MACH-ZEHNDER INTERFEROMETER

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To

My Beloved Mother, Father, Brothers and sisters.

ACKNOWLEDGMENT

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

Praise be to Almighty Allah (Subhanahu Wa Ta'ala) who gave me the courage and patience to carry out this work. Pease and blessing of Allah be upon his last prophet Mohammed (Sallulaho-Alaihe Wassalam) and all his companions (Sahaba), (Razi-Allaho-Anhum) who devoted their lives towards the prosperity and spread of Islam.

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ABSTRACT

Beam propagation method (BPM) was used to study 2x2 Mach-Zehnder interferometer switch with electro-optical effects in titanium diffused lithium niobate $(Ti - LiNbO_3)$ based directional coupler was used to develop the design. This design is capable of de-multiplexing the wavelength1300nm. This project intends to design high performance NxN electro-optic switch. This optical device is widely used in optical network, especially in the optical link of fiber-to-the-home (FTTH). The design is carried out using BPM_CAD, which is a very powerful and user-friendly optics waveguides modeling method as it core element. Research on optical waveguide switching using directional coupler (DC) and Mach-Zehnder interferometer (MZI) has been going on and already created great interest among the researchers. There are different types of material being used in much different way apart from the most common electro-optic materials such as lithium niobate $LiNbO_3$. Recently, the study was also confined to the use of silica on silicon technology considering that the cost of the technology. Other non-linear-optic materials such as polymers have been embedded into part of the silica waveguide.

ABSTRAK

Beam propagation method (BPM) digunakan untuk mengkaji 2x2 Mach-Zehnder interferometer suis dengan efek-efek $(Ti - LiNbO_3)$ based directional coupler dalam membangunlcan relcaan. Relcaan ini mampu dalam de-multiplexing pauy gelombang 1300nm. Projek ini ingin merelca NxN elektro-optik suis yang member fungsi yang tinggi. Alat optical ini digmalcan secasa berleluasa dalam rangkaian optikal terutamanya dalam link optikal bagi fiber-to-the-home (FTTH). Rekaan dilaksanakan dengan menggunakan BPM_CAD yang merupakan satu cara pemodelan paduan gelombang optic sebagai elemen utama yang sangat berkuasa dan sesuai untuk pengguna. Penyelidikan dalam pensuisan panduan gelombang optik menggunatan directional coupler (DC) and Mach-Zehnder interferometer (MZI) telah pun berjalan dan telah mencetuskan benyak minat dalam para penyelidik. Selain dari pada elektro-optik material biasa sperti lithium niobate $(LiNbO_3)$, pelbagai jenis material yang berbeza yang digunakan dalam cara yang berlaina. Sejak kebelakangan ini, kajian dihakan kepada penggunaan silika dalam teknologi silika dengan mengambil kira kos teknolog. Optik material bukan linear yang lain seperti polimer telah digunakan sebagai salah satu behagian dalam pandnan gelombang silica.

TABLE OF CONTENTS

CHAPTER	TITLE		PAGE
	DECLARATION		
	DEDICATION		
	ACKNOWLEDGEMNET		
	ABSTRACT		
	ABSTRAK		
	TABLES OF CONTENTS		
	LIST OF TABLES		
	LIST OF FIGURES		
	LIST OF SYMBOLS		
	LIST OF ABREVIATIONS		
	LIST OF APPENDICES		
1	**PROJECT OVERVIEW**		1
	1.1	Introduction	1
	1.2	Objective	2
	1.3	Scope of Project	2
	1.4	Problem Statement	3
	1.5	Methodology	3
		1.5.1 Case Study	3
		1.5.2 Literature Review	3
		1.5.3 Optical Switch Design	3

2	**OPTICAL WAVEGUIDE ANALYSIS**		6
	2.1	Waveguide	6
	2.2	Optical link of fiber-to-the-home (FTTH)	7
	2.3	Optical Fiber Communication System	9
		2.3.1 Multiplexing Methods in Optical Networks	9
	2.4	WDM System Performance	13
3	**OPTICAL SWITCHING CONCEPTS AND DEVICES**		
	3.1	PIC Space Switches	16
		3.1.1 Mechanical witches	16
	3.2	LiNbO3 Directional Coupler	20
	3.3	Coupling Efficiency	21
	3.4	Types of Optical Switching	22
	3.5	Passive Optical Sitching Device and Operational Principles	24
	3.6	Fiber Coupler	24
	3.7	Waveguide Coupler	30
	3.8	Mach-Zehnder Interferometer	34
	3.9	Application of Integrated Optics in The Evolution of Optical Switching Technology	39
	3.10	Planar waveguide Integrated optical in optical switching	41
	3.11	Active optical switching devices and operational principles	46
	3.12	Electro-optic Mach Zehnder Interferometer	47
4	**DESIGNING OPTICAL SWITCH**		
	4.1	Titanium Diffusion in Lithium Niobate Process	52
	4.2	Electro-Optic Effect	55
	4.3	Optical Switching Using Electro-Optic	58

