PERFORMANCE OF DIFFERENT MACH-ZEHNDER INTERFEROMETER (MZI) STRUCTURES FOR OPTICAL MODULATOR

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To Mama and Ayah.

To my sister, brothers and friends.

You all are my strongest bone.

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All praise to Allah for my good health and well being without His permission, I won't be able to finish my journey until now.

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ABSTRACT

Mach-Zehnder Interferometer (MZI) is an optical modulator device that electrically control the output phase and the output amplitude of the optical signal that passes through the device. Geometrical structure of the MZI modulator will produce different effect on the optical modulator performance. This project analyzed two different types of MZI structures which use the Y-structure and the MMI-structure. Phase modulator is the active region of the MZI modulator in which the optical signal that passes through it will be shifted. The phase modulator arm is the P-I-N structures based on silicon material by Silicon-On-Insulator (SOI) technology. This project is conducted in 2-Dimensions of OptiBPM and OptiSys software. The operating wavelength is 1.55μm and 3.45 as the refractive index. From the simulation that had been conducted MMI-structure shows the best performance as the MZI optical modulator. The performance is based on several parameters which are the insertion loss, extinction ratio, phase shift and modulation efficiency with the results of 5.81dB, 30.54, 2.26 μm and 45.03V.cm

ABSTRAK

Mach-Zehnder Interferometer (MZI) merupakan modulator optik yang menggunakan tenaga elektrik untuk mengawal fasa keluaran dan amplitud keluaran bagi setiap isyarat optic yang melalui nya. Struktur geometri memainkan perana penting bagi prestazi sebuah MZI uktuk dia menghasil kan fungsi modulator optic. Lantas projek ini dianalisis menggunakan dua jenis yang struktur yang berbeza iaitu Y-struktur dan MMI-struktur. Subseksyen yang paling utama di dalam mereka bentuk MZI modulator adalah lengan fasa modulator yang diamana ia akan berubah fasa isyarat yang melaluinya. Lengan fasa modulator akan menggunakan struktur P-I-N yang berasaskan bahan silikon melalui teknologi SOI. Projek ini dijalankan di dalam teknik 2-Dimensi melalui perisian OptiBPM dan OptiSys. Panjang gelombang operasi adalah 1.55μm dan 3.45 sebagai indeks biasan. Dari simulasi yang telah dijalankan MMI-struktur menunjukkan prestasi yang terbaik sebagai modulator optik MZI. Prestasi di ambil ukur melalui beberaoa berdasarkan beberapa parameter antaranya adalah kecekapan kehilangan sisipan, nisbah kepupusan, anjakan fasa dan modulasi dan masing-masing memeperoleh 5.81dB, 30.54, 2.26 mikron dan 45.03V.cm

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LIST OF ABBREVIATIONS

EOM	-	Electro- Optic Modulator
MMI	-	Multimode Interference
MZI	-	Mach-Zehnder Interferometer
SOI	-	Silicon on Insulator
	-	

CHAPTER I

1 INTRODUCTION

In this chapter, a complete explanation about the whole project had been explained. In contains the general idea how this project will be conducted. Related topics include in this chapter are the Project Introduction, Objectives, Problem Statement, Scope, Methodology Summary and Report Structure.

1.1 Project Introduction

Optical modulator is a device that is able to modulate and vary the optical signal in a controlled manner. It is an electrical based controlling the output phase and the output amplitude of the optical signal that passing through the device. This optical devices been used in photonics devices, optical communication systems and now widely used in optical electrical integrated circuit (OIEC).

There are many types of optical device such as directional coupler, single waveguide, microring and Mach-Zehnder (MZ). Implementation of interferometer technique into the optical modulator created a Mach Zehnder Interferometer (MZI). MZI is now becoming a new trend in designing an integrated optical devices modulator due to its simplicity for designing and fabrication[1]. Geometrical structure of MZI that commonly used are Y-structure and MMI-structure.

MZI modulator four main subsections which are input waveguide, output waveguide, reference arm and phase modulator arm. Phase modulator will make optical signal that passes through it been shifted. The structure been used for this phase modulator is P-I-N structure.

P-I-N structure is a silicon based material through Silicon-On-Insulator (SOI) technique. The carrier depletion is the method that inject the electrical field on the phase modulator arm through the P-I-N structure. This doping technique make changing of refractive index of phase modulator compared to the rest of subsection.

1.2 Objectives

The objectives of this project are to:

1. Design and simulate MZI structure using Y-structure and MMI structure
2. Analyze the performance of MZI optical modulator using both Y-structure and MM-structure.
3. Propose the best MZI optical modulator.

1.3 Problem Statements

The Y-structure and MMI-structure are widely used as MZI optical modulator. However, there is no research to compare the performance for both structure can give better performance. Different structure of MZI can produce different effect on the optical modulator. Therefore, this project will analyse which structure can give better performance in MZI modulator.

1.4 Scope

This project focuses to design the MZI structure using Y-coupler and MMI coupler device. Insertion loss (IL), extinction ratio (ER) and modulation efficiency ($V\pi L\pi$) also phase shift ($\Delta\phi$) are among characteristic performance of MZI modulator

that will observed. OptiSys and OptiBPM are the mainly software used to design this project. Dimensions (2D) techniques will be applied to design the coupler device. The operating wavelength used is 1.55 μm while the refractive index will be used at 3.45. The phase modulator used P-I-N structure. Meanwhile the material for the devices is based on SOI.

