UNIVERSITI TEKNIKAL MALAYSIA MELAKA

SENSITIVITY ENHANCEMENT OF OPTICAL FIBER SENSOR FOR LIMONENE SENSING APPLICATIONS BY USING TAPERED OPTICAL FIBER

THANIGAI A/P ANBALAGAN

MASTER OF SCIENCE
IN ELECTRONIC ENGINEERING

2024

Faculty of Electronics and Computer Technology and Engineering

SENSITIVITY ENHANCEMENT OF OPTICAL FIBER SENSOR FOR LIMONENE SENSING APPLICATIONS BY USING TAPERED OPTICAL FIBER

Thanigai A/P Anbalagan

Master of Science in Electronic Engineering

2024

SENSITIVITY ENHANCEMENT OF OPTICAL FIBER SENSOR FOR LIMONENE SENSING APPLICATIONS BY USING TAPERED OPTICAL FIBER

THANIGAI A/P ANBALAGAN

**A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Electronic Engineering**

Faculty of Electronics and Computer Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

DECLARATION

I declare that this thesis entitled “Sensitivity Enhancement of Optical Fiber Sensor for Limonene Sensing Applications by Using Tapered Optical Fiber” is the result of my own research except as citedin the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : Thanigai Anbalagan ……………………………….

Name : Thanigai a/p Anbalagan

Date : 17/01/2024 ……………………………….

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

Signature : ....

Supervisor Name : Dr. Hazura binti Haroon

Date : 17/01/2024

DEDICATION

This thesis is dedicated to my loving and supportive parents, siblings and supervisor who helped me through this journey. Thanks for making me see this adventure journey to the end.

ABSTRACT

Evanescent wave sensing has led to significant advancements in various fields, including the development of optical fiber sensors (OFS). A simple and low-cost optical fiber sensor based on evanescent wave coupling of light into the core modes of plastic optical fiber (POF) coated with Zinc Oxide (ZnO) nanorods is reported here. The main objective of this research is to study the potential of optical sensing characteristics in the characterization of limonene concentration. Current detection methods for limonene sensing, which is one of a liver disease biomarker, lack sensitivity, and there is a need for a more accurate biomarker for early diagnosis. Study on the limonene concentration characterisation by using a fiber-optic sensor has not been conducted and published before. In this work, the sensor's performance was evaluated through changes in refractive index and light intensity. The study involved optimization of the sensor model, optical and electrical characterizations, and performance validations through mathematical analysis. The POF sensor's sensing region was successfully developed using chemical etching and hydrothermal synthesis. Two POF design parameters were varied: tapered waist diameter and sensing region length. The sensor's performance was evaluated using three different lengths: 1 cm, 2 cm, and 3 cm. The effect of sensor diameter differences was also investigated, which included a study of sensor diameters of 0.70 mm, 0.65 mm, 0.60 mm, 0.55 mm, 0.50 mm, and 0.45 mm. The experiment was also conducted using three different LEDs: blue, green, and red together with five different limonene concentrations of 20%, 40%, 60%, 80% and 100%. ZnO nanorods' growth which is horizontal and vertical oriented nanoparticles with time of 10 hours leads to the best sensitivity of the fiber sensors. The best sensor design was discovered to be a vertically oriented ZnO coated sensor with a 0.45 mm tapered waist diameter, a 3 cm sensing region length, and a red LED light source. The sensitivity obtained was 6.85V/RIU, with the linearity of 99%. Limit of detection and standard deviation achieved by 0.03% and 0.06V respectively. This research lays the foundation for further comprehensive assessments and advancements in the field of optical sensing for limonene sensing.

