UNIVERSITI TEKNOLOGI MARA

SURFACE PLASMON RESONANCE QUASI-DISTRIBUTED POLYMER OPTICAL FIBER SENSOR FOR OXYGEN DETECTION

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Thesis submitted in fulfilment
of the requirements for the degree of
Master of Science
(Electrical Engineering)

Faculty of Electrical Engineering

July 2025

ABSTRACT

This thesis explores the development of a quasi-distributed polymer optical fiber (POF) sensor for oxygen detection, utilizing surface plasmon resonance (SPR) and fluorescence-based techniques to enhance performance and versatility. The sensor design incorporates a silver (Ag) coating to amplify SPR effects, paired with fluorescence dyes which are platinum octaethylporphyrin (PtOEP) and 5,10,15,20-tetrakis (pentafluorophenyl) 21H,23H-porphine palladium (II) (PdTFPP), and Tris (4, 7-diphenyl-1, 10-phenanthroline) ruthenium (II) dichloride ($[Ru(dpp)_3]^{2+}$), for photostability and responsiveness to oxygen. The sensing region of the POF was prepared by stripping the cladding to expose the core, allowing direct interaction with the environment. A silver (Ag) coating was then applied to the exposed fiber surface to facilitate SPR excitation, followed by deposition of fluorescent dyes. The sensor's performance was assessed through a custom experimental setup that included precise oxygen and nitrogen flow control, dye-specific laser excitation which are 385 nm, 405 nm, and 450 nm for PtOEP, PdTFPP, and $[Ru(dpp)_3]^{2+}$, respectively. The emission peaks of the fluorescent dyes were recorded at 646.77 nm for PtOEP, 668.62 nm for PdTFPP, and 600.07 nm for $[Ru(dpp)_3]^{2+}$, ensuring effective fluorescence detection and differentiation. When SPR was implemented using the Ag coating, significant shifts in the emission peaks were observed due to the enhanced plasmonic interaction between the metal layer and the fluorescent dyes. For PtOEP, the emission peak shifted from 646.77 nm to 668.1 nm, while for PdTFPP, the peak shifted from 668.62 nm to 668.29 nm. Similarly, the emission peak for $[Ru(dpp)_3]^{2+}$ shifted from 600.07 nm to 550.76 nm. The sensitivity of the fluorescent dyes was measured in terms of the change in fluorescence intensity per unit of oxygen concentration. Without SPR enhancement, the sensitivity values were 0.0324 a.u/% for PtOEP, 0.0994 a.u/% for PdTFPP, and 0.0268 a.u/% for $[Ru(dpp)_3]^{2+}$, highlighting PdTFPP as the most sensitive dye in the fluorescence-only configuration. When SPR was introduced, the sensitivity of the SPR-enhanced configuration was calculated based on the wavelength shifts observed in response to varying oxygen concentrations. The sensitivity improved significantly, with 0.0367 nm/% values for Ag/PtOEP, 0.1045 nm/% for Ag/PdTFPP, and 0.0312 nm/% for Ag/$[Ru(dpp)_3]^{2+}$. Finally, in the quasi-distributed configuration, Ag/PdTFPP showed the highest sensitivity at 0.1317 nm/%, followed by Ag/PtOEP with moderate sensitivity at 0.048 nm/%, while Ag/$[Ru(dpp)_3]^{2+}$ exhibited the lowest sensitivity at 0.0191 nm/%. Distinct excitation peaks validated the effective interaction of dyes with respective laser wavelengths, confirming the multi-point sensing capability of the quasi-distributed configuration. The sensor exhibited robust real-time performance, achieving high sensitivity and reliable detection across multiple locations along the fiber. These advancements demonstrate the system's potential for scalable, distributed sensing in diverse applications, including environmental monitoring, medical diagnostics, and industrial safety.

ACKNOWLEDGEMENT

Alhamdulillah, all praise is due to Allah the Almighty, for granting me the opportunity to pursue and complete my Master of Science (Electrical Engineering) at Universiti Teknologi MARA, Shah Alam. I am deeply grateful to Allah SWT for His blessings and guidance throughout this journey.

