



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

NURUL HASANAH BINTI IBRAHIM

Bachelor of Electronics Engineering Technology (Industrial Electronics) with Honours

2023

DEVELOPMENT OF DOUBLE SIDE-POLISHED TAPERED PLASTIC OPTICAL FIBER SENSOR FOR HUMIDITY APPLICATION

NURUL HASANAH BINTI IBRAHIM

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



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DECLARATION

I declare that this project report entitled "Development of Double Side-Polished Tapered Plastic Optical Fiber Sensor for Humidity Application" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree

Signature

Atur

:

Student Name

Date



APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is eadequate in terms of scope and quality for the award of the degree of Bachelor of Electronics Engineering Technology (Industrial Electronics) with Honours.

Signature

Halm

:

Supervisor Name

Date



DEDICATION

To my beloved parents, Ibrahim bin Basar and Almarhumah Rokiah binti Awang, and my siblings, who have always been there for me and supported me throughout my studies and also during my bachelor's degree project.

I would also like to express my appreciation and give special thanks to my supervisor, Ts. Siti Halma binti Johari, who has been helpful with stimulating suggestions and encouragement and has helped me coordinate my project as well as the writing of this

report.

Last but not least, thank my friends under the supervision of the same supervisor, namely Mohamad Basir and Firdaus Ameen, who also helped share ideas in making their respective

projects a success.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRACT

Humidity levels that are too low might have a negative influence on human health and the environment. Humidity levels that are too high might lead to mould, wetness and also can affect electronics. Humidity sensing is important in a variety of sectors, including industrial processes, agriculture, engineering, medicine, and more. Humidity is a measurement of how much water vapour is present in the air. The amount of water in the air is measured in relation to the greatest amount of water vapour in the atmosphere (moisture). Plastic optical fibers (POF) are a material that can be used as a humidity sensor element. This report examines a simple and small optical fiber that uses a tapered plastic optical fiber (POF) in a U-shape design and is based on modulated light intensity. This project's purpose is to develop a low-cost sensing device for humidity sensing applications. To get the waist diameters of POF for 400 μm, 500 μm, 600 μm, and 700 μm, the POF was tapered manually using a polishing method employing sand paper with a 3 cm tapering length to reduce the waist diameter of the POF. To discover the ideal tapered waist diameter and evaluate how effectively the proposed structure could perceive, three distinct wavelengths of 470 nm, 530 nm, and 645 nm were used in this project. A substantial reaction was recorded for humidity concentration values ranging from 35% RH to 80% RH. This project's data analysis includes repeatability, trendline, hysteresis, stability, sensitivity, linearity, and resolution. For the proposed sensor, 500 µm is the best waist diameter, and the best wavelength of 645 nm has been chosen.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Keywords: Plastic optical fiber, Taper, U-Shaped, relative humidity (RH).

ABSTRAK

Tahap kelembapan yang terlalu rendah mungkin mempunyai pengaruh negatif terhadap kesihatan manusia dan alam sekitar. Tahap kelembapan yang terlalu tinggi mungkin membawa kepada kulat, kebasahan dan juga boleh menjejaskan elektronik. Pengesanan kelembapan adalah penting dalam pelbagai sektor, termasuk proses perindustrian, pertanian, kejuruteraan, perubatan dan banyak lagi. Kelembapan ialah ukuran berapa banyak wap air yang terdapat di udara. Jumlah air di udara diukur berhubung dengan jumlah terbesar wap air di atmosfera (lembapan). Gentian optik plastik (POF) adalah bahan yang boleh digunakan sebagai elemen sensor kelembapan. Laporan ini mengkaji gentian optik ringkas dan kecil yang menggunakan gentian optik plastik tirus (POF) dalam reka bentuk bentuk-U dan berdasarkan keamatan cahaya termodulat. Tujuan projek ini adalah untuk membangunkan peranti penderiaan kos rendah untuk aplikasi pengesan kelembapan. Untuk mendapatkan diameter pinggang POF untuk 400 µm, 500 µm, 600 µm, dan 700 µm, POF ditiruskan secara manual menggunakan kaedah penggilap menggunakan kertas pasir dengan panjang tirus 3 cm untuk mengurangkan diameter pinggang POF. Untuk mengetahui diameter pinggang tirus yang ideal dan menilai ΕΚΝΙΚΔΙ ΜΔΙ ΔΥSIΔ ΜΕΙ ΔΚΔ sejauh mana keberkesanan struktur yang dicadangkan dapat dilihat, tiga panjang gelombang berbeza 470 nm, 530 nm, dan 645 nm telah digunakan dalam projek ini. Tindak balas yang besar telah direkodkan untuk nilai penumpuan kelembapan antara 35% RH hingga 80% RH. Analisis data projek ini termasuk kebolehulangan, garis arah aliran, histerisis, kestabilan, kepekaan, kelinearan dan resolusi. Untuk sensor yang dicadangkan, 500 µm ialah diameter pinggang terbaik, dan panjang gelombang terbaik 645 nm telah dipilih.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to my supervisor, Ts. Siti Halma binti Johari, for her precious guidance, words of wisdom, and patience throughout this project.

I am also indebted to Universiti Teknikal Malaysia Melaka (UTeM) and the student affairs department for the financial support they provided through the budget, which enabled me to accomplish the project. Not forgetting my fellow colleagues, Basir and Firdaus, for their willingness to share their thoughts and ideas regarding the project.

My highest appreciation goes to my parents and other family members for their love and prayers during the period of my study. An honourable mention also goes to Azimah and Syazwani for all the motivation and understanding.

Finally, I would like to thank all the laboratory engineers at the network systems lab, my fellow colleagues and classmates, the faculty members, as well as other individuals who are not listed here for being cooperative and helpful.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TABLE OF CONTENTS

