INTRINSIC OPTICAL FIBER TEMPERATURE AND STRAIN SENSOR FOR STRUCTURAL HEALTH MONITORING OF CONCRETE STRUCTURE

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In the name of Allah, the Most Merciful and the Most Beneficent

This thesis is dedicated to my mother and families. By their endless love, support, and prayers I have been blessed with position and higher education I have earned. May Allah grant them a blessed and happy life on this earth and hereafter.

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ABSTRACT

Structure failure in civil engineering has been a motivation behind the development of monitoring system where it provides analytical data for evaluating the performance of building's structure, highway bridge, tunnel, etc., in order to minimize the risk of engineering disaster that would endanger public’s safety and property. Fiber Optic Sensor (FOS) has been extensively studied and used since its first discoveries. However, erroneous in measurement due to cross-sensitivity of FBG is the main drawback for this sensing principle. Therefore, cascaded FBGs are developed to monitor temperature and strain. Another drawback of FBG toward temperature is it has poor thermal expansion properties. Thus, an analytical temperature model of FBG that able to enhance temperature sensitivity is developed and realized by coating the FBG with metal material that has good thermal expansion coefficient. The metal coating of FBG is done using electroless plating as this method is simpler and low cost.

ABSTRAK

Kegagalan struktur dalam kejuruteraan awam telah menjadi motivasi di sebalik pembangunan sistem pemantauan di mana ia menyediakan data analisis untuk menilai prestasi struktur bangunan, jambatan lebuh raya, terowong, dan sebagainya, untuk meminimumkan risiko bencana kejuruteraan yang akan membahayakan keselamatan awam dan harta benda awam. Sensor Fiber Optic (FOS) telah banyak dikaji dan digunakan sejak pertama kali ditemui. Walau bagaimanapun, salah pengukuran disebabkan oleh sensitiviti silang FBG adalah kelemahan utama untuk prinsip penderiaan ini. Oleh itu, FBGs dibangunkan untuk memantau suhu dan ketegangan. Satu lagi kelemahan FBG ke suhu adalah ia mempunyai ciri pengembangan haba rendah. Oleh itu, model suhu analitik FBG yang dapat meningkatkan kepekaan suhu dikaji dan direalisasikan dengan melapisi FBG dengan bahan logam yang mempunyai pekali pengembangan haba yang baik. Lapisan logam FBG dilakukan menggunakan penyaduran elektrolisis kerana kaedah ini adalah lebih mudah dan kosnya yang rendah,

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LIST OF ABBREVIATION

FOS	-	Fiber Optic Sensor
FBG	-	Fiber Bragg Grating
LPG	-	Long Period Grating
SHM	-	Structural Health Monitoring
AE	-	Acoustic Emission
MEMS	-	Micro Electromechanical System
RFID	-	Radio Frequency identification
EPFI		Extrinsic Fabry-perot interferometric
EDFA	-	Er-droped fiber amplifier
OSA	-	Optical Spectrum Analyzer
OTDR	-	Optical Time Domain Reflector
CFBG	-	Chirped Fiber Bragg Grating
TFBG	-	Tilted Fiber Bragg Grating
SMS	-	Single-Multi-Single
SMF	-	Single Mode Fiber
UV	-	Ultraviolet
RI	-	Refractive Index
FWHM	-	Full Width Half Maximum
ASE	-	Amplified Spontaneous Emission
SLSR	-	Sidelobe suppression ratio

LIST OF SYMBOLS

λ_{res}	-	Resonance wavelength
n_{co}	-	Core refractive index
n_{cl}^{m}	-	Refractive index of the effective m^{th} cladding mode
Λ	-	Grating period
λ	-	Wavelength of light
λ_{FWHM}	-	Wavelength of FWHM
λ_{B}	-	Bragg wavelength
S	-	Strength of reflection grating
N	-	Number of grating planes
L_{FBG}	-	Length of grating
η	-	Thermo-optic coefficient
α	-	Thermal expansion of silica
T	-	Temperature
n_{eff}	-	Effective refractive index
ρ_{e}	-	Photo-elastic coefficient
ε_{z}	-	Longitudinal strain

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

In the field of civil engineering, fiber optic sensor (FOS) is widely used in early detection of structural failure such as a crack in a concrete structure. Crack on the concrete structure will develop due to thermal expansion and contraction when exposed to changes in temperature. Naturally, it will expand when the material is experiencing o hot temperature and contract when the temperature is colder. This crack development will lead to structural failure. FOS also has been used widely in another field such as biomedical, agriculture, chemical and automatic fire detection [1].

