CHARACTERIZATION OF FIBER OPTIC SENSOR FOR LIQUID REFRACTIVE INDEX MONITORING

DIANAY SHAFINA BINTI SHAFEI

UNIVERSITI TEKNOLOGI MALAYSIA

CHARACTERIZATION OF FIBER OPTIC SENSOR FOR LIQUID REFRACTIVE INDEX MONITORING

DIANAY SHAFINA BINTI SHAFEI

A thesis submitted in fulfillment of the
requirement for the award of degree of
Master of Science (Physics)

Faculty of Science
Universiti Teknologi Malaysia

MARCH 2015

Special dedication for my beloved mother, father, brother, sister and husband. May Allah shower his blessings to all of us.

Amin.

ACKNOWLEDGEMENT

In the name of Allah, Most Gracious, Most Merciful. Praise be to Allah, the Cherisher and Sustainer of the worlds. For His Mercy has given me the strength and time to complete this project.

I would like to express my appreciation to my respected supervisors, Dr. Asiah binti Yahaya and Dr. Raja Kamarulzaman bin Raja Ibrahim for their supervision, guidance, enjoyable discussion and motivation throughout this study. Besides, I have much pleasure to those who have assisted me in various ways in carrying out the experimental works. There are my lab technicians, Mr Nasir bin Abu Bakar, Mr Asmawi and also the researcher's group in Advanced Photonics Science Institute (APSI).

My thanks are also due to Government of Malaysia through Research Student Grant (RSG) vote Q.J130000.2626.07J69 for giving us financial support.

Last but not least, my appreciations go to my beloved family and my all best friends for continuing support, patience throughout the present work and who have favored me with correspondence, I have much pleasure in expressing my obligation. May Allah bless those who have involved in this project.

ABSTRACT

This research was conducted to characterize the fiber optic sensor for liquid refractive index monitoring. The sensor system consists of a light source, a 2x2 single mode fused fiber coupler of different coupling ratios and a detector. Diode laser operating at wavelength 1300 nm and 1550 nm was used as a light source. Fresnel's Law of reflection from the fiber-air and fiber-liquid interface was the fundamental of this work. The total reflected light intensity from both coupler outputs was measured in terms of its power. A simple test on the feasibility of the sensor for this type of measurement was conducted and it was found that this sensor was sensitive enough and has a reasonable working range to work with. The refractive index of a solution is a function of its concentration, temperature and also the wavelength of the incident light. In this work the relation of these parameters were investigated. The solution of NaCl was selected as a liquid sample. Various concentrations of salt solution ranging from 0 % - 24 % were tested and were heated from 30 ºC - 90 ºC to observe the change in refractive index. The results revealed that the refractive index of liquid solutions varies linearly with its concentration and temperature. Performance of the sensor system by using single mode fused fiber coupler with different coupling ratio was studied. It was observed that the fiber coupler with 50:50 indicated the highest sensitivity to be used in this sensor system.

ABSTRAK

Kajian ini telah dijalankan untuk mencirikan pengesan gentian optik untuk mengukur indeks biasan cecair. Sistem pengesan terdiri daripada sumber cahaya, 2x2 gentian pengganding mod tunggal dengan nisbah gandingan yang berbeza dan alat pengesan. Diod laser dengan panjang gelombang 1300 nm dan 1550 nm telah digunakan sebagai sumber cahaya. Hukum pantulan Fresnel di antara muka gentian-udara dan gentian-cecair adalah asas kepada kajian ini. Jumlah keamatan cahaya terpantul dari kedua-dua output pengganding telah diukur berpandukan kepada kuasanya. Suatu ujian yang mudah mengenai kesesuaian pengesan untuk jenis pengukuran ini telah dijalankan dan didapati bahawa pengesan ini sensitif dan mempunyai tahap kebolehan yang sesuai untuk dijadikan pengesan. Indeks biasan cecair adalah fungsi kepada kepekatan, suhu dan juga panjang gelombang sumber cahaya yang digunakan. Dalam kajian ini, hubungan diantara parameter ini telah dikenalpasti. Cecair NaCl telah dipilih sebagai sampel cecair. Larutan NaCl yang mempunyai pelbagai kepekatan dari 0 % - 24 % telah diuji dan larutan tersebut telah dipanaskan dengan suhu dari 30 ºC - 90 ºC untuk melihat perubahan indeks biasan. Keputusan menunjukkan indeks biasan cecair berubah secara linear dengan kepekatan dan suhu cecair. Prestasi sistem pengesan dengan menggunakan gentian pengganding mod tunggal yang mempunyai nisbah gandingan yang berbeza telah dibandingkan. Keputusan menunjukkan gentian pengganding yang mempunyai nisbah gandingan 50:50 mencatat kepekaan yang paling tinggi untuk digunakan di dalam sistem pengesan ini.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