PAGE

ABS	TRACT	i
ABS	ТКАК	.ii
ACK	NOWLEDGEMENTS	iii
TAB	LE OF CONTENTS	iv
LIST	OF TABLES	/ii
LIST	VOF FIGURES	iii
CHA	PTER 1	.1
INT	RODUCTION	.1
1.1	Background	.1
1.2	Problem Statement	.1
1.3	Project Objective	.1
1.4	Scope of Project	.2
CHA	PTER 2	.3
LITI	ERATURE REVIEW	.3
2.1	Introduction	.3
2.2	Related Previous Work	.3
2.2 bo S 1	2.1 "Enhance sensitivity of plastic optical fiber sensor by spiral configuration for dy temperature applications" by A Arifin, K R Amaliyah, A K Lebang, N Hamru Dewang, and D Tahir (2020).	or n, .3
2.2 bo S 1 2.2 an	 2.1 "Enhance sensitivity of plastic optical fiber sensor by spiral configuration for dy temperature applications" by A Arifin, K R Amaliyah, A K Lebang, N Hamrun Dewang, and D Tahir (2020). 2.2 "Plastic Optical Fibers: An Introduction to Their Technological Processes d Applications" by Joseba Zubia and Jon Arrue (2001). 	or n, .3
2.2 bo S 1 2.2 an 2.2 Ma	 2.1 "Enhance sensitivity of plastic optical fiber sensor by spiral configuration for dy temperature applications" by A Arifin, K R Amaliyah, A K Lebang, N Hamrup Dewang, and D Tahir (2020). 2.2 "Plastic Optical Fibers: An Introduction to Their Technological Processes d Applications" by Joseba Zubia and Jon Arrue (2001). 2.3 "POF-Type Optic Humidity Sensor and Its Application" by Osamu Suzuki, asahiro Miura, Masayuki Morisawa and Shinzo Muto (2002). 	or n, .3 .4
2.2 bo S 1 2.2 an 2.2 Mi 2.2 Fil	 2.1 "Enhance sensitivity of plastic optical fiber sensor by spiral configuration for dy temperature applications" by A Arifin, K R Amaliyah, A K Lebang, N Hamrup Dewang, and D Tahir (2020). 2.2 "Plastic Optical Fibers: An Introduction to Their Technological Processes d Applications" by Joseba Zubia and Jon Arrue (2001). 2.3 "POF-Type Optic Humidity Sensor and Its Application" by Osamu Suzuki, asahiro Miura, Masayuki Morisawa and Shinzo Muto (2002). 2.4 "Humidity and Isopropyl Alcohol Detection Sensor Based on Plastic Optica Optica Optica (2021). 	or n, .3 .4 .5 I
2.2 bo S 1 2.2 an 2.2 Mi 2.2 Fil 2.2 C.	 2.1 "Enhance sensitivity of plastic optical fiber sensor by spiral configuration for dy temperature applications" by A Arifin, K R Amaliyah, A K Lebang, N Hamrup Dewang, and D Tahir (2020). 2.2 "Plastic Optical Fibers: An Introduction to Their Technological Processes d Applications" by Joseba Zubia and Jon Arrue (2001). 2.3 "POF-Type Optic Humidity Sensor and Its Application" by Osamu Suzuki, asahiro Miura, Masayuki Morisawa and Shinzo Muto (2002). 2.4 "Humidity and Isopropyl Alcohol Detection Sensor Based on Plastic Optica optica (2021). 2.5 "Humidity Sensing using Plastic Optical Fibers" by C. M. Tay, K. M. Tan, S Tjin, C. C. Chan, and H. Rahardjo (2004). 	or n, .3 .4 .5 I .7 S. .8
2.2 bo S 1 2.2 an 2.2 Ma 2.2 Fil 2.2 C. 2.2 Ka Sin	 2.1 "Enhance sensitivity of plastic optical fiber sensor by spiral configuration for dy temperature applications" by A Arifin, K R Amaliyah, A K Lebang, N Hamrun Dewang, and D Tahir (2020). 2.2 "Plastic Optical Fibers: An Introduction to Their Technological Processes d Applications" by Joseba Zubia and Jon Arrue (2001). 2.3 "POF-Type Optic Humidity Sensor and Its Application" by Osamu Suzuki, asahiro Miura, Masayuki Morisawa and Shinzo Muto (2002). 2.4 "Humidity and Isopropyl Alcohol Detection Sensor Based on Plastic Optica by Lorant A. Szolga (2021). 2.5 "Humidity Sensing using Plastic Optical Fibers" by C. M. Tay, K. M. Tan, S Tjin, C. C. Chan, and H. Rahardjo (2004). 2.6 "All Plastic Optical Fiber-based Respiration Monitoring Sensor" by Wern am, Waleed S. Mohammed, Gabriel Leen, Kieran O' Sullivan, Mary O'Keeffe, nead O'Keeffe and Elfed Lewis (2017). 	or n, .3 .4 .5 I .7 S. .8
2.2 bo S 1 2.2 an 2.2 Mi 2.2 Fil 2.2 C. 2.2 Ka Sin 2.2 Mi Yu	 2.1 "Enhance sensitivity of plastic optical fiber sensor by spiral configuration for dy temperature applications" by A Arifin, K R Amaliyah, A K Lebang, N Hamrun Dewang, and D Tahir (2020). 2.2 "Plastic Optical Fibers: An Introduction to Their Technological Processes d Applications" by Joseba Zubia and Jon Arrue (2001). 2.3 "POF-Type Optic Humidity Sensor and Its Application" by Osamu Suzuki, asahiro Miura, Masayuki Morisawa and Shinzo Muto (2002). 2.4 "Humidity and Isopropyl Alcohol Detection Sensor Based on Plastic Optica per" by Lorant A. Szolga (2021). 2.5 "Humidity Sensing using Plastic Optical Fibers" by C. M. Tay, K. M. Tan, S Tjin, C. C. Chan, and H. Rahardjo (2004). 2.6 "All Plastic Optical Fiber-based Respiration Monitoring Sensor" by Wern un, Waleed S. Mohammed, Gabriel Leen, Kieran O' Sullivan, Mary O'Keeffe, nead O'Keeffe and Elfed Lewis (2017). 2.7 "Parallel Polished Plastic Optical Fiber-Based SPR Sensor for Simultaneou easurement of RI and Temperature" by Lian Liu, Jie Zheng, Shijie Deng, Libo an and Chuanxin Teng (2021). 	or n, .3 .4 .5 I .7 S8 .9 s

2.2.9 "Development of LSPR based U-bent plastic optical fiber sensor Gowri, and V.V.R. Sai (2016)	s" by A. 11
2.2.10 "Tapered Plastic Optical Fiber Coated With Al-Doped ZnO Nan for Detecting Relative Humidity" by Zuraidah Harith, Ninik Irawati, Ha Rafaie, Malathy Batumalay, Sulaiman Wadi Harun, Roslan Md Nor, and Ahmad(2015).	oostructures rtini Ahmad l Harith 12
2.3 Software Implementation	13
2.3.1 Proteus 8 Professional	13
2.3.2 Arduino IDE	14
2.4 Hardware Implementation	14
2.4.1 Light Emitting Diode (LED)	14
2.4.2 Phototransistors	15
2.4.3 Digital Humidity Temperature Meter	16
2.4.4 Amplifier Circuit	16
2.4.5 Plastic Optical Fiber Sensor	17
2.4.6 NodeMCU	17
2.5 Summary	18
CHAPTER 3	19
METHODOLOGY	19
3.1 Introduction	19
3.2 Methodology	19
3.2.1 Flowchart	19
3.2.2 Fabrication of Tapered Plastic Optical Fiber (POF)	20
3.5 Experimental Setup ITI TEKNIKAL MALAYSIA MELAKA	27
3.6 Gantt Chart	31
3.7 Summary	31
CHAPTER 4	32
RESULTS AND DISCUSSIONS	32
4.1 Introduction	32
4.2 Results and Discussions	32
4.2.1 Repeatability Test	32
4.2.1.1 Red (645 nm)	32
4.2.1.2 Green (530 nm)	35
4.2.1.3 Blue (470 nm)	37
4.2.2 Trendline	40
4.2.3 Hysteresis	45
4.2.4 Stability	47

4.3 Summary	
CHAPTER 5	49
CONCLUSION AND RECOMMENDATIONS	49
5.1 Conclusion	49
5.2 Future Works	
REFERENCES	51



LIST OF TABLES

Tabel 3. 1 Gantt chart	31
Table 4. 1 The characteristics of a U-shaped tapered POF for the red wavelength	43
Table 4. 2 The characteristics of a U-shaped tapered POF for the green wavelength	43
Table 4. 3 Characteristics of a U-shaped tapered POF for the blue wavelength	44
Table 4. 4 Characteristics of a U-shaped tapered POF for 500 um at all wavelength	44
Table 4. 5 ΔV for each wavelength at 55% RH	47



LIST OF FIGURES

Figure 2. 1 Head structure of POF-type humidity sensor.	6
Figure 2. 2 Experimental setup for relative-humidity sensing using POF	8
Figure 2. 3 Proteus 8 Professional.	13
Figure 2. 4 Arduino IDE.	14
Figure 2. 5 Light Emitting Diode (LED).	15
Figure 2. 6 Phototransistors	15
Figure 2. 7 Digital Humidity Temperature Meter	16
Figure 2. 8 Amplifier circuit.	16
Figure 2. 9 Plastic Optical Fiber Sensor.	17
Figure 2. 10 NodeMCU.	18
Figure 3. 1 Project Implementation	20
Figure 3. 2 Plastic Optical Fiber cable	20
Figure 3. 3 Fiber optic and wire stripper, POF cutter and ruler	21
Figure 3. 4 Shows the measurement of POF cables	21
Figure 3. 5 (a) using fibre optics and a wire stripper and (b) a 20 cm POF cable	22
Figure 3. 6 Using POF cutter	22
Figure 3. 7 (a) using folding knife and (b) POF cable after the middle is cut	23
Figure 3. 8 Polish using sandpaper.	23
Figure 3. 9 Illustration of tapered POF.	24
Figure 3. 10 Thickness of POF cable	24
Figure 3. 11 Digital micrometer	24
Figure 3. 12 Tapered POF with waist diameters of (a) 400 um, (b) 500 um, (c) 600	um, and (d)
700 um	25
Figure 3. 13 Tapered POF with label	
Figure 3. 14 Shows the LED light (a) and tape (b)	27
Figure 3. 15 Solder the container to make the hole.	27
Figure 3. 16 Adjusting the item's Component.	
Figure 3. 17 Chamber cover with black tape.	
Figure 3. 18 Shows the hardware components: (a) amplifier circuit, (b) digitation	al humidity
temperature, (c) battery, (d) LED light and phototransistor, (e)	Component
arrangement, and (f) Experimental setup.	