Effect
4.4 Phase Mismatch 60
4.5 Switching Voltage 61
4.6 Coupling Efficiency Control of 2x2 Optical Switch 64
4.7 Analysis on Effect of Changing Separation Distance between Waveguides (d) 65
4.8 Analysis on Effect of Changing Wavelength (λ_0) 67
4.9 Design 2x2 Optical Switch using Mach-Zehnder Interferometer 69
4.9.1 First Design of Mach-Zehnder 2x2 optical switch 71
4.9.2 Second Design of Mach-Zehnder 2x2 Optical Switch 72
4.10 Configuration of BPM_CAD for Diffused Waveguide in BPM_CAD 73
4.11 Simulation Results of First Design of Mach-Zehnder 2x2 Optical Switch Zero Voltage 74
4.11.1 Simulation Results of First Design of Mach-Zehnder 2x2 Optical Switch with Switching Voltage 75
4.12 Simulation Results of 2x2 Optical Switch with Zero Voltage 76
4.12.1 Simulation results of 2x2 Optical Switch with Switching Voltage 78

5 CONCLUSIONS AND RECOMMENDATION
5.1 Conclusions 81

REFERENCES
APPENDICES A

LIST OF TABLES

TABLE NO.	TITLE	PAGE
4.2	Electro-Optic Effect	55
4.7	Analysis on Effect of Changing Separation Distance between Waveguides (d)	65
4.8	Analysis on Effect of Changing Wavelength (λ_0)	67
4.9	Design 2x2 Optical Switch using Mach-Zehnder Interferometer	69
4.10	Configuration of BPM_CAD for Diffused Waveguide in BPM_CAD	69

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Rays propagating by total reflection in a slab waveguide, H_x Component of the Magnetical Field, H_z Component of the Magnetical Field, E_y Component of the Electrical Field	5
2.2	Fiber to the home	8
2.3	Attenuation spectrums for an ultra-low-loss single mode fiber	9
2.4	Two multiplexing techniques for increasing the transmission capacity of optical networks. (a) Time division multiplexing and (b) wavelength division multiplexing. The modulated signal provides the time frames available for each logical state (0 or 1)	10
2.5	Three network topologies. (a) Star (broadcast and select network) (b) Ring and (c) bus	11
2.6	Typical structures of a (optical) cross connect which is used for interchanging the three wavelength channels in the three inputs of the OXC	13
2.7	The intra channel crosstalk penalties for 1, 10 and 100 crosstalk introducing elements, as functions of the crosstalk level of each element in the network for a BER of 10-9. All elements are assumed to produce crosstalk at equal powers	14

3.1	The wave guiding structures of the most commonly used switch architectures. In (a), (b), (c) and (d) switches are depicted which employ a refractive index change for the switching property, the switch in (e) is based on the functionality of a semiconductor optical amplifier (SOA). The grey areas represent the parts with adjustable effective refractive indices	17
3.2	A Directional coupler designed by BPM-CAD for 2x2 DC switch	19
3.3	Relationship between coupling ratio and phase-mismatch parameter	21
3.4	Relationship between coupling Efficiency and applied voltage	22
3.5	4x4 Active optical switches	23
3.6	4x4 Active optical switch	23
3.7	Fiber coupler	24
3.8	Normalized coupled powers P_2 / P_1 and P_1 / P_0 as a function of the coupler draw length for a 1300nm power level P_0 launched into fiber 1	26
3.9	Dependence on wavelength of the coupled powers in completed 15mm long coupler	26
3.10	Generic 2x2 guided- wave coupler	28
3.11	An uniformly asymmetric directional waveguide coupler in which one guide has a narrower width in coupling region.	30
3.12	Theoretical through-path and coupled power distribution as a function of the guide length in a symmetric 2x2 guided-wave coupler with $k = 0.6mm^{-1}$ and $\alpha = 0.02mm^{-1}$	32
3.13	wavelength response of the coupled power P_2 / P_0	33
3.14	2x2 Mach-Zehnder interferometer	35
3.15	Four channel wavelength multiplexer there 2x2 MZI	37
3.16	A planar slab waveguide. The film with h refractive index	41

