LEAKY MODE EXPANSION FOR OPTICAL FIBRE SENSOR APPLICATION

FOUZIYAH ABDULSALAM HAMID ALQAZOUIN

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Faculty of Engineering
Universiti Teknologi Malaysia

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DEDICATION

Specially dedicated to,

My father and mother, who are always praying for my success, as well as my beloved family, who has accompanied me throughout my struggle and success.

To my supervisor, who has helped, inspired, motivated, and advised me during this project,

Thank you to all of my friends who have helped me.

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ABSTRACT

A multimode interference (MMI) based sensor for high refractive index sensing was proposed and demonstrated in this simulation work. The proposed sensor scheme works by a mode expansion according to leaky modes instead of traditionally used radiation modes. The simulation work tried to exhibit whether and how light delivered multimode interference before it worn out. The MMI structure that was used in the simulation consists of a Single-mode-Multimode-Single-mode (SMS) fibres configuration. In this structure, the multimode fibre (MMF) segment was assumed to have only the core while the cladding was discarded and has a specific length. This work exhibited high refractive index (RI) sensing based on the Guided-mode-Leaky-mode-Guided-mode (GLG) structure or the SMS fibre structure previously cited by comprehending the fundamental theories of leaky mode expansion. The work also attempted to analyse the effects of important parameters of leaky mode expansion on sensing performances such as length and diameter of MMF, and changing value of surrounding refractive index. The simulation work was performed utilising BeamProp software to ascertain the needed power intensity and RI sensitivity to excite light into the MMF for detection. The economical and simple sensor structure is ideal in numerous applications, including for detection, diagnosis, health determination, safety, environmental, liquid food, and water quality control.

ABSTRAK

Karya simulasi ini mencadangkan dan menunjukkan sensor berasaskan gangguan multimode (MMI) untuk pengindeksan indeks biasan tinggi. Skema sensor yang dicadangkan berfungsi melalui pengembangan mod berdasarkan mod kebocoran dan bukannya mod radiasi yang digunakan secara konvensional. Kerja simulasi cuba menunjukkan sama ada dan bagaimana cahaya memberikan gangguan multimode sebelum usang. Struktur MMI yang digunakan dalam simulasi terdiri daripada konfigurasi gentian mod tunggal-multimode-mod-tunggal (SMS). Dalam struktur ini, segmen serat multimode (MMF) dianggap hanya mempunyai inti sementara pelapisannya dibuang dan mempunyai panjang tertentu. Karya ini akan menunjukkan penginderaan indeks biasan tinggi (RI) berdasarkan struktur berpandu-mod-bocor-mod-berpandukan (GLG) atau struktur gentian SMS yang disebutkan sebelumnya dengan memahami teori-teori asas pengembangan mod kebocoran. Karya ini juga berusaha untuk menganalisis kesan parameter penting pengembangan mod kebocoran pada persembahan penginderaan seperti panjang dan diameter teras MMF, dan perubahan nilai indeks biasan sekitarnya. Kerja simulasi dilakukan menggunakan perisian BeamProp untuk menentukan intensiti daya yang diperlukan dan kepekaan RI untuk memancarkan cahaya ke MMF untuk penginderaan. Struktur sensor kos rendah dan sederhana diperlukan dalam banyak aplikasi termasuk untuk pengesanan, diagnosis, dan penentuan kesihatan, keselamatan, persekitaran, makanan cair, dan pengendalian kualiti air.

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LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
RI	-	Refractive Index
FBG	-	Fibre Bragg Grating
LPG	-	Long Period Grating
SMF	-	Single Mode Fibre
SMS	-	Single mode Multimode Single mode
MMF	-	Multi-Mode Fibre
GLG	-	Guided mode Leaky mode Guided mode
MMI	-	Multi-Mode Interference
FOS	-	Fibre Optic System
TIR	-	Total Internal Reflection
EMI	-	Electro Magnetic Interference
LMF	-	Leaky Mode Fibre
BPM	-	Beam Propagation Method

LIST OF SYMBOLS

n_1	-	Refractive index for the core
n_2	-	Refractive index for the cladding
W_m	-	Wavelength of the multimode waveguide
W_s	-	Wavelength of the single mode waveguide
L	-	Length of the multimode waveguide
l	-	Orbital momentum of light
p	-	Number of radials mode oscillations
β	-	Propagation constant
n_{eff}	-	Profile and effective index
c	-	Vacuum light speed
u	-	Normalize transverse phase
w	-	Attenuation constant
M	-	Number of guided modes
w_0	-	Spot size
β_0	-	Longitudinal propagation constant
a	-	Radius of SMF
E_{in}	-	Input light in SMF
E_m	-	The field profile of the MMF's mth eigenmode
m	-	Number of guided modes in the MMF
c_m	-	Excitation coefficient
v	-	Index suffix for the guided radial
μ	-	Index suffix for the azimuthal elements
$\beta_{v,\mu}$	-	Propagation constant for step index mmf of mth modes
β_m	-	The phase constant of mth excited leaky mode in the MMF
$\propto_m$	-	The attenuation constant of mth excited leaky mode in the MMF
T_{out}	-	The normalize output intensity

