EPOXIDIZED NATURAL RUBBER 50 POLYMER COATED FBG SENSOR FOR PRESSURE APPLICATIONS

By

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LIST OF ABBREVIATIONS

Db	Decible
ENR50	Epoxydized Natural Rubber
FBG	Fiber Bragg Grating
FS	Full scale
FTIR	Frustated Total Internal Reflection
LVDT	Linear Variable Differentiation Transmitter
MEMS	Microelectromechanical System
NR	Natural Rubber
OSA	Optical Spectrum Analyzer
Pa	Pascal
RH	Relative Humidity
SLED	Single Light Emitting Diode
UV	Ultraviolet

LIST OF SYMBOLS

º	Degree
%	Percentage
F	Force
A	Area
L_O	Original Length
L_n	New Length
ε	Strain
d	Depth
v	Poisson Ratio
E	Young Modulus
m	mass
g	gravity
ʌ	grating
λ_B	Bragg wavelength
$\Delta\lambda_B$	Bragg wavelength shift
n_{eff}	Effective refractive index
K	Gauge factor

P	Pressure
ρ	Density of fluid
ΔP	Pressure change
ρ_e	Photo elastic coefficent
ρ_{11}	Strain Optic tensor strain
ρ_{12}	Strain Optic tensor strain
h	Height
N	Newton

ABSTRAK

Pegesan Fiber Bragg Grating (FBG) bersalut ENR50 adalah hampir menjadi pilihan terbaik yang memenuhi keperluan ciri-ciri sebuah pengesan tekanan. Pengesan tekanan yang konvensional tidak dapat mengukur dengan sangat tepat, disamping terdedah dengan kuasa elektromagnetik, tenaga electrik yang tidak stabil dan penyambungan kabel yang terlalu banyak. Pengesan Fiber Bragg Grating (FBG) mempunyai saiz yang kecil, rintangan yang rendah, cepat bertindak balas, imuniti kepada gangguan elektromagnetik, boleh digunakan dalam persekitaran berbahaya, dan mempunyai sistem yang fleksibel. Walaubagaimanapun, sifat semulajadi FBG yang rapuh agak berbahaya jika digunakan tanpa mempunyai salutan atau pembungkusan yang baik. Oleh itu, ENR50 telah dipilih di dalam penyelidikan in memandangkan ianya juga mampu untuk meningkatkan sensitiviti pengesan FBG.ENR50 menjadi calon terbaik di dalam penyelidikan ini kerana ia mempunyai Poisson's ratio dan Young Modulus yang rendah yang membawa maksud ianya lebih fleksibel dan tidak terlalu keras. Analisis secara teori dan eksperimen dijalankan untuk menyiasat prestasi ENR50 sebagai pembalut pengesan FBG.Oleh itu, nisbah peningkatan sensitiviti diantara keputusan sensitiviti eksperimen dan teori telah dikira. Di samping itu, nisbah perbezaan sensitiviti secara teori untuk nilai sensitiviti pengesan FBG bersalut ENR50 dan FBG yang asal juga dikira. Prestasi pengesan FBG bersalut ENR50 terhadap aplikasi tekanan juga dikaji seperti berat dan kedalaman air untuk mengetahui yang aplikasi yang paling sesuai diukur menggunakan pengesan ini. Keputusan teori menunjukkan bahawa pengesan FBG bersalut ENR50 telah meningkatkan sensitiviti pengesan FBG asal sebanyak 4.146 x 10^5 untuk aplikasi berat dan 4.11 x 10^5 untuk aplikasi kedalaman air dan ini sekaligus membuktikan pengesan FBG bersalut ENR50 dapat meningkatkan sensitiviti pengesan FBG yang asal. Walaubagaimanapun, keputusan eksperimen tidak dapat menjadi sebaik keputusan teori kerana terdapat beberapa kekangan ketika eksperimen dijalankan seperti ketepatan nilai tekanan yang diberikan yang dibuat berdasarkan formula fizik tidaklah setepat niali tekanan yang diberikan oleh kebuk tekanan. Oleh itu, nilai sensitiviti teori menunjukkan ianya 5.313 x 10^{13} lebih tinggi daripada nilai sensitiviti eksperimen untuk aplikasi berat dan 5.2916 x 10^{15} untuk aplikasi kedalaman air. Secara kesimpulannya, teori telah membuktikan bahawa pengesan FBG bersalut ENR50 dapat meningkatkan sensitiviti pengesan FBG yang asal sebanyak 4.11 x 10^5 hingga 4.146 x 10^5 kali ganda tetapi untuk eksperimen, pelbagai penambahbaikkan perlu dilakukan untuk mencapai nilai sebaik teori.

