FIBER OPTIC TEMPERATURE SENSOR BASED ON NO-CORE FIBER (NCF) FOR HIGH TEMPERATURE SENSING

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DEDICATION

Special dedicated,

To my beloved family who are always praying for my success,

To my supervisor who always motivate, encourage and give me advise throughout this project,

To all my friend for their support.

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ABSTRACT

This paper proposes an improved fiber optic temperature sensor based on No-Core-Fiber (NCF) with sol-gel coating material for high temperature sensing. The main advantage of this sensor is the multimode interference (MMI) effect could react better to the changes of its surrounding compared with the multimode fiber. Without a physical cladding, an NCF will consider its surrounding as the cladding layer that facilitates the total internal reflection of the propagated light wave. With that configuration, changes of surrounding refractive index will impact the MMI effect directly. The design of sensor using Rsoft Beam Prop software has been carried out to determine the power intensity and temperature sensitivity. In addition, three different sol-gel materials were used to evaluate the sensor performance. From the simulation result, compared to TiO_2 and SiNx, it is found that the ZrO_2 coating has most significant performance in enhancing seven time greater than without coating within temperature range of 25 °C to 100 °C. The temperature sensitivity became 0.01637 dB/°C rather than 0.0225 dB/°C. Therefore, the sensor with ZrO_2 is the most suitable for monitoring the high-temperature sensing applications.

ABSTRAK

Kajian ini mencadangkan binaan sensor suhu gentian optik yang lebih baik menggunakan gentian optik tanpa teras dengan diselaputi bahan sol-gel untuk pengukuran suhu pada julat yang tinggi. Kelebihan utama sensor ini ialah kesan gangguan berbilang mod dapat bertindak balas dengan lebih baik kepada perubahan persekitarannya berbanding sensor yang menggunakan gentian optik berbilang mod biasa. Gelombang cahaya akan merambat ke dalam gentian optik tanpa teras dengan penghasilan pantulan dalam penuh oleh gentian optik tanpa teras yang menjadikan udara sebagai teras. Oleh yang demikian, kesan gangguan berbilang mod dapat bertindak balas secara terus kepada perubahan indeks biasan di persekitannya. Reka bentuk sensor telah dibangunkan dengan menggunakan perisian RSoft Beamprop untuk menentukan kepekaan suhu sensor. Di samping itu, bagi menilai kepekaan suhu yang lebih baik bagi sensor gentian optik tanpa teras, ia akan disalut oleh tiga bahan sol-gel iaitu TiO_2, ZrO_2 and SiNx. Hasil simulasi menunjukkan salutan ZrO_2 mempunyai prestasi yang paling baik kerana kepekaan suhu meningkat sebanyak tujuh kali ganda dari kepekaan suhu sensor tanpa salutan. Kepekaan suhu menjadi 0.01637 dB/°C berbanding 0.225 dB/°C pada julat suhu antara 25 °C hingga 100 °C. Oleh itu, sensor dengan salutan ZrO_2 adalah paling sesuai dalam penggunaan aplikasi penderia suhu tinggi.

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LIST OF ABBREVATIONS

FBG	-	Fiber Bragg Grating
FOS	-	Fiber Optic Sensor
MMF	-	Multimode Fiber
MM FBG	-	Multimode Fiber Bragg Grating
MMI	-	Multimode Interference
NCF	-	No-Core Fiber
RI	-	Refractive index
SNS	-	Single mode – no core – single mode
SMS	-	Single mode – multimode – single mode
SMF	-	Single mode fiber
SiNx	-	Silicon Nitride
TiO_2	-	Titanium dioxide
TFBG	-	Tilted Fiber Bragg Grating
TOC	-	Thermo-optic coefficient
ZrO_2	-	Zirconium dioxide

LIST OF SYMBOLS

λ	-	Wavelength
d	-	Diameter
n	-	Refractive index
θc	-	Critical angle

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Fiber optic sensors (FOS) have good durability against harsh environments, high sensitivity and stability, fast response, high resolution, and immune to electromagnetic interferences [1, 2]. The superiority of FOS in term of its durability in extreme environment and the stability of optical signals from external factors makes FOS widely applied in industries to monitor temperature development in a certain environment such as a hazardous environments that are constituted with toxic chemical and flammable gases or substances. Therefore, FOS plays a vital role in preventing a disastrous event from taking place.

Many different classification of FOS have been developed for high temperature measurement in the past two decades. The most reported researches are on Bragg grating in multimode optical fibers. Multimode fiber Bragg grating (MM-FBG) are well known for its simplicity in construction and lower cost compared to the other such as Brillouin scattering and Raman scattering. In aspect of temperature resolution, MM-FBG has lower temperature resolution compared to Brillouin scattering and Raman scattering.