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Refractive index (RI) are required for some applications in the fields of biomedicine, biochemistry, processing manufacturing control, food industry quality control, and ecosystem safety, where exact estimations of the centralizations of various analytes are required [1]. A wide range of optical fibre-based sensing techniques have been proposed. Due to their susceptibility to electromagnetic interference, minimised size, conceivably minimal expense, and the capability of distributed measurement over long distances, optical fibre sensors can become tremendously powerful and flexible devices. RI sensing can be applied in various ways, for instance using a fibre Bragg grating (FBG)[2], a long-period grating (LPG), a macro-bend single-mode fibre (SMF), a surface plasmon resonance, a Fabry-Perot interferometer, a multi-D-shaped optical fibre, or a single mode-multimode-single mode (SMS) fibre structure. An optical sensor on an SMS fibre structure has the extra advantages of minimal expenses and simple assembling. External interruption may affect the multimode interference between modes in the multimode fibre (MMF). It is the basic operation of sensors in SMS fibre structures. So far, most RI sensor functions have focused on using the modal interference in the fully coordinated mode to estimate the surrounding IR below the multimode fibre core. If the surrounding RI is greater than the RI of the multimode fibre core instead of guided modes, the multimode fibre part will become a leaky waveguide that promotes progressive spectrum radiation modes. Instead of having multimode interference, the leaky structure conventionally defined that the light would leak out [3].

Although there is a leaky of light along the transverse direction, the light spreads with attenuate amplitude along the longitudinal direction. This system is called a guided-mode-leaky-mode-guided-mode (GLG) fibre structure with such a leaky mode expansion in the multimode fibre.

1.2 The Motivation of the Study

Recently, a single mode-multimode-single mode (SMS) fibre optic sensor has been employed to measure changes in refractive index. With the expanding research attempts to find various additional detecting plans and strategies that could be gained from simple optical fibre structures, SMS fibre contributes to improving certain sensor applications with its simple design. This study demonstrated the improved performance sensitivity of the SMS fibre analytical design based on the multimode interference (MMI) through a theoretical study of leaky mode approximation for modal expansion in the optical fibre structure.

1.3 Problem Statement

Several methods have been used to achieve RI sensing, such as using sensing elements as a long-term grating (LPG) or Bragg grating with etched fibre, based on leaky mode expansion (FBG). These two approaches have their downsides that the fibre grating requires precise manufacturing procedures, high costs, and not so good sensitivity. On the other hand, the leakage modes, especially those used in long distances, do not fully leak through the optical fibres, and this increases the attenuation and thus, the lower sensitivity and the leakage loss in the fibre structure are greater.

Furthermore, in view of the MMI occurring within the SMS fibre structure, the traditional SMS working principle has been used to obtain sensing capabilities. However, due to the cladding of the multimode fibre (MMF), the structure of the SMS fibre limits the sensing sensitivity. The sensing principle of most fibre optic sensors (FOS) is achieved by interfering with changes in the refractive index within the environment. However, the guided modes wrapped within the MMF render the fibre insensitivity to changes in the surrounding refractive index and result in negligible influence of the MMI.

For that reason, the refractive index sensor dependent on unique MMF without cladding is the alternative solution, which has various applications, including high refractive index sensing applications. In order to make the light waves propagating in the MMF completely internally reflected, the surrounding environment was used as a cladding layer. As a result, changes in the refractive index of the surrounding medium would have a direct impact on the MMI effect.

1.4 Project Goal

This project focused on developing a leaky mode expansion theoretical research model to enhance leaky mode structure analysis. Since the surrounding refractive indexes (RIs) are higher than the RIs of the silica fibre, the present researcher's concern was on the transmission criteria of the SMS structure. Moreover, as it studied optical waveguides, this project greatly verified the efficacy of analogous leaky mode expansion.

1.5 Project Objectives

a) To understand the underlying theories of leaky mode expansion.
b) To apply leaky mode expansion for high surrounding refractive index sensing application.

c) To analyse the effects of important parameters (length and diameter of MMF core, and changing value of surrounding refractive index) of leaky mode expansion and fibre optic sensor structures on sensing performances using Beam Prop software.

1.6 Scope of Project

(a) To drive theories of leaky mode expansion on guided-mode-leaky-mode-guided-mode GLG fibre structure.

(b) To use Beamprop software in simulating normalised output intensity of the SMS structure with several surrounding RIs around multimode fibre core.

1.7 Thesis Outline

This thesis is organised into five chapters, each of which covers and examines the literature study, the overall evolution of the project, and its implementation.

The first chapter of the project describes the project's introduction. This chapter offers an overview of the project history, issue description, goals, and scope of activity.

Chapter 2 discusses the project's literature review, which includes the various types of fibre optics and light propagation.

Chapter 3 looks at the flow of the method utilised throughout this project. The sensor design was created using RSoft Beamprop software.

The simulation results, as well as a discussion of the findings, are provided in Chapter 4. The sensitivity differences between the sensors are depicted using a graph.

Chapter 5 contains the conclusion and recommendations for further study.

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