I extend my heartfelt appreciation to my supervisor, Ir. Ts. Dr. Maizatul Zolkapli, and my co-supervisors, Prof. Ir. Dr. Ahmad Sabirin Zoolfakar and Prof. Ir. Dr. Ahmad Ashrif A. Bakar, for their invaluable guidance, insightful advice, and unwavering support in the completion of my studies. I am very thankful to the Photonics Technology Laboratory at Universiti Kebangsaan Malaysia for allowing me access to their modern facilities and equipment, which were essential for completing this research. I would also like to thank the laboratory staff for their consistent help in preparing the equipment and managing the storage and disposal of chemicals.

Furthermore, I would like to express my gratitude to the Ministry of Higher Education and Universiti Teknologi MARA for financially supporting my study under the Fundamental Research Grant Scheme (FRGS) [Grant No.: FRGS/1/2023/TK07/UITM/02/17].

On a personal note, I am deeply grateful to my parents, En. Hishamuddin Shafie and Puan for their unwavering support, constant prayers, and encouragement, which have been a source of strength throughout this journey. I also extend my heartfelt appreciation to my siblings, which are Azre Hafriz, Azreen Hanieza, Azleen Haziera, and Azle Hazziq, for continuous motivation and understanding. To my dear friends, Dr. Nur Hidayah Azeman, Dr. Wan Mohd Ebtisyam Mustaqim Mohd Daniyal, Dr. Mohd Hafiz Abu Bakar, Dr. Rozita Sulaiman, Dr. Nur Afifah Ahmad Nazri, Athiyah Sakinah Masran, Muhammad Qayyum Othman, and Nurul Izzah Zakaria, your constant support and encouragement have meant so much to me, and I am truly thankful for your presence throughout this journey.

Lastly, I would like to thank everyone who contributed, directly or indirectly, to the completion of this research. This journey has been a shared effort, and I am truly grateful to have encouragement and assistance along the way. Thank you for being part of this important chapter in my life.

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INTRODUCTION

1.1 Research Background

Low oxygen (O_2) levels in physiologic and environmental conditions offer major health concerns to human and ecosystem health. Hypoxia, caused by insufficient oxygen delivery, inhibits the respiration of cells, resulting in reduced biological functions and potential organ failure, with serious implications such as loss of consciousness and even death [1]. Similarly, low oxygen levels in ecosystems threaten aerobic organisms, interfering with metabolic activities, nutrient cycling, and overall ecosystem function. This breakdown can result in the expansion of hazardous anaerobic bacteria, pollution, and the extinction of aquatic animals, eventually endangering biodiversity and ecosystem equilibrium [2]. As a result, continual monitoring of oxygen levels is critical for ensuring human health and environmental safety. Furthermore, measuring oxygen levels enables early detection of threats such as oxygen-depleted conditions in tight or polluted places. Other gases, such as carbon dioxide (CO_2) and methane (CH_4), are also important to monitor for environmental health and safety reasons [3], focusing on oxygen measurement ensures an immediate assessment of the environment's ability to support life, making oxygen an essential element of environmental monitoring efforts.

Despite the necessity of oxygen detection, conventional oxygen-sensing devices confront numerous problems. There are several types of oxygen sensors, including electrochemical and optical sensors [4]. Electrochemical sensors, one of the most prominent methods of oxygen detection, have disadvantages such as slow response times, drift over time, and the need for frequent calibration [5]. These limitations compromise long-term stability and precision. Apart from that, electrochemical sensors are frequently large and expensive. and may be influenced by interfering gases [6]. Meanwhile, the main disadvantage of optical fiber oxygen sensors is the necessity for complicated optical setups. These sensors normally require a light source for activating the fluorescent dye and a detector for determining the fluorescence emitted. This can raise the sensor's cost and size, making these sensors unsuitable for some applications.