Although the desired feature in most temperature sensor is its high-temperature resolution, in many cases, the reflected factor in the final sensor commercial value is the fabrication cost. Therefore, there is always the need for the development of a fiber optic temperature sensor that is simple, reliable, and cost-effective.

1.2 Motivation of the Study

In recent times, single mode-multimode-single mode (SMS) fiber optic sensor has been used to monitor temperature development. With the increasing research works in its ability to sense temperature up to 375° C [2], single mode-NCF (No-Core Fiber)-single mode (SNS) fiber also contributes to improving the temperature sensitivity with its simple design. This research will demonstrate the improved performance in temperature sensitivity of the analytical design of SNS fiber with an operating principle based on multimode interference (MMI) effect.

1.3 Problem Statement

The operating principle of the traditional single mode-multimode-single mode (SMS) based on MMI effect that occurs within the SMS fiber structure has been exploited to achieve the sensing capability. In spite of that, the SMS fiber structure has limited sensing sensitivity due to the presence of cladding in the multimode fiber (MMF). The nature of sensing principle of most FOS is through the changes in refractive index in perturbation environment. However, the guided modes enclosed inside the MMF makes the fiber insensitive to the changes of refractive index in its surrounding and causes a minimal impact from the MMI effect [3].

Therefore, an alternative to the solution is temperature sensor based on special MMF without cladding known as the NCF that has many different applications including high-temperature sensing application. The surrounding environment replacing the physical cladding layer will facilitate the total internal reflection of the propagating light wave in an NCF [4]. As a result, changes of surrounding refractive index will impact the MMI effect directly.

1.4 Objectives

This research aims to assess a high temperature sensor by developing an FOS based on NCF sensing configuration. The objectives of this research are stated as below:

a) to develop an analytical design of temperature sensor based on NCF.
b) to determine the sensitivity to temperature change for both bare NCF and coated NCF in a range of high temperature.
c) to evaluate the performance of NCF by adding additional material that suits high temperature application.

1.5 Scope of Study

The scope of this study is to develop a fiber optic temperature sensor based on NCF for high temperature sensing application and to investigate the performance of the bare NCF and coated NCF in term of power intensity to the temperature change which will attribute to the temperature sensitivity of the NCF. The sensing configuration of the NCF constitutes of SNS fiber, as shown in Figure 1.1, replace the traditional multimode fiber to improve the sensitivity to its surrounding.

In this study, the optical properties of SMF and NCF and coating material will be required to design the models of the sensor. The design of the sensor models involves in this research are bare SMF-NCF-SMF and coated-NCF. Suitable coating materials will be used to coat the surface of the fiber sensor, NCF to study the influence of each coating material to its structure. The technique that will be used to coat the material on NCF is through the sol-gel process. The refractive index of the coating material and optical properties such as thermo-optic coefficient (TOC) will be investigated to ensure the validity of the performance of the sensor.

The effect of the coating material to the temperature sensitivity of the sensor and the power intensity to the temperature change of the both bare and coated sensor will be studied and highlighted. The simulation will be carried out using RSoft Beamprop software.

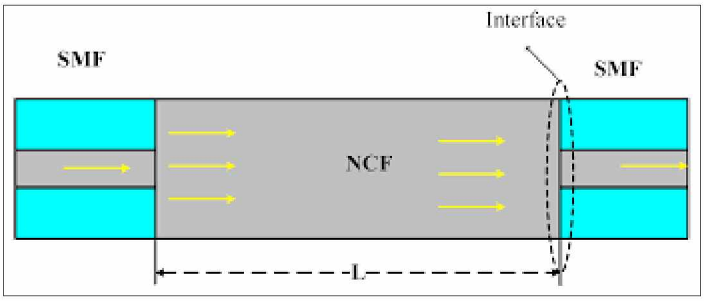

Figure 1.1 The structure of SNS fiber

1.6 Thesis Outline

This thesis encompasses five chapters covering and discussing the literature research, the overall progression, and the implementation of the project.

Chapter 1 describe the introduction part of the project. The overview of the project background, problem statement, objectives, and scope of the project will be carried out to this chapter.

Chapter 2 discuss the literature review on this project including the types of the fiber optic, the light propagation, MMI effect and additional material as a coating of the sensor.

Chapter 3 focuses on the flow of the methodology used throughout this project. The design of the sensor will be carried out using RSoft Beamprop software.

Chapter 4 provide the simulation result and discussion on the findings. The comparison of sensitivity among the sensors will be illustrated using graph.

Chapter 5 include the conclusion of the project and recommendation of the future work.

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