	n_1 acts as the guiding layer and the cover layer is usually air where $n_3 = n_0 = 1$	
3.17	A planar slab waveguide. The film with h refractive index n_1 acts as the guiding layer and the cover layer is usually air where $n_3 = n_0 = 1$	43
3.18	cross section of some strip waveguide structures structure (a) Ridge guide (b) diffused channel (c) rib guide	44
3.19	A simple strip waveguide phase modulator	48
3.20	A Y-junction interferometric modulator based on the Mach Zehnder interferometer	49
4.1	Flow chat of optical switch design	51
4.2	dependency of optical power transfer ratio, $\Im$, on phase mismatch $\Delta\beta L_o$	60
4.3	A design of 2x2 electro-optic switch based Mach-Zehnder interferometer	62
4.4	Effect of changing separation distance, d, at V=12	67
4.5	Effect of changing separation distance, λ_0 at V=12	69
4.6	First Design a 2x2 optical switch of Mach-Zehnder interferometer without electrode region	71
4.7	First Design a 2x2 optical switch of Mach-Zehnder interferometer	71
4.8	Design a 2x2 optical switch based on Mach-Zehnder interferometer without electrode region	72
4.9	Design a 2x2 optical switch based on Mach-Zehnder interferometer with electrode region	72
4.10	Simulation results of a 2x2 optical switch when $V_2 = 0$ volt Optical signal is fully coupled from P_{in1} to P_{out2}	74
4.11	Simulation results of a 2x2 optical switch when $V_2 = 0$ volt Optical field and effective refractive index at the output	75

4.12	simulation results of a 2x2 optical switch when $V_2 = 12$ volt Optical signal is fully coupled from $P_{in}1$ to P_{out1}	76
4.13	Simulation results of a 2x2 optical switch when $V_2 = 0$ volt Optical signal is fully coupled from P_{in2} to P_{out1}.	77
4.14	Simulation results of a 2x2 optical switch when $V_2 = 0$ volt Optical field and effective refractive index at the output	78
4.15	Simulation results of a 2x2 optical switch when $V_2 = 12$ Volt Optical signal is switched from P_{in2} to P_{out2}	79
4.16	Simulation results of a 2x2 optical switch when $V_2 = 12$ Volt Optical filed and effective refractive index at the output	80
5.1	Fiber-To-The-Home system architecture	82

LIST OF SYMBOLS

a_v	-	Modal Field Amplitude
d_i	-	Thickness of Layer i
D	-	Depth of a Switching Matrix
$\vec{E}$	-	Vectorial Electrical Field
E_x	-	x Component of the Electrical Field
E_y	-	y Component of the Electrical Field
E_z	-	z Component of the Electrical Field
f_m	-	Modulation Frequency
$\vec{H}$	-	Vectorial Magnetical Field
H_x	-	x Component of the Magnetical Field
H_y	-	y Component of the Magnetical Field
H_z	-	z Component of the Magnetical Field
h	-	Slab Height
H	-	Rib Height Including Slab
h_{eff}	-	Effective Slab Height
H_{eff}	-	Effective Rib Height
j	-	$\sqrt{-1}$
k_0	-	Wave number of Free Space
k_y	-	Wave number in y -Direction
k_z	-	Wave number in z -Direction

$\bar{k}$	-	Mean Wave number
L	-	Device Length
L_c	-	Transfer of Coupling Length
l	-	Mode Order
L_b	-	Length Spanned by a s-Bend
l_b	-	Path Length of a s-Bend
M	-	Density of Light Scatterers
M_i^{TM}	-	Transfer matrix of Layer i for TM wave
n	-	Refractive Index
$\underline{n}$	-	Complex Refractive Index
N	-	Number of Layers
n_i	-	Refractive Index of Layer i
n_{eff}	-	Effective Refractive Index
n_{sub}	-	Refractive Index of the Substrate
P_{in}	-	Power at the Input Port
P_{out}	-	Power at the Output Port
P	-	Number of Single Switching Elements Switching Matrix
q	-	Fit Parameter
R	-	Phase Bend Radius
R_x	-	Phase Bend Radius x-Direction
R_y	-	Phase Bend Radius in y -Direction
T	-	Temperature
v	-	Imaginary Complex Coordinate
w	-	Rib Width
w_c	-	Cutoff Width
y	-	Spatial Coordinate
y_i	-	Upper Bound of Layer i
z	-	Spatial Coordinate

α	-	Full Intersection Angle of Waveguides
β	-	Propagation Constant
β_{eff}	-	Effective Propagation Constant
$\Delta\phi$	-	Phase Difference
$\Delta\beta$	-	Propagation Constant Difference
ε	-	Dielectricity
ε_0	-	Dielectricity of Free Space
ε_r	-	Relative Dielectricity
γ	-	Linear Thermal Expansion Coeficient
λ	-	Wavelength
μ	-	Mode Order
w_1, w_2	-	Weighting Functions
η	-	Phase Correction for Gaussian Beams
θ	-	Angular Range
ξ	-	Polarizability per Scatterer

