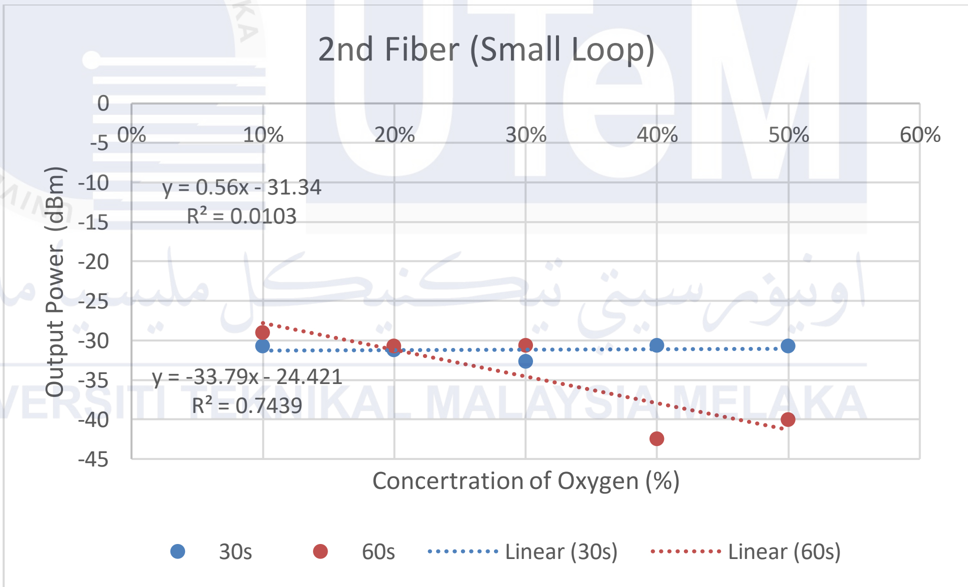

Figure 4.5.1: Response 2nd Fiber

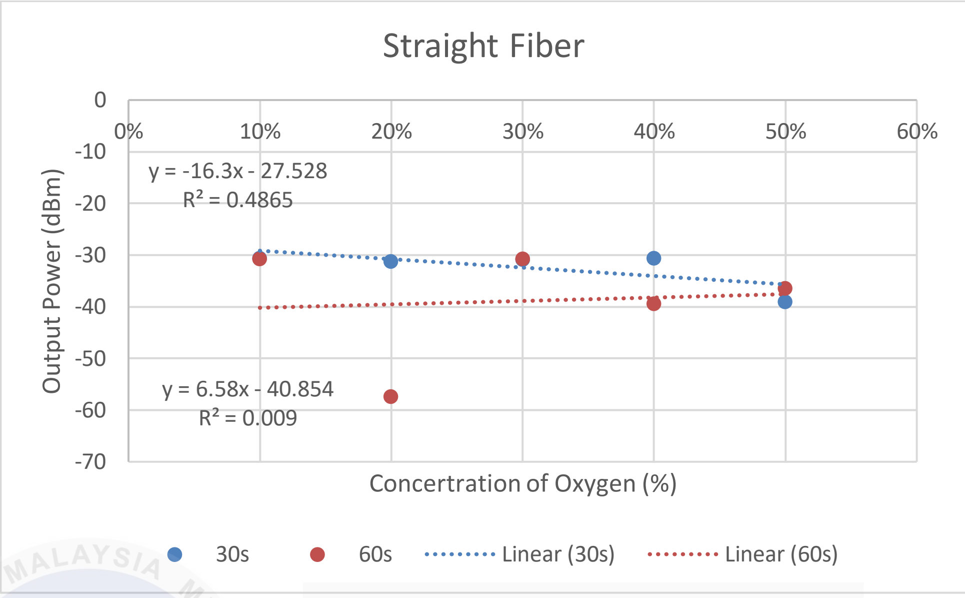

Figure 4.5.2: Response for Straight Fiber

1st Fiber (Big Loop)

The output readings showed stable performance at 30 seconds, with a slight variation from -29.06 dB to -31.26 dB. At 1 minute, a broader range was observed, from -38.25 dB to -29.05 dB, indicating increased sensitivity over time.