n	-	Refractive index
c	-	Speed of light in vacuum
v	-	Speed of light in medium
I	-	Incident ray
θ_i	-	Angle of incident
θ_r	-	Angle of reflection
θ_t	-	Angle of refraction
n_1	-	Refractive index of medium 1
n_2	-	Refractive index of medium 2
R	-	Reflectance
T	-	Transmission
R_S	-	s-polarized light
R_P	-	p-polarized light
μ	-	Permeability
μ_o	-	Vacuum permeability
P_{out}	-	Output power
P_{in}	-	Power input
L	-	Length oh the interaction region
κ	-	Coupling coefficient

dB	-	Decibel
P_{excess}	-	Excess loss
Si	-	Silicon
Ge	-	Germanium
InGaAs	-	Indium Gallium Arsenide
C	-	Concentration
T	-	Temperature
λ	-	Wavelength
V_g	-	Group velocity
β	-	Propagation constant
ω	-	Radian optical frequency
n_f	-	Effective index
n_g	-	Group index
ε	-	Optical dispersion
mV	-	Milivolt

LIST OF ABBREVIATIONS

EMI	-	Electromagnetic interference
CR	-	Coupling ratio
IL	-	Insertion loss
D	-	Directivity
RL	-	Return loss
FBT	-	Fused biconical taper
LED	-	Light emitting diode
SLD	-	Superluminescent diode
OPM	-	Optical power meter
NIST	-	National Institute of Standards and Technology
FBG	-	Fiber brag grating
RI	-	Refractive index
IMG	-	Index matching gel

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Optical sensing can be described as a field of optoelectronics that has used optics and electronics to sense variations in physical quantities through their interaction with optical signals (A. H.Morshed, 1999). Generally, this field was focused on military and aerospace usages during the late 1970s. Nowadays, improvement of optical sensors and fiber optic sensors are been revolutionized with the development of optical device invention and the proliferation of sensing applications. The rapid development in the field of fiber optic sensors is mainly due to the flexibility in the application of optical fiber in a various industries.

The rapid development of optical fiber-based sensing is due to it has several advantages like small size, light weight, immunity to electromagnetic interference (EMI), high temperature performance capability, environmental ruggedness, large bandwidth, and the capability of distributed sensing (David R.G,2004). Optical fiber for sensing applications are used to communicate with a sensor device or use a fiber as the sensor itself to conduct monitoring of physical, biological and chemical properties, changes in the subject or object of study. In optical fiber sensors, information is primarily conveyed in all optical sensors by a change in phase, frequency(wavelength), polarization or intensity depend on it modulation mechanism.

1.2 Background of the Study

Today, the revolution in optoelectronic industries has enabled the development of fiber optic sensor that offers a series of advantages over conventional electronic sensors (E.Udd, 2006). This development, in combination with advances in the industrial control process technology, has opened the new field of fiber optic sensor in many field of application to the world. By dealing with a simple monitoring system that only use optics and electronics device, it can function as a good sensor to detect variation in physical quantities of interest such as refractive index, pressure, density, temperature and many others through their interaction with optical signal. However, refractive index measurement using optical fiber sensors have attracted attention to be explored and applied to various applications.

Refractive index (RI) is a basic optical property of material that describes an important part of its interaction with electromagnetic radiation. It is an inherent characteristic and very useful to find the physical parameter such as concentration, pressure, density and so on.

Recently, the measurement of liquid refractive index has attracted much attention due to its wide applications in basic research, biochemical analysis, environment and contamination assessments and chemical industry. Due to the correlation between the wavelength, concentration and temperature and the refractive index of a liquid, the optical methods can be apply to measure the changes in the liquid refractive index. The fiber optic technique based on Fresnel reflection is a very appropriate method since it's very close to refractive index of medium interface.

1.3 Problem Statement

At present, several methods with various principle of monitoring refractive index of liquid are available including critical angle principle, surface plasma resonance (SPR) and grating-based refractive index sensor. Most of them proved to be sensitive for certain condition involved but in terms of the sensor preparation or fiber modification, they could get rather tedious and complicated. Furthermore, each measurement has its own limitation such as cannot be used at hard to reach area and only appropriate for certain liquid. In this work, another approach is being looked into to see the viability of producing a simple and direct measurement fiber sensor for monitoring the small changes of refractive index of liquid. The sensor must be sensitive, flexible, small and handy which can be used in remote and hard to reach and hazardous areas especially in industrial applications. The realization of how important accurate refractive index of liquid contributes advantages in our industries especially in monitoring or analyzing process control and the rapid growth of fiber optic sensor technology is the reason why the this work is carried out.