PENINGKATAN KEPEKAAN PENDERIA GENTIAN OPTIK UNTUK APLIKASI PENDERIAAN LIMONENA DENGAN MENGGUNAKAN GENTIAN OPTIK TIRUS

ABSTRAK

Penderiaan gelombang fana telah membawa kepada perkembangan di dalam pelbagai bidang, termasuk pembangunan penderia gentian optik. Penderia gentian optik yang mudah dan berkos rendah berasaskan gandingan cahaya gelombang fana ke dalam teras gentian optik plastik (POF) yang disalut dengan nanorod Zink Oxida (ZnO) dilaporkan di dalam kajian ini. Objektif utama kajian ini adalah bagi mengkaji potensi ciri-ciri penderia optik di dalam pencirian kepekatan limonen. Kaedah pengesanan sedia ada untuk mengesan limonen, salah satu penanda- bio bagi penyakit hati kekurangan ciri kepekaan, dan memerlukan penanda-bio yang lebih tepat bagi pengesanan awal. Kajian tentang pencirian kepekatan limonene dengan menggunakan sensor gentian optik belum pernah dijalankan dan diterbitkan sebelum ini. Di dalam kajian ini, prestasi penderia dinilai melalui perubahan indeks biasan dan keamatan cahaya. Kajian ini melibatkan pengoptimasian model penderia, pencirian optik dan elektrik, dan pengesahan prestasi melalui analisis matematik. Kawasan penderiaan penderia POF telah berjaya dibangunkan menggunakan punaran kimia dan sintesis hidrotermal. Dua parameter rekabentuk divariasi: lebar tirus dan panjang kawasan penderiaan. Prestasi penderia dikaji menggunakan tiga panjang yang berbeza: 1 cm, 2 cm dan 3 cm. Kesan perbezaan diameter penderia juga dinilai, dengan mengambilkira diameter 0.70 mm, 0.65 mm, 0.60 mm, 0.55 mm, 0.50 mm, dan 0.45 mm. Experimen ini juga dijalankan menggunakan tiga LED yang berbeza: biru, hijau dan merah dengan lima variasi limonen konsentrasi 20%, 40%, 60%, 80% dan 100%. Masa pertumbuhan 10 jam nanorod ZnO yang berorientasi menegak dan mendatar membawa kepada sensitiviti terbaik penderia gentian ini. Rekabentuk penderia terbaik adalah penderia bersalut ZnO berorientasi menegak dengan diameter lebar 0.45 mm, kawasan penderia 3 cm dan menggunakan sumber cahaya LED merah. Kepekaan yang diperolehi ialah 6.85V/RIU, dengan keariti 99%. Had pengesanan dan sisihan piawai dicapai sebanyak 0.03% dan 0.06V. Penyelidikan ini meletakkan asas untuk penilaian dan kemajuan komprehensif lebih lanjut dalam bidang penderiaan optik bagi pengesanan limonen.

ACKNOWLEDGMENTS

It is with immense gratitude that I would like to acknowledge the support and help of my supervisor, Dr. Hazura Binti Haroon. She has been a source of inspiration and has convincingly conveyed a spirit of adventure regarding research. The initial ideas she suggested and her vast knowledge on optical sensor were invaluable in helping me get set on the right track. The successful completion of my task would not have been possible without her constant encouragement and guidance throughout the whole period of my research work. Most importantly, I would like to express my heart-felt gratitude to my parents Anbalagan and Parvathy, thank you for your encouragement and prayers. My deepest appreciations from bottom of my heart go to my sisters Tharani and Khirtini for all your love and support. Lastly, I would like to thank Universiti Teknikal Malaysia Melaka (UTeM) and Ministry of Higher Education Malaysia (MOHE) for sponsoring my master's degree.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

Au	-	Gold
BW	-	Bandwidth
CYTOP	-	Amorphous fluorinated polymer
DI	-	De-ionized
EW	-	Evanescent Wave
FBG	-	Fiber Bragg Grating
GBP	-	Gain Bandwidth
GO	-	Graphene Oxide
LCD	-	Liquid Crystal Display
LED	-	Light Emitting Diode
LOD	-	Limit of Detection
LPSR	-	Localized Surface Plasmon Resonance
MI	-	Michelson Interferometer
MMF	-	Multimode Fiber
MZI	-	Mach Zehnder Interferometer
NA	-	Numerical Aperture
OFS	-	Optical Fiber Sensor
OSA	-	Optical Spectrum Analyzer
OTDR	-	Optical Time Domain Reflectometry
PANI-ZnO	-	Polyaniline-Zinc Oxide
PD	-	Photodetector
PMMA	-	Polymethyl Methacrylate