Figure 4. 1 The repeatability test of (a) 400 um, (b) 500 um, (c) 600 um and (d) 700 um for red
wavelength
Figure 4. 2 The repeatability test of (a) 400 um, (b) 500 um, (c) 600 um and (d) 700 um for
green wavelength
Figure 4. 3 The repeatability test of (a) 400 um, (b) 500 um, (c) 600 um and (d) 700 um for
blue wavelength
Figure 4. 4 Trendline graph for the red wavelength
Figure 4. 5 Trendline graph for the green wavelength41
Figure 4. 6 Trendline graph for the blue wavelength
Figure 4.7 Hysteresis for the 500 um waist diameter of (a) red wavelength, (b) green
wavelength, and (c) blue wavelength46
Figure 4. 8 U-shaped tapered POF voltage stability in 600 seconds



CHAPTER 1

INTRODUCTION

1.1 Background

Plastic optical fiber, also known as polymer optical fibre or POF, is a plastic optical fiber. It typically consists of fluorinated polymers as the cladding material and PMMA (acrylic) as the core, which promotes light transmission (96% of the cross section in a fibre 1 mm in diameter) [1]. Plastic optical fiber emits a harmless green or red light that is visible to the human eye. Plastic optical fibers is more durable and flexible than glass fiber.

1.2 Problem Statement

The equipment being built is lightweight and portable, thanks to recent technical advancements. The experimental setup is the issue here. The current optical fiber sensor is big and expensive to manufacture. Because the cost of glass optical fiber is higher than that of plastic optical fiber, choosing based on optical fiber quality could have an impact on cost.

1.3 Project Objective

- To design LED light source and phototransistor circuits for Plastic Optical Fiber (POF).
- ii. To optically characterize and optimize the polished fiber waist diameter.
- iii. To validate experimentally the sensing application of the humidity sensor.

1.4 Scope of Project

The primary aim of this project is to use U-shaped tapered Plastic Optical Fiber (POF) with specific taper waist diameter, taper length, and bend radius to accurately measure the humidity. The waist diameters of polished POF were 400 µm, 500 µm, 600 µm, and 700 µm. The taper length was 3 cm, and the fiber was bent into a 3 cm radius. The light source has a parameter of LED wavelengths that is 470 nm for blue, 530 nm for green, and 645 nm for red. POF were exposed to relative humidity (RH) ranging from 35% to 80%. The output measurement for sensing performance is voltage (V). Sensitivity, linearity, average standard deviation, resolution, responsiveness, and stability are all sensor qualities. Relative humidity is the focus of the application.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The journal, the researcher, and the article about similar projects, past analyses, and comparisons between methodologies, analyses, and approaches will be the subject of this chapter. This chapter covers everything there is to know about plastic optical fibre sensors and humidity applications.

- 2.2 Related Previous Work
- 2.2.1 "Enhance sensitivity of plastic optical fiber sensor by spiral configuration for body temperature applications" by A Arifin, K R Amaliyah, A K Lebang, N Hamrun, S Dewang, and D Tahir (2020).

Optical fibres have been used in a number of research projects, including the use of Fiber Bragg Grating (FBG) sensors to measure body temperature during radio frequency medical therapy. The downsides of this tool include its high cost and low precision. To monitor body temperatures with a complex connection process, a Mach-Zehnder interferometer is used to measure temperature. The temperature sensor is based on a low-sensitivity Long Period Grating (LPG) optical fibre. FBG, which focuses on sensor sensitivity, is used in the body temperature sensor. The disadvantages of this sensor are its high cost and limited sensitivity. Another study used multicore optical fibre to assess temperature, but the methods were difficult. Sensors to assess body temperature were produced utilising a macro-bending analysis based on POF in this journal. Variations in diameter and bend number cause fibre optic sensors to form a spiral pattern. The body temperature sensors are positioned under the armpit and attached to an elastic cloth. Body temperature affects the light from an LED sent into an optical fibre sensor, resulting in power loss in the sensor. The phototransistor and differential amplifier receive less light as a result of power loss [2]. The Arduino Uno microcontroller will display the sensor's power loss and temperature measurement information on the computer. The temperature range chosen was 28°C to 42°C. The best sensor characteristic values were found in a spiral arrangement with four bends and a diameter of 0 cm. The range values of 0.421 V, sensitivity of 30.071 mV/°C, and resolution of 0.033 °C are the best results recorded. The sensor's properties improve as the spiral's diameter decreases and the number of bends increases. The temperature sensor's sensitivity can be improved by using POF. This sensor is ideal for sensing body temperature because of its high sensitivity, low cost, ease of manufacture, and straightforward measurements.

2.2.2 "Plastic Optical Fibers: An Introduction to Their Technological Processes and Applications" by Joseba Zubia and Jon Arrue (2001).

ونبؤم سيتي تنكنيكم مليسيا ملاك

As recently expressed, POFs enjoy a few huge upper hands over their glass partners. On account of their colossal measurement, which goes from 0.25 to 1 mm, low-accuracy plastic connectors can be used, bringing down the framework's overall cost. POFs are likewise remarkable for their expanded adaptability and resilience to shocks and vibrations, as well as the expanded light coupling from the light source to the fiber. Due to these benefits, an extensive variety of POF applications have been created and popularized, ranging from essential light transmission guides in presentations to sensors and broadcast communications links. POFs are very flexible waveguides made of almost transparent dielectric materials that are used in optical communications. These fibres have a circular cross-section that can be divided into three layers. The core, cladding, and jacket, a protective cover, are the three layers. Specifically highlight that optical fibres' flexibility and small size enable them to attain high sensitivity without taking up a lot of space. Besides, a POF has been displayed to identify a large number of elements, including temperature, moisture, tension, natural and inorganic compound presence, wind speed, and refractive record. Then again, POF-based optical sensors lessen the gamble of electric flashes in dangerous conditions and can be perused from a far distance.

The most important characteristics of POFs are discussed, including the many varieties of POFs, how they are made, and what applications they may have now and in the future. Discussions include topics such as their bandwidth, absorption, and the effect of outside variables. These fibres are using in short-haul communications networks in place of glass fibres because they are simple to handle, adaptable, and affordable. Because of these advantages, a wide range of POF applications have been developed and marketed, ranging from simple light transmission guides to sensors and telecommunications cables. This journal provides a thorough overview of POFs. Furthermore, the large number of references makes additional research on the issue easier [3].

2.2.3 "POF-Type Optic Humidity Sensor and Its Application" by Osamu Suzuki, Masahiro Miura, Masayuki Morisawa and Shinzo Muto (2002).

A simple POF-type humidity sensor based on the structure change from leaky-POF to guided-POF was confirmed to work over a wide humidity range and can be employed as a breathing-condition monitor by employing a mixture of swelling polymers. Certain types of polymers generate swelling by attracting water molecules and altering their refractive indices, as is well known. Therefore, by using these polymers as just a cladding material for POF, the POF-type humidity sensor unit may be easily produced. It acts as a leaky-type POF in this sensor head if the refractive index of the cladding layer is configured to be somewhat higher than that of the fibre core. When exposed to water vapour, however, the cladding layer's refractive index begins to fall and falls below that of the core. The POF structure then changes to guided mode, and the light intensity travelling through the sensor head increases dramatically. Create a humidity sensor of the POF type based on this method, utilising a combination of inflating polymers [4]. To modify the cladding layer's refractive index and response time, the expanding polymer mixing ratio was established through experimental testing. These cladding polymers were dissolved in EtOH:H20 = 1:1 or DMSO:H20 = 1:1 solutions and then dip-coated onto a PMMA (n=1.49) plastic fibre core with a diameter of 1 mm. The sensor heads were trimmed to a length of 5–6 cm, and the cladding layer thickness was varied from 1 to 51 metres. The sensor head was linked to the regular POFs after polishing both ends, as illustrated in Figure 2.1," Head structure of a POF-type humidity

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

sensor."



Figure 2. 1 Head structure of POF-type humidity sensor.