The Straight Fiber

It exhibited a significant drop in output at higher oxygen concentrations at 30 seconds, ranging from -30.53 dB to -39.01 dB. At 1 minute, fluctuations were more pronounced, with a steep drop at 20% (-57.32 dB). The linear fit showed moderate correlation at 30 seconds (R2=0.4865R^2 = 0.4865R2=0.4865) but poor correlation at 60 seconds (R2=0.009R^2 = 0.009R2=0.009).

The 2nd Fiber (Small Loop)

The fiber remained stable at 30 seconds, with minimal variation from -30.67 dB to -30.68 dB. At 1 minute, the readings were consistent until higher concentrations, where a decline was observed from -42.45 dB at 40% to -40.03 dB at 50%. The linear fit displayed low correlation at 30 seconds (R2=0.0103R^2 = 0.0103R2=0.0103) and improved correlation at 1 minute (R2=0.7439R^2 = 0.7439R2=0.7439).

4.6 Comparison in Linerity and Sensitivity between 1310 nm and 1550 nm across 3 Types of Fiber

	1st Fiber (30s)	1st Fiber (60s)	2nd Fiber (30s)	2nd Fiber (60s)	Straight Fiber (30s)	Straight Fiber (60s)	Wavelength
Sensitivity (1310 nm)	0.807	7.437	0.14	3.34	15.16	31.44	1310 nm
Linearity (1310 nm)	40%	71%	37%	60%	38.20%	29.17%	1310 nm
Sensitivity (1550 nm)	6.06	23.17	0.56	33.79	16.3	6.58	1550 nm
Linearity (1550 nm)	89%	88%	10%	86%	69%	9.40%	1550 nm

Figure 4.6: Table of Comparison between 1310 nm and 1550 nm in 3 types of fiber

The comparison between the fiber configurations has been refined to reflect the best performance, considering the Straight Fiber for 1310 nm and the 2nd Fiber (Small Loop) for 1550 nm, with the most reliable data observed at 60 seconds.

For 1310 nm, the Straight Fiber demonstrates outstanding sensitivity, particularly at 60 seconds, where it achieves a value of 31.44, significantly higher than both the 1st and 2nd fibers. Although its linearity is lower, at 29.17%, the high sensitivity makes it the ideal choice for applications that prioritize the ability to detect subtle changes in oxygen concentration. At 30 seconds, the Straight Fiber also shows high sensitivity (15.16), but the data at 60 seconds is more robust and reliable, providing greater confidence in its application. The 1st Fiber, despite having better linearity at 60 seconds (71%), cannot match the sensitivity levels of the Straight Fiber, solidifying the Straight Fiber as the preferred choice for 1310 nm at 60 seconds.

At 1550 nm, the 2nd Fiber (Small Loop) stands out with exceptional sensitivity at 60 seconds, achieving a value of 33.79, far surpassing both the 1st Fiber (23.17) and the Straight Fiber (6.58). While its sensitivity at 30 seconds is moderate (0.56), the 60-second data clearly demonstrates the fiber's capacity to detect changes in oxygen concentration with high accuracy. The linearity of the 2nd Fiber also improves significantly at 60 seconds, reaching 86%, which is comparable to the 1st Fiber (88%) and far superior to the Straight Fiber (9.40%). This combination of high sensitivity and reliable linearity at 60 seconds makes the 2nd Fiber the best choice for 1550 nm.

In conclusion, the Straight Fiber is the optimal choice for 1310 nm, with the most reliable data obtained at 60 seconds, where its high sensitivity is unmatched. For 1550 nm, the 2nd Fiber (Small Loop) is the preferred configuration, delivering excellent sensitivity and strong linearity, particularly at 60 seconds, making it the most dependable option for long-duration measurements.

4.7 Summary

This analysis evaluates the performance of three fiber configurations—1st Fiber (Big Loop), 2nd Fiber (Small Loop), and Straight Fiber—across 1310 nm and 1550 nm wavelengths for oxygen concentration measurements. Data was recorded at 30 seconds and 60 seconds, with the 60-second interval providing the most consistent results.