ABSTRACT

ENR50 Polymer coated Fiber Bragg Grating sensor is almost a perfect choice for satisfying requirement characteristic of pressure sensor. The conventional pressure transducers are not too precise in measurement, besides being highly exposed to electromagnetic interference, power fluctuations and has complicated cabling. FBG sensor shows that it has small size, low attenuation, quick response on time, immunity to electromagnetic interference, safety in hazardous environment, and flexible configuration. However, the nature of frangible of FBG sensor is quite dangerous without packaging and coating. Therefore, the ENR50 polymer selected in this study to be a coating as it also can enhances the sensitivity of FBG sensor. ENR50 becomes a good candidate in this research because it has lower Poisson Ratio, v and Young Modulus, E which means it more flexible and less stiffness. Theoretical and experimental analysis was done to investigate the performance of ENR50 as FBG's coating. Thus, the ratio sensitivity enhanced between the theoretical and experimental result of sensitivity was calculated. Beside, the ratio differentiation sensitivity of theoretical of ENR50 polymer coated FBG with bare FBG was also calculated. The performance of ENR50 coated FBG for type of pressure applications such weight and level or depth also analyzed to investigate which type of pressure applications more compatible with this kind of sensor. Theoretical result shows that ENR50 coated FBG was enhanced the sensitivity of bare FBG about 4.146 x 10^5 times higher for weight applications and 4.11 x 10^5 times higher for level or depth application, and this totally proved that ENR50 polymer can enhance the sensitivity of FBG bare sensor. However, experimental result not achieves the theoretical expectation due to the some limitations in the experimental setup such as the accuracy of value pressure given based on physics calculation is not as accurate compared to pressure value from the pressure chamber. So, the theoretical result shows that it was 5.313 x 10^{13} times higher than the experimental result for weight application and 5.2916 x 10^{15} times higher for level or depth applications. As conclusion, theoretically, it was proved that ENR50 can enhances sensitivity of FBG sensor for about 4.11 x 10^5 to 4.146 x 10^5 times higher, but experimentally, there some improvements need to be done in the experimental setup to achieve as per theoretical results.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Pressure sensors can be defined as a device which senses pressure and converts it into an analog electric signal whose magnitude depends upon the pressure applied. Since the device convert the pressure into an electrical signal, it was also termed as pressure transducers. Pressure sensors are used for controlling and monitoring in thousands of every day applications. It is a key technology for the safe operation of different technical products, systems and technologies. Pressure sensors can be classified according to four types of sensors which are optical, electronic, mechanical, and Microelectromechanical systems (MEMS) sensors.

A traditional pressure sensor has very limited usage in heavy industrial environments, particularly in explosive or electromagnetically noisy environments. Utilization of optics in these environments eliminates all surrounding influences. The main benefit of this solution consists of increasing sensitivity, low attenuation, immunity to electromagnetic interference, small size, flexible configuration, lightweight, quick response of time, chemically inert, and safety in hazardous environments (anti corrosion and absence of sparks sources hazard for flammable and explosive environments) (D. R. Sparks,1998).

Wavelength modulated fiber sensor happens when light moves from a medium of a given refractive index, n_1 into a second medium with refractive index, n_2. Thus, both reflection and refraction may occur. Consequently when another region or different refractive index is introduced inside an optical fiber which already has different refractive indexes in the core and cladding, reflection of light can occur. The new region with a different index of refraction from the core and cladding is known as Bragg Grating.

Fiber Bragg Grating (FBG) has many types of structures such as uniform and chirped structure, but the most important aspect is that it has constant pitch that will reflect certain incoming wavelengths to yield Bragg wavelength.

A coating is needed on the FBG pressure sensor as fiber will affect the pressure given. Epoxidized Natural Rubber 50 (ENR50) is a good candidate material as it has lower Young's Modulus and Poisson's ratio compare to another polymer. It also had stiffness compare to natural rubber so it is more suitable to be used compared to natural rubber even natural rubber show the lowest poisson ratio. This means that the material is a type of rubber that can assist the FBG sensor to improve the sensitivity of results.

In order to accomplish the investigation on FBG sensors towards pressure applications, there are three main pressure applications which are pressure due to weight, and level or depth. Pressure due to weight application expressed that weight is directly proportional to the pressure applied. So this sensor can be used to measure weight of objects. Lastly, pressure due to level or depth can also be measured because different depth of water has different value of pressure. Therefore, it is not only useful to detect the depth of water but it can also be used to detect altitude.

In this research, how FBG acts as a pressure sensor and provide many benefits in terms of various aspects were studied. The technique that has been formed for each applications and the level of sensitivity were investigated. A study to compare the theoretical performance of bare and coated FBG was done to investigate the optimal condition of FBG as a pressure sensor. An experimental was also conducted to investigate the performance of ENR50 as the coating material for FBG pressure sensors. The main motivation of this research is to prove that ENR50 can act as a protection and sensitivity enhancer for FBG pressure sensors. The result of the experimental then will be compared to the theoretical results.