Researchers have looked at the POF-type simple optic humidity sensor, which is based on the POF structure changing from thermal sensors to being guided by the adaptation of water molecules. As a result, the provided sensors performed well throughout a wide humidity range. Furthermore, a connection to a respiratory condition monitor is now possible.

2.2.4 "Humidity and Isopropyl Alcohol Detection Sensor Based on Plastic Optical Fiber" by Lorant A. Szolga (2021).

The capabilities of plastic optical fiber for the detection of humidity and of isopropyl alcohol as a high-risk combustible chemical were examined in this journal. Optical fibre sensors have found success in a variety of industries where sensitivity and precision are critical. Electronic sensors are prohibited in combustible materials where electricity is a real threat. Optical fiber-based sensors are more than welcome in these circumstances. Glass optical fibers have already proven to be highly accurate in monitoring a variety of factors, ranging from mechanical (elongation, pressure) to temperature and humidity. The high cost of the interrogator and the specialist manpower required to instal and maintain these glass fiber sensors are disadvantages. A basic, low-cost system that runs with good precision and sensitivity is a useful solution in some instances. By constructing a proper testing environment, this research was able to demonstrate the operation of the plastic optical fiber in comparison to an electronic humidity sensor. Also, it was shown how sensitive an optical fiber-based sensor is to isopropyl alcohol vapours.

This journal study demonstrated the sensitivity of a plastic optical fibre as a humidity sensor if certain well-defined conditions were met, such as the use of an infrared LED and photodetector for transmitting and receiving light over the fiber; good connection and alignment of the fibre by polishing out the cladding; and at least 2 cm of the fiber's core exposed to the surrounding medium [5].

2.2.5 "Humidity Sensing using Plastic Optical Fibers" by C. M. Tay, K. M. Tan, S. C. Tjin, C. C. Chan, and H. Rahardjo (2004).

This journal shows how to measure relative humidity using plastic optical fibres (POFs) curved at the sensor area and coated with cobalt chloride (CoCl2) and gelatin as the overlay material. The sensitivity of the sensor is hugely affected by the fiber-core diameter and bending radius of the sensing site. Figure 2.2 depicts the experimental setup employed for relative-humidity sensing using POF.



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

It was discovered that increasing the fibre diameter makes the evanescent wave stronger, enhancing the sensor's sensitivity [6]. The sensitivity of the sensor is also affected by the radius, with smaller radii resulting in greater evanescent wave penetration depths in the absorption film. This causes more light absorption and, as a result, a higher optical-intensity modulation. Some difficulties, such as light coupling into and out of the fibre and bending loss due to handling, must be handled before the sensor can be used efficiently.

2.2.6 "All Plastic Optical Fiber-based Respiration Monitoring Sensor" by Wern Kam, Waleed S. Mohammed, Gabriel Leen, Kieran O' Sullivan, Mary O'Keeffe, Sinead O'Keeffe and Elfed Lewis (2017).

The humidity change during intake and exhalation has been detected using a fluorescent plastic optical fibre as a humidity sensor in a breathing-condition monitor. A respiratory monitoring sensor made entirely of plastic optical fibres was developed in this study. The input and output plastic optical fibers (POF) are housed in 3-D printed sections with a flexible part in between to allow for movement changes in the chest or other site of attachment during respiration. The sensor is small and compact, and it can be worn near the lung and diaphragm in any section of the upper body.

To precisely measure the human respiration signal, an all-plastic, non-invasive optical fibre respiration monitoring sensor was created in this paper. The sensor is tiny enough to be worn on the body and detects the signal of various breathing patterns. For individuals (patients) in a sitting and lying posture, the sensor output was compared with a commercial device, and the results showed satisfactory agreement. For both normal breathing and chest breathing, the measurements of respiration rate recorded with the POF and a commercial sensor varied by up to 4% [7]. The sensor's all-plastic architecture permits it to be used in potentially hazardous electromagnetic environments, such as during MRI scans.

2.2.7 "Parallel Polished Plastic Optical Fiber-Based SPR Sensor for Simultaneous Measurement of RI and Temperature" by Lian Liu, Jie Zheng, Shijie Deng, Libo Yuan and Chuanxin Teng (2021).

A parallel polished plastic optical fiber (POF)-based surface plasmon resonance (SPR) sensor for simultaneous measurement of refractive index (RI) and temperature is proposed and

demonstrated in this paper. The sensor is made by symmetrically double polishing the POF and putting a gold film on both sides of the polished regions. By depositing the polydimethylsiloxane (PDMS) layer on one of the polished sides, another temperature-sensing resonance peak may be seen in the transmission spectrum. The wavelength shifts of the two resonance peaks will change as the RI and temperature change, allowing the RI and temperature to be monitored simultaneously by monitoring the wavelength shifts of the two peaks. The sensor has a RI sensitivity of 1174 nm/RIU in the RI range of 1.335–1.37 and a temperature sensitivity of 0.7 nm/C in the temperature range of 30 C–80 C, according to test results [8]. Furthermore, the results reveal that there is no crosstalk between the proposed sensor's two sensing channels. The parallel polished structure is advantageous in the development of multiparameter measuring sensors with biochemical sensing applications.

2.2.8 "Tapered Plastic Optical Fiber Coated With HEC/PVDF for Measurement of Relative Humidity" by Malathy Batumalay, Asiah Lokman, Fauzan Ahmad, Hamzah Arof, Harith Ahmad, and Sulaiman Wadi Harun (2013).

Plastic optical fibres (POFs) provide various advantages over silica-based fibres, including ease of handling, mechanical strength, disposability, and mass manufacture of components and systems. To sense changes in relative humidity, tapered POF is coated with a polymer blend of hydroxyethylcellulose/polyvinyli-denefluoride (HEC/PVDF) composite in this paper. In reaction to an external stimulus, the tapered fiber's coating changes its optical characteristics. The measurement is based on an intensity modulation technique that looks at the output voltage of transmitted light to see if it changes with changes in relative humidity. The change in the intensity of the transmitted light of the HEC/PVDF composite on tapered fiber increases with relative humidity in a quadratic manner.

A tapered POF coated with HEC/PVDF composite has been developed and tested as a basic humidity sensor. To achieve a waist diameter of 0.45 mm and a tapering length of 10 mm, the tapered POF was manufactured using an etching procedure involving acetone, sand paper, and de-ionized water. The sensor's output voltage increases linearly as the relative humidity rises from 55 to 80%, with a sensitivity of 0.0231 mV/percent and a linearity of more than 99.65% [9]. The detection threshold is estimated to be 5.75 percent. As the humidity level rises, the composite cladding's effective refractive index decreases, enabling more light to pass through. The suggested sensor delivers a stable and efficient humidity detector with several advantages, such as simplicity of design, low cost of manufacture, increased mechanical strength, and ease of handling. The results show that the HEC/PVDF coated fibre changes its conductance in response to changes in humidity, demonstrating its usefulness as a relative humidity sensor.

2.2.9 "Development of LSPR based U-bent plastic optical fiber sensors" by A. Gowri, and V.V.R. Sai (2016).

The theory of evanescent wave optic fiber refractive index (RI) sensors is attenuated total reflection, in which the intensity of light propagating through the fibers changes as the medium's refractive index (RI) changes. By decladding, tapering, or side polishing the optical fibre, the evanescent wave (EW) is revealed to the sample medium. Due to its ease of machinability and handling, POF has now received more attention than traditional silica fibres due to its potential as a viable mass-production option. The U-bent probe has several advantages over other geometries, including high EW absorbance sensitivity due to the reformation of lower order modes into higher order modes, less fragility than other geometries, ease of probe fabrication and repeatability, and the ability to be developed into a point sensor. After that, a highly durable and machinable sensor could be devised and produced by utilising the advantages of both U-bent geometry and POF. In addition, when compared to silica, POF only requires low-temperature bending procedures.