At 1310 nm, the Straight Fiber demonstrated superior sensitivity, achieving 31.44 at 60 seconds, making it ideal for applications requiring high sensitivity despite lower linearity. The 1st Fiber showed better linearity but lower sensitivity, while the 2nd Fiber was stable but less sensitive overall.

At 1550 nm, the 2nd Fiber (Small Loop) outperformed the others with sensitivity of 33.79 and linearity of 86% at 60 seconds, making it reliable for long-duration applications. The Straight Fiber, while highly sensitive at shorter intervals, lacked consistent linearity, and the 1st Fiber balanced sensitivity and linearity.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

This project successfully demonstrated the development and application of a microfiber single-loop resonator as a high-performance oxygen gas sensor. The research aimed to address the limitations of existing gas sensors by leveraging the unique properties of microfiber optics, including high sensitivity, compact size, and the potential for real-time monitoring. The design process involved tapering single-mode fibers to submicron diameters and forming them into loop resonators, enabling effective interactions between the guided light and the surrounding oxygen gas. The sensor's performance was evaluated at two wavelengths, 1310 nm and 1550 nm, across oxygen concentrations ranging from 10% to 50%, with data collected at intervals of 30 seconds and 60 seconds.

The findings confirmed that the sensor performed exceptionally well, with the 60-second interval providing the most consistent and reliable measurements. At 1310 nm, the Straight Fiber showed the highest sensitivity, achieving 31.44 at 60 seconds, making it suitable for applications requiring precise detection of oxygen concentrations. On the other hand, at 1550 nm, the 2nd Fiber (Small Loop) demonstrated the best overall performance, with superior sensitivity (33.79) and linearity (86%) at 60 seconds, highlighting its reliability for long-duration measurements. These results underscore the versatility and effectiveness of microfiber loop resonators in gas sensing applications.

The study also highlights the potential for further advancements in microfiber resonator technology. By combining precision in fabrication with robust optical properties, this research contributes to the growing field of optical gas sensing. The versatility of the sensor opens up possibilities for its application in diverse fields, including environmental monitoring, industrial safety, and biomedical diagnostics.

In summary, this project not only validates the viability of microfiber single-loop resonators for oxygen sensing but also sets the foundation for future advancements in optical sensing technology. The results achieved underscore the potential of these sensors to address real-world challenges and establish their relevance in both industrial and research contexts. Future efforts to optimize the design and expand its capabilities can further enhance its applicability, ensuring its utility in a broad spectrum of applications.

5.1 Future Recommendations

Optimization of Sensor Design:

- Explore alternative materials or coating methods to enhance sensitivity further and extend operational ranges.
- Investigate other wavelengths beyond 1310 nm and 1550 nm for broader applications.

Improvement in Sensor Durability:

- Focus on ensuring the fiber configurations are robust for industrial and field-based applications.

Integration with IoT:

- Develop a system to integrate real-time data transmission for remote monitoring and analysis of oxygen levels.

Expansion to Other Gas Types:

- Extend the research to detect gases such as methane, ammonia, or hydrogen sulfide, which have critical applications in industrial safety and environmental monitoring.

Enhanced Testing:

- Conduct additional testing in varying environmental conditions, including humidity and temperature, to evaluate sensor stability and performance under practical scenarios.

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APPENDICES

Gantt Chart For PSM 1

Activity	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Meet with supervisor	X	X	X	X										
Research literature review & gather information		X	X	X	X	X	X							
Submission of logbook progress						X								
Proposal writing			X	X	X									
Report writing									X	X	X	X	X	X
Submission of draft report											X			
Submission of report														X
Preparation for presentation														X

Gantt Chart For PSM 2

Activity	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	
Meet with supervisor	X	X	X	X	x	x	x	x	x	x	x	x		
Planning Experiment		X	X	X	x	x	x	x	x					
Submission of logbook progress						X								
Testing Experiment								X	X	X	x			
Data Analysis										X	X	x		
Writing chapter 4 and 5										x	X	X	X	
Submission of draft report												x	X	
Preparation for presentation													x	

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