POF	-	Polymer Optical Fiber
PS	-	Polystyrene
RI	-	Refractive Index
SD	-	Standard Deviation Error
SEM	-	Surface Electron Microscope
SI	-	Saganc Interferometer
SMF	-	Single Mode Fiber
Sn	-	Stannum
SUT	-	Sample under Test
TIA	-	Transimpedance Amplifier
UA	-	Uric Acid
UV	-	Ultraviolet
VLS	-	Vapor–Liquid–Solid
ZIF-8	-	Zeolitic Imidazolate Framework-8
ZnO	-	Zinc Oxide

LIST OF SYMBOLS

η	-	Efficiency
λ	-	Wavelength
θ	-	Angle of Incidence
n	-	Refractive Index
C_f	-	Feedback Capacitor
E_x	-	Evanescent Field
d_p	-	Penetration depth
δn_{eff}	-	Different between refractive indices

LIST OF APPENDICES

LIST OF PUBLICATIONS

1. Thanigai Anbalagan, Hazura Haroon, Hazli Rafis Abdul Rahim, Siti Halma Johari, Siti Khadijah Idris, Hanim Abdul Razak, Maisara Othman. 2023. A novel examination of limonene detection using plastic fiber optic sensors and the tapered approach. *Bulletin of Electrical Engineering and Informatics*, 12 (2), pp. 807-814.

2. Thanigai Anbalagan, Hazura Haroon, Huda Adnan Zain, Hazli Rafis and S.W. Harun. 2022. Recent Progress of Tapered Optical Fiber for Biosensing Applications. *Journal of Engineering Science and Technology Review*, 15 (5), pp. 204 – 209.

3. Hazura Haroon, Siti Noraminah Nordin, Hazli Rafis Abdul Rahim,Thanigai Anbalagan, Maisara Othman. 2022. Examination Of Adulterated Coconut Oil By Fiber Optics Displacement Sensor Using Lateral Offset Approach. *Jurnal Teknologi*, 84:5, pp. 185–190.

4. H Haroon, SN Nordin, T Anbalagan, M Othman. 2022. Edible oils adulteration analysis by fiber optic multimode displacement sensor. *Optoelectronics and Advanced Materials - Rapid Communications*, 16, 1-2, January-February, pp.36-40 (2022).

5. Thanigai Anbalagan, Hazura Haroon, Hazli Rafis Abdul Rahim and Siti Halma Johari. 2022. Examination for limonene concentration using tapered plastic optical fiber sensor. *Journal of Physics: Conference Series 2411*, 012010 Photonic Meeting 2022.

CHAPTER 1

INTRODUCTION

1.1 Background Study

Evanescent wave study has brought tremendous advancements in many fields, which has opened the door to new research lines and possibilities. There has been a lot of research into optical fiber sensor (OFS) in recent times, due to its excellent performance and cost reduction. The trend has been driven by many telecommunications fields that resulted in a firmer penetration of fiber-optic sensors into various industrial, medical, environmental, power, and protection applications.

The primary goal of this study is to evaluate the potential of evanescent wave sensing as a non-invasive technique for limonene concentration characterisation, which is one of the biomarkers for liver disease detection. As liver disease is difficult to detect, researchers have found that the limonene compound in individuals diagnosed with liver disease is higher than in healthy individuals. Recently, typical biomarkers, such as isoprene, acetone, and ethanol were employed for liver disease detection. However, the technique was found to be insufficiently specific since they can be biomarkers for other types of disorder or produced by a variety of normal metabolic processes. Therefore, there is a need for an extensive research to establish an accurate, precise, specific, and sensitive non-invasive biomarker for early liver disease diagnosis.

This project proposed a development of fiber-optic sensor as an alternative to the bio-sensor, and subsequently explored the potentials of fiber-optic sensor for limonene characterisation. The fiber-optic sensing mechanism is the basis for the sensor development.