Narrower diameter fibres may offer better response due to increased evanescent wave interactions within a smaller active sensing zone, which is dictated by the applications of interest, which can range from simple chemical to sensitive biomolecular investigations. This research shows a simple way to make U-bent POF probes with the best geometry for making an RI sensor based on evanescent wave absorbance that is more sensitive. A simple and cost-effective method for fabricating U-bent POF probes has been created. According to this research, the maximum possible RI sensitivity is achieved by using a U-bent probe of a given fibre diameter with an ideal bent diameter of 2 to 3 times the fibre diameter [10]. These discoveries are important in the creation of highly sensitive sensors for a variety of chemical and biosensor applications, which require optimization of probe design using POF diameters of less than 1 mm. The RI sensitivity of U-bent POF probes based on LSPR has increased eightfold. POF probes that are bent into a U shape may be a better option than silica optical fibres in terms of being easy to work with and being sensitive.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.2.10 "Tapered Plastic Optical Fiber Coated With Al-Doped ZnO Nanostructures for Detecting Relative Humidity" by Zuraidah Harith, Ninik Irawati, Hartini Ahmad Rafaie, Malathy Batumalay, Sulaiman Wadi Harun, Roslan Md Nor, and Harith Ahmad(2015).

A tapered plastic optical fibre (POF) coated with Al-doped ZnO nanostructures is used to demonstrate a relative humidity (RH) sensor. The tapering POF, which uses intensity modulation technology, was made using a simple etching method. After that, the tapered fibre was coated with Al-doped ZnO nanostructures using a sol–gel immersion technique with various mol percents of Al nitrate as a dopant. When compared to the other doping concentrations, the 1 mol percent Al nitrate utilised in the manufacturing process performed better. The results were then compared and analysed for both undoped ZnO and 1 mol percent Al-doped ZnO. The performance of 1 mol percent Al-doped ZnO was better, with linearity and sensitivity of 97.5 percent and 0.0172 mV/percent, respectively, whereas the performance of undoped ZnO was 93.3 percent and 0.0029 mV/percent, respectively [11]. When compared to silica fibre optic sensors, the suggested sensor has a number of advantages, including simplicity of design, low manufacturing costs, higher mechanical strength, and ease of handling. The results suggest that using tapered POF with Al-doped ZnO nanostructures improves fibers sensitivity for detecting changes in RH.

2.3 Software Implementation

2.3.1 Proteus 8 Professional

Proteus 8 Professional is software that enables users to create schematics, PCB designs, code, and even simulate them. This programme was used in this project to build the amplifier circuit. Figure 2.3, "Proteus 8 Professional," displays the software used.



Figure 2. 3 Proteus 8 Professional.

2.3.2 Arduino IDE

The Arduino IDE is free software that is primarily used to write code for Arduino modules. On the IDE platform, the primary code, also known as a sketch, generates a hex file, which is then translated and transmitted to the board's controller. Figure 2.4 Arduino IDE shows the software used.



To make things easier to comprehend, the project's code is written in the Arduino IDE software, and when you're ready to upload it to the board, a Hex file is created. This software was used to generate code that was then uploaded to the NodeMCU.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.4 Hardware Implementation

2.4.1 Light Emitting Diode (LED)

LEDs are a solid-state light source capable of delivering high light intensities when correctly configured into luminaires. Light-emitting diodes are widely regarded as the most energy-efficient light source. However, the effectiveness of LEDs is determined by the wavelength of light they produce. Red and blue wavelengths are often more efficient than green or orange wavelengths. As a result, luminaires using red, blue, or white materials have higher efficiency than other types of lighting. It should also be mentioned that technical innovation, particularly in LED lighting, is quickening, which will inevitably result in more efficient LEDs when compared to alternative lighting sources. LEDs are seen in Figure 2.5.



Figure 2. 5 Light Emitting Diode (LED).

2.4.2 Phototransistors

The phototransistor is a semiconductor device that can sense light levels and adjust the current flowing between the emitter and collector based on the amount of light received. Phototransistors can be used to detect light, but due to the gain offered by the fact that it is a bipolar transistor, the phototransistor is more sensitive. As a result, phototransistors are better suited for a variety of applications. Figure 2.6 displays the phototransistors.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA



Figure 2. 6 Phototransistors

2.4.3 Digital Humidity Temperature Meter

2.4.4

Digital Humidity Temperature Meter is accurate, stable, and safe. The split-type construction of the UT-333S tiny temperature meters makes it easy and quick to correctly detect temperature in a variety of settings. The split-type construction of the handheld temperature and humidity meter is ideal for monitoring small and hard-to-reach ventilation ducts. The UT 333S digital humidity temperature meters as display in Figure 2.7.



The amplifier circuit contains resistors, IC sockets, and capacitors, as well as a female header connector for components such as the NodeMCU, LED, LCD, phototransistor, and variable resistor, as shown in Figure 2.8.



Figure 2. 8 Amplifier circuit.

2.4.5 Plastic Optical Fiber Sensor

External force measurement with plastic optical fibre can be done in three different ways. Intensity modulation, phase modulation, and Bragg wavelength shift are the three techniques used. Other strategies are derived from these and applied to highly specialised POF kinds to generate precise and accurate sensors. Because of its chemical resistance and inert qualities, POF is not only a cost-effective sensor material, but it is also fundamentally safe. López et al. conducted extensive testing and discovered that it is unaffected by significant temperature variations while in operation [12]. The optical fibre is mechanically protected by the jacket or coating, which also provides robustness. It is often constructed of polyethylene; however, other materials such as polyvinylchloride and chlorinated polyethylene are also acceptable. Most of the light propagates along the core, which is achieved by surrounding the core with a cladding of a lower refractive index. Figure 2.9 display the plastic optical fiber

sensor.



Figure 2. 9 Plastic Optical Fiber Sensor.

2.4.6 NodeMCU

The NodeMCU (Node Microcontroller Unit) is an open-source software and hardware development environment based on the ESP8266, a low-cost System-on-a-Chip. The NodeMCU supports a number of development environments, including Arduino IDE compatibility (Integrated Development Environment). The Arduino add-on was created by the NodeMCU/ESP8266 community, who took the IDE selection a step further. Figure 2.10 shown the NodeMCU component.



Figure 2. 10 NodeMCU.

2.5 Summary

The potential for a deeper knowledge of plastic optical fibre has evolved as a result of the numerous literature reviews listed above. Many authors from various fields base their creation and design on their distinct and full-of-ideas recommendations. As a result of the many literature reviews above, a proper and sophisticated project has been researched, and the successful achievement of a goal can be made. A number of enhancements would be made to the development of the double-sided polished tapered plastic optical fibre sensor for humidity applications. In the following chapter, there are more developments and project recommendations.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology provides a comprehensive overview of a variety of research paradigms and procedures, as well as the instruments and techniques that support them. This chapter's purpose is to focus on the overall research and hardware process flow as well as the design methodology. Conducting research through journals and articles, planning a project's design and parts that will be required, implementing hardware and software into the project, testing the project, troubleshooting problems that arise, and writing a report are all part of this methodology's structured plan. Any project requires an organisation that elaborates on the technique for finishing it. To do so, a detailed flow chart outlining the steps required to complete the project from start to finish is created. Apart from that, it is critical to understand the hardware and software tools that will be used before beginning this project.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.2 Methodology

The purpose of project methodology is to assure the success of specific processes, approaches, techniques, methodologies, and technologies throughout the management process by enabling effective decision-making and problem-solving.

3.2.1 Flowchart

The figure 3.1 shows the flowchart of project implementation. The flowchart below represents the project's overall workflow.



3.2.2 Fabrication of Tapered Plastic Optical Fiber (POF)

The plastic optical fibre (POF) cable was first prepared. Figure 3.2 shows a plastic optical fibre (POF) cable.



Figure 3. 2 Plastic Optical Fiber cable.

Fiber optic and wire strippers, a POF cutter, and a ruler have been prepared as shown in Figure 3.3. This equipment used to measure and cut plastic optical fiber (POF) cables. Prepare the other tools needed for this process, such as a folding knife, sandpaper, micrometer, and markers



Figure 3. 3 Fiber optic and wire stripper, POF cutter and ruler.

With a pen or something visible, measure and mark the length of the 20cm cable POF.

Figure 3.4 shows the measurement and marking process of POF cable.



Figure 3. 4 Shows the measurement of POF cables.

By using a fibre optic and a wire stripper, cut the length of the POF to 20 cm as needed.

Figure 3.5 shows the POF cables being cut by using fiber optic and wire strippers.