1.4 Objectives of the Study

The objectives of this work are:

- To develop a simple fiber coupler measurement system for liquid refractive index monitoring
- To optimize the sensor parameter such as coupling ratio, probe-sample position, detector and light source
- To investigate the total reflected light intensity to the change of liquid refractive index and liquid level.

1.5 Scope of the Study

This work is based on Fresnel reflection at flat interface between two different media which is air and liquid. The sensor system is based on the use of 2x2 single mode fused fiber coupler with different coupling ratio. Two light sources of different wavelength and two optical detectors namely the power meter and the photodiode are used. Reflected light produced from Fresnel reflection at the interface was measured in term of power due to change of liquid refractive index.

Parameters such as concentration, temperature and wavelength of incident light that are related to the change of liquid refractive index were studied and their relations were investigated. A light source with operating wavelength 1300 nm and 1550 nm was used while a salt solution with concentration by mass in range 0%- 24% was tested as a liquid sample. In order to study the sensor's respond to temperature, the liquid sample was heating in the range of 30ºC – 90ºC. The variation of reflected light intensity detected by optical detectors then relate to the change in the refractive index due to the variation of tested parameters.

1.6 Significant of the Study

The precise measurement of liquid refractive index is important to many fields such as fundamental research, bio-chemical analysis, environments and contamination assessment, diagnostics, foods, and chemical industry. The study of fiber optic sensor for liquid refractive index monitoring is very important to produce a simple and high sensitivity for many uses and applications such as monitoring the quality of frying oil, investigate purity of honey and so on. It also contribute more efficient measurement techniques for the improvement of the process control and to preserve the quality of final products by offering remote sensing, with low disturbance and no explosion risks.

REFERENCES

A. H. Morshed (1999) Senior Projects in Optical Fiber Sensing, Electronics and Communications Engineering Dept., Faculty of Engineering, Ain Shams University.B.Max, Wolf, Emil, *Principles of Optisc*,Cambrige,University Press pp.14-24,ISBN 0-521 64222-1, October 1999.

B.Gholamzadah and H.Nabovati(2008),*Fiber Optic Sensors*, World Academyof Science Engineering and Technology.

B. Max; Wolf, Emil (October 1999). *Principles of Optics*, Cambridge: Cambridge University Press. pp. 14–24. ISBN 0-521-64222-1.

C. Yeh.(1990), Handbook of Fiber Optic Theory and Applications, *Academic Pess , Incc* ,pp.515.

C.B. Kim and C.B.Su (2004), Measurement of Refractive Index of Liquids at 1.3 and 1.5micron Using a Fiber Optic Fresnel Ratio Meter, Department of Electrical Engineering, Texas A&M University, College Station, USA.

C.H. Yeh, C.W. Chow, J.Y. Sung , P.C. Wu, Wha.T.Whang , and F.G.Tseng,(2012) Measurement of Organic Chemical Refractive Indexes Using an Optical Time-Domain Reflectometer, *Sensors* **2012**, *12*, 481-488; doi:10.3390/s120100481

D. R.Goft (2004), Fiber Optic Reference Guide : A Pratical Guide to the Technology, *Reed Elsevier Group*, *British Library Cataloguing in Publication Data*, (20-55)

D.K Mynbaev and L.L Mynbaev(2001), Fiber Optics Communication Technology. Upper Saddle River, New Jersey:*Prentice Hall, Inc*. pp 589-595.

D.P Subedi,., D.R Adhikari,., U.M Joshi,., H. N Poudel,., B Niraula, (2006). Study of Temperature and Concentration Dependence of Refractive Index of Liquid Using a Novel Technique, Kathmandu University, *Journal of Science,Engineering and Technology*, Vol. 11.

E. Fujiwara, E. Ono, Tarcio P. Manfrim, J. S. Santos, C. K. Suzuki (2011),Measurement of sucrose and ethanol concentrations in process streams and effluents of sugarcane bioethanol industry by optical fiber sensor, The State University of Campinas, Laboratory of Photonic Materials and Devices, 13083-970 Campinas, Brazil.

E. Udd (2006), Fiber Optics Sensors an Introduction for Engineers and Scientists, *John Wiley & Sons.Inc.Hoboken* (pp 49-50).

E.Udd Et Al (2006), *Fiber optic smart structures*. John Wiley& Sons INC, New York.