1.2 Problem statements and motivation

The existing pressure transducers are not too precise in measurement, besides being highly exposed to electromagnetic interference and power fluctuations. Most transducers require complicated cabling which is not suitable for the pressure sensor application. Pressure sensors are usually applied in harsh environment applications such as oil and gas industry, power plants, train sites and river streams (Aulakh, N. S., 2010).

Mainly three technologies are currently commercially available for pressure measurement with fiber-optic sensors which are based on intensity, phase modulated and wavelength modulated (Eric Pinet, 2011). The first one is probably the simplest and cheapest but it is limited to applications where having 2 fixed or up to 4 flexible fibers, whereas the two other technologies require only one fiber. The intensity based sensor had risk which the reflectivity of target can be alter relative position of the transmitting and receiving fibers in relation to the target which means this type of sensor is quite not too robust for high pressure application (Suhairi Saharuddin, 2016).

Phase modulated based sensor such as Fabry-Perot system can provide higher accuracy, the interrogation system and the sensor design are sophisticated, but the cost is unaffordable.

Wavelength modulated based pressure sensor which is Fiber Bragg Grating pressure sensors are still limited to marginal applications as it was had no higher accuracy. However, with applied the polymer coating on the fiber Bragg Grating sensor, the sensitivity of this sensor enhanced for a lot compared to the bare one. The nature of the frangible FBG also quite dangerous if it is applied without coating or packaging. Thus, the coating or packaging that can enhance the sensitivity of FBG sensors is the most important criteria to produce a good sensor. There are researches in this field which shows the importance of coating as protector and sensitivity enhancer towards FBG sensors (Indu, F. S., and Kaleo, H.,(2010) ; Saidi, P. et. al. (2011) ; Yun Q. L. (2000)).

There are several types of pressure applications such as weight and level or depth. The problem is most researches were done the experimental by directly using the pressure chamber. Because of that, there is no record of sensitivity comparisons for pressure sensor applications. This comparison is an important criterion that can show the ability of FBG sensors towards type of applications. Thus, with the comparison of sensitivity for each type of applications, the performance of every pressure applications can be analyzed and the suitability to choose FBG sensors as a pressure measurement device can be determined.

This project tries to solve this entire problem by proposing sensitivity investigations towards ENR50 as the polymer coating for FBG sensor and their performance on each application for pressure sensor measurement. This project will take into account the type of FBG coating material that can enhance the sensitivity of pressure sensors. The type of material or polymer were chosen by considering the value of Poisson's ratio and Young Modulus because low Poisson ratio and Young Modulus materials can enhance the sensitivity of pressure sensors. After the ENR50 polymer was decided to be choose, theoretical and experimental measurements have been done to investigate the performance of these sensors.

Fundamental equation of Bragg grating formula is used before it will be modified by inserting the value of Young Modulus,E and Poisson ratio,v into the equation (Ying Zhang et. al. , 2001). With this equation, the theoretical sensitivity of coated FBG sensors can be yielded. The equation for bare FBG had also been measured as a reference line to get the percentage of its sensitivity enhancement.

The problem statements of this research can be conclude as follows:

1.2.1 The mechanical pressure transducer are not precise in measurement.

1.2.2 Electronic transducer is expose to electromagnetic interference and power fluctutations and not suitable to be apply in the harsh environment.

1.2.3 MEMS pressure transducer sensitive to electromagnetic interference and the environmental temperature was limited.

1.2.4 Intensity modulated based optical pressure sensor had complicated cabling as it need 2 fixed or up to 4 flexible fibers.

1.2.5 Phase-modulated based pressure sensor was unaffordable in term of cost.

1.2.6 Bare FBG is frangible in nature and had low sensitivity.

1.3 Objective of the Research

Due to the problems discussed, the research to study the performance of ENR50 coated FBG sensor was done and compared with the bare FBG sensor. Then, the performance of ENR50 coated FBG was analyzed towards a few of pressure applications which os weight and level/depth.

The objectives of this research can be concluded as follows:

1. To design an ENR50 polymer coated FBG sensor tetsbed.
2. To compare the performance of ENR50 coated FBG sensor towards the bare FBG sensor through theoretical and experimental work.
3. To analyze the performance of ENR50 coated FBG for pressure applications which are weight and level or depth.

1.4 Thesis Organization

This paper consists of five chapters. Chapter 1 gives overview to the thesis title, ENR50 Polymer Coated for FBG Sensor towards Pressure Applications in a brief introduction. Problem statement and motivation, objectives, scopes of the thesis were also explained as well as the flow of this research project.

Chapter 2 details the literature review on pressure sensor systems that include the types of existing pressure sensors and their examples. Types of optical pressure sensors were also discussed to differentiate their methods with the FBG measurement method. A brief history background on FBG pressure sensor and previous research on the effectiveness