Using pens, markers, or other objects whose marks can be seen to be cut, measure and mark at the POF cable's midpoint for up to 3 cm in length. Then, using a POF cutter, cut the 3 cm mark at the POF cable's midpoint. Figure 3.6 depicts the use of a POF cutter.



Figure 3. 6 Using POF cutter.

Figure 3.7 shows the POF cable jacket removed using a folding knife. Based on Figure 3.7 (a), with a folding knife, scrape the outer layer (jacket) of the POF at the centre that has been cut using a POF cutter before. Figure 3.7 (b) shows the results after the jacket is removed.



Figure 3. 7 (a) using folding knife and (b) POF cable after the middle is cut.

Then, the tapered POF was followed by polishing the core fiber using sandpaper of 1000 grit, as shown in Figure 3.8. Thin the POF cable (core) in the middle on both sides (double side) using sandpaper and measure with a micrometer until the appropriate size is achieved. Figure 3.8 shows the polishing core POF cable.



Figure 3. 8 Polish using sandpaper.

The illustration of a tapered POF cable shows the layer condition of the cable after polishing the core fiber. Figure 3.9 shows an illustration of a tapered POF.



Figure 3. 9 Illustration of tapered POF.

Figure 3. 10 Thickness of POF cable. A digital micrometer is regularly used to measure the stripped area, to ensure that the

Figure 3.10 shows the thickness of the POF cable after polishing the core fiber.

desired tapered fiber waist diameter value is accurate. After polishing the core fiber, measure using digital micrometer as in Figure 3.11.



Figure 3. 11 Digital micrometer.

Figure 3.12 shows how it is measured. Using 1000 grit sandpaper, polish the core fiber. Digital micrometers were used on a regular basis to measure the stripped area to ensure that the tapered fiber's waist diameter was 400 um, 500 um, 600 um, and 700 um as in Figure 3.12 (a), (b), (c), and (d).



Figure 3. 12 Tapered POF with waist diameters of (a) 400 um, (b) 500 um, (c) 600 um, and (d) 700 um.

Figure 3.13 shows the tapered POF cable has been labelled with a waist diameter. Then, the proposed sensor was inserted into a plastic holder to form the fiber into a U-shape structure.



Figure 3. 13 Tapered POF with label.

3.5 Experimental Setup

The experimental setup for POF sensing in this project is shown in Figure 3.18 (f). Start the setup for this project. It consists of a LED light, a chamber, digital temperature humidity, a phototransistor, an amplifier circuit and a battery. Figure 3.14 display the preparation of LED light and phototransistor.



Attach the phototransistor and LED light to the jumper as in Figure 3.14 (a) using tape as in Figure 3.14 (b). Then, construct the project's chamber. Measure the size of each component and mark it. Use masking tape, stick, mark, and ion solder to make holes. Figure 3.15 displays the process of constructing a chamber.



Figure 3. 15 Solder the container to make the hole.

Try out the hollowed-out space using real components. Figure 3.16 show currently adjusting the item's component with the hole that has been made.



Figure 3. 16 Adjusting the item's Component.

After finishing the adjustment, wrap the chamber with black tape and then insert the component to be placed in the chamber into the hole that has been made, as in Figure 3.17. Black tape was used to completely cover the chamber, preventing outside light from penetrating.



Figure 3. 17 Chamber cover with black tape.

The components of the experimental setup and the experimental setup for humidity sensing are shown in Figure 3.18.



(a)

(b)



(e)



(f)

Figure 3. 18 Shows the hardware components: (a) amplifier circuit, (b) digital humidity temperature, (c) battery, (d) LED light and phototransistor, (e) Component arrangement, and (f) Experimental setup.

WALAYS/4

Based on Figure 3.18, the battery was used to operate the amplifier circuit, then the LED and the phototransistor, while the LCD at the amplifier circuit was used to monitor the output voltage of humidity sensing. To accomplish relative humidity detection, one tip of the sensor was connected to the LED light, while the other tip of the sensor was connected to the LED light, while the other tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the LED light, while the other tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the her tip of the sensor was connected to the phototransistor. The optical fibre effects on light transmission through the fibers were explored in depth using a red LED wavelength of 645 nm, a green LED wavelength of 530 nm, and a blue LED wavelength of 470 nm, and the optical fiber was transformed into an electrical signal using a phototransistor. This experiment was done three times for each 5% relative humidity level starting at 35% relative humidity to ensure the reliability of both sensors.

3.6 Gantt Chart

Tabel 3. 1 Gantt chart.

No	Activity	Week													
INO.	Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Briefing BDP 2														
2	Polish Fiber Process														
3	Modify PCB board														
4	Test PCB board as a complete circuit to see if it works or not.														
5	Construct the project's chamber.														
6	Submit LogBook until week 6														
7	Collecting data for each diameter and wavelength of LED light.														
8	Midsem break and continue	40													
9	Create a repeatability test with the data using Excel.		N N A												
10	Create a trendline and hysteresis graph.														
11	Create a stability test graph.				-						-				
12	Update LogBook and Report.	6	2		1º C		عن				i	0			
13	Submit LogBook and Draft				4. ¹⁰			÷G	**	0					
14	Submit report to panel.	TE	KN	IK/	\L	MA	LA	rsi	AN	ΠEL	.AP	A			
15	BDP 2 Presentation														

3.7 Summary

In summary, a complete project with all these phases has been completed, and all the prerequisites mentioned above, including software and hardware, have been met. In order to achieve the objective, any challenges that arise during the implementation of the project have been handled as well as possible. Data will be collected and analysed, as described in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The results and analysis of the Development of a Double Side-polished Tapered Plastic Optical Fiber Sensor for Humidity Applications are presented in this chapter. This chapter will go over the results of the sensitivity of the double side-polished tapered POF sensor with humidity. The data analysis from the graph will also be included in this chapter.

4.2 **Results and Discussions**

In this project, a total of four different waist diameter Double Side-polished Tapered POF's were used. The waist diameters used were 400µm, 500µm, 600µm and 700µm for U-shaped tapered POF. This measurement was conducted three times between 35% RH and 80% RH. The output measurement was recorded in voltages (V) from LCD at amplifier circuit.

4.2.1 Repeatability Test

A repeatability test was done to see the consistency of repeated measurements. To evaluate the sensor performance, output voltage of humidity at wavelength of red (645 nm), green (530 nm) and blue (470 nm), were observed as shown in graph of Figure 4.1, Figure 4.2 and Figure 4.3.

4.2.1.1 Red (645 nm)

Begin by experimenting with the red wavelength for all types of waist diameter. The graph in Figure 4.1 shows the repeatability test of the U-shaped tapered POF against humidity for the red wavelength.







(d)

Figure 4. 1 The repeatability test of (a) 400 μ m, (b) 500 μ m, (c) 600 μ m and (d) 700 μ m for red wavelength.

It can be observed that as relative humidity increases from 35% to 80%, the output voltage decreases. However, at a relative humidity of 80% to 35%, the output voltage increases. The large output voltage gap between runs 1, 2, and 3 for each humidity level and for each waist diameter of the u-shaped tapered POF contributes to the irregular output voltage shift. And while the output voltage for the waist diameter of a U-shaped tapered POF that shows less gap has better consistency. The output voltage for the 500 μ m of U-shaped tapered POF shows better consistency.

4.2.1.2 Green (530 nm)

Figure 4.2 shows the graph for the repeatability test of the U-shaped tapered POF against humidity for the green wavelength.



(a)







⁽c)



(d)

Figure 4. 2 The repeatability test of (a) 400 μm, (b) 500 μm, (c) 600 μm and (d) 700 μm for green wavelength.

TEKNIKAL MALAYSIA MELAKA

It is observed that the output voltage decreases from 35% to 80% relative humidity but increases from 80% to 35% relative humidity. The output voltage for the 500 µm U-shaped tapered POF shows less gap and better consistency.

4.2.1.3 Blue (470 nm)

WALAYSIA

UNIVERSITI

Figure 4.3 shows the graph for the repeatability test of the U-shaped tapered POF against humidity for the blue wavelength.





(b)







(d)

Figure 4. 3 The repeatability test of (a) 400 um, (b) 500 um, (c) 600 um and (d) 700 um for blue wavelength.