E. Hecht,*Optics* (4th ed.). Pearson Education. ISBN 0-8053-8566-5

F. T.S.Yu Shizhuo Yin (2002), *Fiber Optic Sensors*, The Pennsylvania State University, University Park, Pennsylvania, (pp.15-16)

Hecth (2003), *Optics*, Fourth Edition. Pearson Higher Education.ISBN 978-0-321-18878-6).

Hecht, Eugene (1987). *Optics* (2nd ed.). Addison Wesley. ISBN 0-201-11609-X

H.Tazawa,T.Kanie and M.Katayama (2007), Fiber Optic Coupler based Refractive Index Sensors and its Application to Biosensing, *Optical Communication R&DSumitomo Electric Industries*, Ltd, Tayacho, Sakae-ku,Yokohama. 244-8588, Japan.

H.Su and X.G.Huang (2007), Fresnel-reflection-based Fiber Sensor for On-line Measurement of Solute Concentration in Solution, *Laboratory of Photonic Information Technology*, South China Normal University, Guangzhou,51006,China.

J. Ready ., Fundamental of photonics, Optical Detectors and Human Vision, *Formerly with Honeywell Technology Center Edina*, Minnesota, (pp 211-214).

Jeunhomme, L.B.M.Dekker (1983), Single Mode Fiber Optics,Principle and Application, *Marcel Dekker Inc*.New York.

J.C.Palais (1998), *Fiber Optic Communications*, 4th edition,New Jersey, USA:Prentice-Hall.

J.R.Zhao,X.G.Huang and J.H.Chen (2009), A Fresnel-reflection-based fiber sensor for simultaneous measurement of liquid concentration and temperature, *Journal of Applied Physics*, American Institute of Physics.

K.Fidanboylu, and H. S Efendioglu, (2009), "*Fiber optic sensors and their applications*," Proc. IATS, pp 1-6

K.R. Sohn(2010) , Liquid sensors using refractive intensity at the end-face of a glass fiber connected to fiber-Bragg grating, Department of Electronics and Communications Engineering, Korea Maritime University, Busan 606-791, South Korea, *Sensors and Actuators A* 158 , pp193–197.

K. Thyagarajan and Ajoy Ghatak (2007), Fiber Optic Components: Fiber Optic Couplers, *ISH Globalspec electronic.*

M.G Shlygin, R.M Manual, O.Esteban, (2013), Optical- fiber self-referred refractometer based on Fresnel reflection at the fiber tip. *Sensors and Actuators* B 178. pp 263-269

M.Yu (2008), Fiber Optic Sensor Technology, Assistant Professor *Sensors and Actuators* Laboratory Department of Mechanical Engineering University of Maryland, USA.

M. Medhat et al (2002), Application of fringes of equal chromatic order for investigating the effect of temperature on optical parameters of a GRIN optical fibre. *Journal of Optics: Pure and Applied Science*

M.Nic.J.Jirat. B.Kosata, eds. (2006–). "Photodiode". *IUPAC Compendium of Chemical Terminology*(Online ed.). doi:10.1351/goldbook.P04598. ISBN 0-9678550-9-8.

P.P.Khare (2004), Fiber Optics and Optoelectronics, *Oxford University Press India.*

P. Nath and M. Buragohain (2012), *Journal of Physics*, Indian Academy of Sciences Vol. 79, No. 6,(pp. 1525–1532)

R. Tricker (2002) , Optoelectronics and Fiber Optic Technology.

R.C.Stanley, (1968). *Light and sound for engineers*. New York City: Hart Publishing Company.

T. Erdogan, Ph.D, *Semrock Technical Note Series:* Understanding Polarization, The Standard in Optical Filters for Biotech & Analytical Instrumentation

T.S.Yu, S.Yin, (2002) Fiber Optic Sensors (Optical Science and Engineering), ISBN: 0-8247-0732-X.

V.K.Singh, B.S. Jaswal, V.Kumar, R.Prakash, P.Rai, (2013), Application of He-Ne laser to study the variation of refractive index of liquid solutions with the concentration, *Journal of Integrated Science and Technology* , 1, 1, 13-18

W. Sun, Q. Liu, Y. Li, X. Li, F.Jiang, L. Yuan (2006), Liquid analysis based on fiber micro-drop sensors, ICO20: Optical Devices and Instruments, [ISBN]:0-8194-6055-9, Dec 2005, *Opt. Techn*., 32, pp. 65–70

W. Xu, X.G. Huang, J.S. Pan (2012), A Simple Fiber-Optic Refractive Index Sensor Based On Fresnel Reflection and Optical Switch, *Sensors*-6399.