Features of FOS such as immune to the electromagnetic field, stable signal, robustness to a harsh environment and its compact size make this technology superior to other sensor technique. Fiber Bragg grating (FBG) is well known in its sensor application. It requires no calibration, length limit due to very small losses in optical fiber, passive technology, and long-term stability [2]. In this study, FBG, a type of grating-based FOS is used over another type of grating-based sensor configuration as FBG is simple inherent self-referencing capability, easily multiplexed and able to provide real-time monitoring.

1.2 Problem Statement

Recently, there are many engineering disasters has been reported. Some incident may have put many lives in stakes and has taken lives, such case like St. Francis dam where it broke and killed more than 432 sleeping residents [3]. Curing for concrete at its early age is a maintenance method in order to maintain adequate moisture and temperature in concrete to prevent cracking from developed. Which explain what happened to St. Francis dam where cracks were developed under the heat generated by the hydration of the cement. Furthermore, the heat generated by curing causes thermal stresses and of shrinkage of the mass concrete leading to further cracking and without early preventive action taken to cool down the concrete, this fateful event was allowed to take place.

Structural Health monitoring (SHM) application provides real-time inspection, monitoring, and damage detection and all together will provide an early warning to the responsible management to tackle the problem. Leakage in pipelines, tunnel sewerage leakage, cracks in the concrete structure, failing geotechnical infrastructure such as landslide can be monitored through a variety of techniques of fiber optic sensor (FOS) technique has been implemented.

Conventional techniques that are bulky, circuitry and electrical based possess many disadvantages such as prone to electromagnetic and electrical interference, hence the signal is not stable and also make them difficult to be implemented in a harsh environment. These drawbacks make FOS superior as it is immune to electrical and electromagnetic interference and its small in size makes this technology easy to be implemented and withstand in a harsh environment.

1.3 Motivation of the Study

In the field of civil engineering, there are many reported cases of engineering failure. There are few primary reasons for engineering disaster which are human factors, design flaws, material failure, extreme conditions or environments and most commonly and importantly the combination of these reasons. According to a research conducted by Swiss Federal Institute [4], a total of 800 cases of structural failure that killed 504 people, 594 people injured and total damage of million dollars.

The research concluded that the causes of structural failure were human errors in many aspects such as lack of knowledge, ignorant and carelessness, underestimation of influence, forgetfulness and relying upon others. Therefore, it is engineer duties to ensure the safety and durability of the project for the benefit of the company, civilian and workers. The aim of this research area is to develop FBG sensor that will provide real-time critical data for evaluating concrete performance derive from temperature and strain variances.

1.4 Objectives of the Study

This is study aim to develop dual FBG sensors, to measure strain optic coefficient and thermal sensitivity. Therefore, this study underlines the following key objectives:

1. To develop analytical temperature and strain model of FBG as sensor.
2. To determine the characteristic and capability of the proposed FBG sensor in response to the different temperature and strain variation at various wavelength shift.
3. To develop cascaded FBGs to overcome cross-sensitivity of FBG

1.5 Scope of the Study

In this paper, fundamental of FBG sensing principle, the behavior of metal coated FBG toward temperature and strain and preventive method for cross-sensitivity of FBG are discussed. The main goal of this paper is to develop a temperature model of FBG, aiming to enhance its temperature sensitivity which attributes to greater wavelength shift towards changes in temperature. This can be done by coating the FBG with metal material that has good thermal expansion coefficient.

This study is also conducted to overcome the main drawback of fiber Bragg grating which is cross-sensitivity as it may cause inaccurate judgment of interest parameter which is temperature and strain. This can be done by cascading two FBGs with two different center Bragg wavelengths with one FBG monitoring temperature while the other monitoring strain. Furthermore, a comparative experimental study is carried out between metal coated FBG and bare FBG in order to study the behavior of FBG after metallization.

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