It can be seen in all the graphs that the output voltage increases from 80% to 35% relative humidity while decreasing from 35% to 80% relative humidity. The output voltage of the 500 μ m U-shaped tapered POF displays smaller gap and better stability. All light

wavelengths have good repeatability at 500 μ m. The results indicate that polished tapered POF absorbs more water particles, causing larger fluctuations in the evanescent wave (EW) in relation to the quantity of humidity adsorption required for good repeatability.

4.2.2 Trendline

The humidity sensing response for the double side-polished tapered POF sensor from 35 %RH to 85 %RH was obtained, and presented in the trendline graph. Figure 4.4 shows a trendline for each of the different U-shaped tapered POF waist diameters. The output voltage from the phototransistor, which was directly proportional to the light transmission, decreased linearly as the relative humidity increased. It can be observed that the sensitivity of the U-shaped tapered POF for waist diameter 500 µm is 0.110 V/%RH with a linearity of 99.32%. Linearity is obtained by multiplying the graph's R-square by the square root and 100. Table 4.1 summarises the characteristics of a U-shaped tapered POF for the red wavelength.



Figure 4. 4 Trendline graph for the red wavelength.

Figure 4.5 presents the trendline for each of the different U-shaped tapered POF waist diameters. It is clearly shows how the output voltage (V) from the phototransistor, which was inversely proportional to the amount of light transmitted for each different U-shaped tapered POF waist diameter, fell linearly as the relative humidity increased. It can be observed that the U-shaped tapered POF's sensitivity for a waist diameter of 500 μ m is 0.0117 V/%RH with a linearity of 98.74%. Table 4.2 summarises the characteristics of a U-shaped tapered POF for the green wavelength.



Figure 4. 5 Trendline graph for the green wavelength.

Figure 4.6 shows a trendline for each of the different U-shaped tapered POF waist diameters. The output voltage (V) from the phototransistor, which was inversely proportional to the amount of light transmitted for each different U-shaped tapered POF waist diameter, fell linearly as the relative humidity increased. It can be observed that the U-shaped tapered POF's sensitivity for a waist diameter of 500 μ m is 0.0041 V/%RH with a linearity of 98.16%. Table 4.3 summarises the characteristics of a U-shaped tapered POF for the blue wavelength.



Figure 4. 6 Trendline graph for the blue wavelength.

As the RH levels increased, the output voltages for polished tapered POF's waist diameter fell linearly. The slope of the curve between output voltage and percent relative humidity serves as a measure of a sensor's sensitivity. The 500 µm waist diameter has higher sensitivity and linearity than the other waist diameters.

Tables 4.1, 4.2, and 4.3 show a summary of the sensor performance for the four waist diameters of tapered POF, as well as the sensitivity, linearity, and resolution. All waist diameter U-shaped tapered POF sensors showed superiority in terms of sensing performance, with more than 95% linearity. The standard deviation is the amount of variation from the average value of repeated measurement data, whereas the resolution is the minimum relative humidity percentage of the specified sensor, which is calculated by dividing the standard deviation by the sensitivity.

Based on Table 4.1, the highest sensitivity was obtained with the 500 µm tapered POF,

which was 0.0110 V/% with a minimum resolution of 1.28%. The lowest sensitivity was obtained with the 600 μ m tapered POF, which was 0.0058 V/% with a maximum resolution of 4.06%.

	Wavelength							
	Red = 645 nm							
Waist Diameter (um)	400 µm	500 µm	600 µm	700 µm				
Sensitivity (V/%RH)	0.0066	0.0110	0.0058	0.0058				
Linearity (%)	98.2751	99.3227	97.8877	98.8028				
Resolution (%RH)	1.50427	1.2865	4.06119	1.63889				

Table 4. 1 The characteristics of a U-shaped tapered POF for the red wavelength.

Based on Table 4.2, the highest sensitivity was obtained with the 500 μ m tapered POF, which was 0.0117 V/% with a minimum resolution of 0.61%. The lowest sensitivity was obtained with the 600 um tapered POF, which was 0.0071 V/% with a maximum resolution of 1.73%.

2 Malunda	L	· · · · · · · · · · · · · · · · · · ·	13 mar 1	4 minut					
	- Wavelength -								
	Green = 530 nm								
Waist Diameter (um)	400 µm	500 µm	600 µm	700 µm					
Sensitivity (V/%RH)	0.0074	0.0117	0.0071	0.0082					
Linearity (%)	96.8865	98.7421	98.2853	99.1665					
Resolution (%RH)	1.20091	0.6108	1.73328	1.03119					

Table 4. 2 The characteristics of a U-shaped tapered POF for the green wavelength.

Based on Table 4.3, the highest sensitivity was obtained with the 500 μ m tapered POF, which was 0.0041 V/% with a minimum resolution of 1.65%. The lowest sensitivity was obtained with the 600 μ m tapered POF, which was 0.0025 V/% with a maximum resolution of 4.22%.

	Wavelength							
	Blue = 470 nm							
Waist Diameter (um)) 400 µm 500 µm 600 µm 70							
Sensitivity (V/%RH)	0.0025	0.0041	0.0034	0.0038				
Linearity (%)	95.7027	98.1631	98.8787	98.5901				
Resolution (%RH)	4.22968 1.65207 1.7769 2.06235							

Table 4. 3 Characteristics of a U-shaped tapered POF for the blue wavelength.

The slope of the curve between the output voltage (V) and relative humidity (%) is used to describe the sensor's sensitivity. Based on Table 4.4, the highest sensitivity was obtained with the 500 μ m tapered POF of green wavelength, which was 0.0117 V/% with a minimum resolution of 0.61%. The green wavelength of 500 μ m has the highest sensitivity of 0.0117 V/%.

Table 4. 4 Characteristics of a U-shaped tapered POF for 500 um at all wavelength.

2	>		
		Wavelength	
11.94	Red = 645 nm	Green = 530 nm	Blue = 470 nm
Waist Diameter (um)	500 μm	500 μm	500 μm
Sensitivity (V/%RH)	0.0110	0.0117	0.0041
Linearity (%)	99.32270637	98.74208829	98.16312953
Resolution (%RH)	1.286504801	0.610797212	1.652073827
UNIVERSIT	I TEKNIKAL	MALAYSIA	MELAKA

Aside from that, the porous structure of the polished and tapered POF can be attributed to the quick adsorption of water molecules on the surface. This surface adsorption process also affects the optical characteristics of the polished taper. As the RH levels increase, more water molecules are absorbed by the polished, tapering surfaces of the POF. This behaviour was also reported by Liu et al., who found that increasing the number of water molecules increases the effective surrounding medium refractive index as well as the factor of absorption of polished tapered u-shape surfaces, resulting in greater leakage and light absorption within the tapered POF structures [13].

4.2.3 Hysteresis

One of the major parameters used to measure the accuracy of a humidity sensor is hysteresis. The highest difference in observed relative humidity levels during the forward and reverse cycles is defined as hysteresis. Figure 4.7 shows hysteresis for the 500 μ m waist diameter of each light wavelength. It was performed by recording data during forward and reversed measurements. Based on the hysteresis graph for (a), (b), and (c), the output voltage at 55% RH for each wavelength shows a large gap between the forward and reverse processes, which have the lowest ΔV .



(a)







(c)

Figure 4.7 Hysteresis for the 500 µm waist diameter of (a) red wavelength, (b) green wavelength, and (c) blue wavelength.

Refer to the Tables 4.5, it is show the ΔV for each wavelength at 55% RH. ΔV is the voltage variation at a specific humidity level. The lowest ΔV is good, which means that it is the optimal fiber. A sensor's low hysteresis results in greater reliability and consistency of measurement.

Table 4. 5 ΔV	for each wa	avelength a	at 55% RH.
		<i>L</i>)	

	Wavelength		
	Red = 645 nm	Green = 530 nm	Blue = 470 nm
ΔV	0.02	0.05	0.01

To get ΔV , the forward output voltage value is subtracted with the reverse output voltage value. The optimal fiber is blue provide lowest $\Delta V = 0.01$ V. The stability test will be performed next.

4.2.4 Stability



Figure 4. 8 U-shaped tapered POF voltage stability in 600 seconds.