LIST OF ABREVIATIONS

ADI	-	Alternating Direction Implicit
Al	-	Alluminium
Ar	-	Argon
AWG	-	Arrayed Waveguide Grating
BCB	-	Benzocyclobutene
BPM	-	Beam Propagation Method
CAD	-	Computer Aided Design
CIF	-	Caltech Intermediate Format
CT	-	Cross Talk
FBG	-	Fiber Bragg Grating
FD	-	Finite Differences
FFT	-	Fast Fourier Transform
GaAs	-	Galium-Arsenid
HeCd	-	HeliumCadmium
HF	-	Hydrofluoric Acid
HNO_3	-	Nitric Acid
H_2O	-	Water
H_3PO_4	-	Ortho-PhosphoricAcid
IL	-	Insertion Loss
InGaAsP	-	Indium-Galium-Arsenid-Phosphid
$LiNbO_3$	-	Lithiumniobat
MEMS	-	Micro ElectroMechanical System

LIST OF APPENDICIES

APPENDIX	TITLE	PAGE
A	BPM Diffused Waveguides	85

CHAPTER 1

PROJECT OVERVIEW

1.1 Introduction

Future telecommunication network will be largely based optical fiber as the transmission medium. With the proliferation of fiber in May parts of telecommunication network, it becomes increasingly apparent that photonic switching and optical signal processing, including optical multiplexing, will play important role in the network evolution into all photonic networks.

The external sources such as voltage, current or thermal have been used to change the optical propagation characteristics, the basis of optical switching. For example a rearrange able no blocking polymer wavelength thermo-optic 4x4 switching matrix with low power consumption at 1550 nm has been worked out by using thermal to control the 4x4 switches. Recently, low power compact 2x2 thermo optic silica-on-silicon waveguide switch with fast response has been successfully shown by using MZI.

Thermal effect was used to activate the MZI. High performance wavelength multiplexing and demultiplexing optical channels spaced 100GHz apart (0.8nm spacing at 1550nm) has been shown by the device based on Mach-Zehnder interferometer.

Active wavelength switching technology is one of the latest approach in fiber optical communication in order to make wavelength division multiplexing (WDM) becoming a better choice for switching technology, knowing that WDM can exploit the huge bandwidths of optical fiber. In this project we report the results of a simulation study on the dependence of wavelength using beam propagation method (BPM) on $LiNbO_3$ directional coupler (DC) switch. The variation of the output splitting ratio is the major outcome from the simulation.

This directional coupler switch, which we call as WDM switch, is also having the same behavior as a passive directional coupler but with variable coupling efficiencies when under an external field. By applying an external voltage of less than 10V, the change of coupling efficiency of each optical wavelength between. 1.10µm and 1.55µm can be observed.

1.2 Objective

- Define the material of Mach-Zehnder switch.
- Simulation using BPM-CAD.
- Optimization of Mach-Zehnder switch.

1.3 Scope of Project

- To understand the concepts and operational principles of different types of optical devices used as optical switching.
- Investigation some of the parameters (β, Refractive index, Width, Length, size, material) that are used for designing an optimum optical switch.
- Designing an optical switch by using MZI technique by using BPM CAD software.
- Analysis on Mach-Zehnder in terms of light coupling efficiency.

1.4 Problem Statement

- Using optical-electrical conversion switches results in expensive and non-reliable systems due to large coupling loss.
- By designing optical-optical switches, the performance of the system is proved much better.

1.5 Methodology

1.5.1 Case Study

This part covered a study case about different types of coupler for example, Fused fiber coupler, waveguide coupler, Mach-Zehnder interferometer.

1.5.2 Literature Review

This covered titanium diffusion in lithium niobate process upon the literature review through materials for design this choice was based on that it has low loss and switching voltage need to be applied is small which is normally below 10v, Further more, silicon based substrate normally acts passively to electric field. In designed electro-optic switch, material is the best choice due to its electro-optic and piezo-electric characteristics.

1.5.3 Optical Switch Design

Initially, the switch be design using Mach-Zehnder interferometer as a beginning, 2x2 switches be designed.

1.5.4 Simulation

The simulation will be done by using BPM_CAD. This simulation will show the propagation in the switch.

1.6 Thesis Structure.

This thesis consists of main chapters. The first chapter consists of a general introduction, the scope and objective of the project and also the flow of this thesis.

Chapter 2 is an introduction about Waveguide and Fiber-to-the-home. The chapter discusses in detail about the waveguide analysis and WDM system performance.

Chapter 3 studies about the optical switches and waveguide coupler and fiber coupler and Mach-Zehnder.

Chapter 4 in this chapter has simulation results and discuses the results.

Chapter 5 is a conclusion for this project. The chapter also has future works