To verify the sensor's stability, the output voltage changed at 35% RH and 80% RH, and humidities were measured, as shown in Figure 4.8. The results show that the 500 µm green wavelength is more stable than other wavelengths throughout the tested period of 600 seconds. It was observed that the output voltage had barely varied over time, indicating that the sensor was steady. The transmission waveform depicted in Figure 4.8 showed the fewest changes. The

unpredictability of the instrument's outputs was an unavoidable problem, but the output graph of the repeating test was consistent. Therefore, according to the graph, the 500 μ m green wavelength fiber provides superior stability.

4.3 Summary

All the graphs in the repeatability, flow line, and hysteresis tests show that the output voltage of the U-shaped POF decreases as the relative humidity (%) increases, and conversely, when the relative humidity (%) decreases, the output voltage of the U-shaped POF increases. The slope-intercept form of the equation of a line on a trendline graph is defined as y = mx + c, where m is the slope of the line. So, the sensitivity of the U-shaped POF sensor refers to the highest value of the gradient m. The highest sensitivity is also determined by the average standard deviation, v/% sensitivity, % linearity, and % resolution for each waist diameter for each wavelength of light.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

48

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

A double side-polished tapered plastic optical fiber (POF) sensor for humidity applications was successfully developed. In this work, the consistency as well as the reversibility of the sensor's reaction to relative humidity were investigated. The experimental results showed that when the relative humidity changed from 35% to 80%, the sensor had good output linearity with a sensitivity of 0.0117 V/%. The sensor's response showed 98.74 percent linearity, which is excellent. By selecting a suitable waist diameter, the POF sensor could produce maximum sensitivity for various humidity sensing applications. The U-shaped tapered POF green wavelength structure with a waist diameter of 500 um has great sensitivity performance as compared to the other LED wavelengths and waist diameters even as the fabrication process becomes less difficult. Finally, when tested continuously for 600 seconds at 55% relative humidity, the sensor provided superior stability. The suggested sensor was appropriate for applications involving humidity since it featured a broad linear range and excellent sensitivity without requiring a large volume.

5.2 Future Works

For future applications, by removing the fiber cladding and coating the core with a thin layer of a substance capable of interacting with the chemical to be detected, plastic optical fibers can be used as the primary ingredient in producing very low-cost sensors for environmental monitoring. In addition, POF can be applied for gas sensing applications. POF sensors can also be used to create products. To summarise, POF-based sensors are predicted to remain a hot research area in the near future.



REFERENCES

- [1] L. Bilro, N. Alberto, J. L. Pinto, and R. Nogueira, "Optical Sensors Based on Plastic Fibers," Sensors, vol. 12, no. 9, pp. 12184-12207, 2012. [Online]. Available: https://www.mdpi.com/1424-8220/12/9/12184.
- [2] K. R. A. A Arifin, A K Lebang, N Hamrun, S Dewang, D Tahir "Enhance sensitivity of plastic optical fiber sensor by spiral configuration for body temperature applications," 2020.
- [3] J. Zubia and J. Arrue, "Plastic Optical Fibers: An Introduction to Their Technological Processes and Applications", Optical Fiber Technology, vol. 7, no. 2, pp. 101-140, 2001. Available: 10.1006/ofte.2000.0355.
- [4] O. Suzuki, M. Miura, M. Morisawa, and S. Muto, "POF-type optic humidity sensor and its application [as breathing-condition monitor]," in 2002 15th Optical Fiber Sensors Conference Technical Digest. OFS 2002 (Cat. No. 02EX533), 2002: IEEE, pp. 447-450.
- [5] L. Szolga, "Humidity and Isopropyl Alcohol Detection Sensor Based on Plastic Optical Fiber", 2021 25th International Conference Electronics, 2021. Available: 10.1109/ieeeconf52705.2021.9467472 [Accessed 5 June 2022].
- [6] C. Tay, K. Tan, S. Tjin, C. Chan and H. Rahardjo, "Humidity sensing using plastic optical fibers", Microwave and Optical Technology Letters, vol. 43, no. 5, pp. 387-390, 2004. Available: 10.1002/mop.20479.
- [7] W. Kam et al., "All plastic optical fiber-based respiration monitoring sensor," in 2017 IEEE SENSORS, 2017: IEEE, pp. 1-3.

- [8] L. Liu, J. Zheng, S. Deng, L. Yuan and C. Teng, "Parallel Polished Plastic Optical Fiber-Based SPR Sensor for Simultaneous Measurement of RI and Temperature", IEEE Transactions on Instrumentation and Measurement, vol. 70, pp. 1-8, 2021. Available: 10.1109/tim.2021.3072136.
- [9] M. Batumalay, A. Lokman, F. Ahmad, H. Arof, H. Ahmad and S. Harun, "Tapered Plastic Optical Fiber Coated With HEC/PVDF for Measurement of Relative Humidity", IEEE Sensors Journal, vol. 13, no. 12, pp. 4702-4705, 2013. Available: 10.1109/jsen.2013.2272329.
- [10] Z. Harith et al., "Tapered Plastic Optical Fiber Coated With Al-Doped ZnO Nanostructures for Detecting Relative Humidity", IEEE Sensors Journal, vol. 15, no. 2, pp. 845-849, 2015. Available: 10.1109/jsen.2014.2353038.
- [11] A. Gowri and V. Sai, "Development of LSPR based U-bent plastic optical fiber sensors", Sensors and Actuators B: Chemical, vol. 230, pp. 536-543, 2016. Available: 10.1016/j.snb.2016.02.074.
- [12] A. P. S. Liehr, "Polymer Optical Fiber Sensors in Structural Health Monitoring," SpringerLink, [Online]. Available: https://link.springer.com/chapter/10.1007/978-3-642-21099-0_13. [Accessed: Jan. 17, 2023]
- [13] L. Liu, J. Zheng, S. Deng, L. Yuan, and C. Teng, "Parallel Polished Plastic Optical Fiber-Based SPR Sensor for Simultaneous Measurement of RI and Temperature," IEEE Transactions on Instrumentation and Measurement, vol. 70, pp. 1–8, 2021, doi: 10.1109/tim.2021.3072136. [Online]. Available: http://dx.doi.org/10.1109/tim.2021.3072136
- [14] "Comprehensive Biotechnology," Comprehensive Biotechnology | ScienceDirect.
 [Online].Available:http://www.sciencedirect.com:5070/referencework/978044464047
 5/comprehensive-biotechnology.

- S. H. Johari et al., "ZnO Nanorods Coated Tapered U-Shape Plastic Optical Fiber for Relative Humidity Detection," MDPI, Oct. 25, 2022. [Online]. Available: https://www.mdpi.com/2304-6732/9/11/796. [Accessed: Jan. 18, 2023]
- Y. Hu, A. Ghaffar, Y. Hou, W. Liu, F. Li, and J. Wang, "A Micro Structure POF Relative Humidity Sensor Modified With Agarose Based on Surface Plasmon Resonance and Evanescent Wave Loss," Photonic Sensors, vol. 11, no. 4, pp. 392–401, Oct. 2020, doi: 10.1007/s13320-020-0603-4. [Online]. Available: http://dx.doi.org/10.1007/s13320-020-0603-4
- [17] M. H. Jali et al., "Humidity sensing using microfiber-ZnO nanorods coated glass structure," Optik, vol. 238, p. 166715, Jul. 2021, doi: 10.1016/j.ijleo.2021.166715.
 [Online]. Available: http://dx.doi.org/10.1016/j.ijleo.2021.166715
- [18] M. H. Jali et al., "Optical characterization of different waist diameter on microfiber loop resonator humidity sensor," Sensors and Actuators A: Physical, vol. 285, pp. 200– 209, Jan. 2019, doi: 10.1016/j.sna.2018.11.025. [Online]. Available: http://dx.doi.org/10.1016/j.sna.2018.11.025
- [19] I. Yulianti, N. M. D. Putra, H. Rumiana, Z. A. F. Latif, K. E. Kurniansyah, and S. Maimanah, "Characterization of Mach Zehnder interferometer plastic optical fiber for intensity-based temperature sensor," Journal of Physics: Conference Series, vol. 1918, no. 2, p. 022010, Jun. 2021, doi: 10.1088/1742-6596/1918/2/022010. [Online]. Available: http://dx.doi.org/10.1088/1742-6596/1918/2/022010