1.5 Methodology Summary

The methodology of this research is briefly about how the project being conducted from the designing the coupler device until complete design of the MZI optical modulator. The project is involving two different kind of software which are OptiSys and OptiBPM. The OptiSys software been used to design coupler device. The OptiBPM software been used to design the MZI optical modulator. Further details will be discussed in Chapter III.

1.6 Report Structure

This report consists of 5 chapters. Chapter I will cover the overview of the project. It will include the introduction, the objective, problem statements, scope, methodology review and the report structure.

Chapter II contain the literature review of the project. All information obtained from the articles and reference books.

Chapter III about the methodology and the project implementation process. This chapter also describe all parameters used.

Chapter IV describe about the result and discussion based on the simulation. Observation based on the optical modulator performance has been made

Chapter V conclude the project. This chapter also recommend future work and step to overcome any limitation.

CHAPTER II

2 LITERATURE REVIEW

This chapter will explain more about theoretical analysis and basic principle project. Through this chapter, all key terms and definition will be explained. All information had been obtained through journals and reference books. This chapter will describe about the optical modulator, phase modulator, MZI optical modulator, P-I-N structure for the phase modulator, performance of the optical modulator and the OptiBPM and OptiSys software.

2.1 Optical Modulator

Optical Modulator is a device that is able to modulate or vary the amplitude optical signal in a controlled manner. It is divided into two types of modulator which are the absorptive modulator and the refractive modulator. This project focused on the refractive modulator on the electro-optic Modulator (EOM). EOM is a device used to control the phase, polarization or power of optical signal beam with an electrical control signal.

Optical modulators are used to electrically control the phase or the output amplitude of the optical wave passes through it. The changes of output waveform is proportional to the applied electric field [2]. Figure 2.1 show basic block diagram of optical modulator. Elements that highlighted on the optical modulator are laser, polarizer, electro-optic modulator, analyser and photo detector.

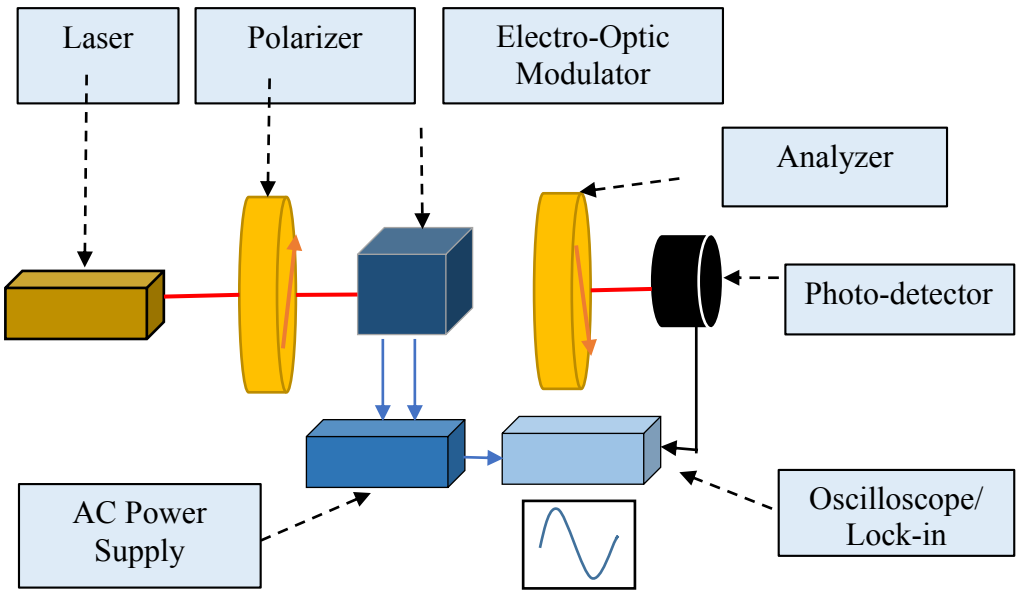

Figure 2.1: Basic optical modulator block diagram

Laser act as the input optical signal that will pass through the polarizer. At polarizer it will vary sinusoidal input signal with linear change. The electro-optic modulator where the phase or amplitude modulator run their function. It will compare the reference signal with modulated signal. The signal will be transmitted to the analyzer so that the product of differentiating between the previous signal and current signal can be monitored. When optical signal is received at the photo detector the signal will transmit to the oscilloscope lock in where reference signal will be compared with the incoming signal. When both signal fully matched it means that the overall signal successfully perform their function and will continuous repeating.

Interference structures that can be implemented as the optical modulator introduce to the MZI. MZI is an interference structure that can applied on optical processing signals like switching, add-drop, multiplexing and modulator [3].

2.2 Phase Modulator

Phase modulator is a device locate on the phase modulator arm of MZI optical modulator. Phase modulator region is where the electrical field applied to it through the plate electrodes. Then it will change the phase delay of the optical signal [4].

It changes the phase delay of optical signal by applied different density of the material. Adjusting the value the refractive index can produce different density of material and it is become a key for semiconductor optical devices. Hence, phase modulator concern on the refractive index changes and immune from absorption changes semiconductor waveguide. Effect from that, phase modulator is a device that the suitable design compared to the absorption modulator in terms of detecting present changing of refractive index.

Phase modulator measure and detect some signal by differentiating the incoming signal with the reference signal. Phase modulation is a technique that manipulate the changes of phase angle and create new sequence output signal. Figure 2.2 show effect on the signal wave after passed through the phase modulator region.

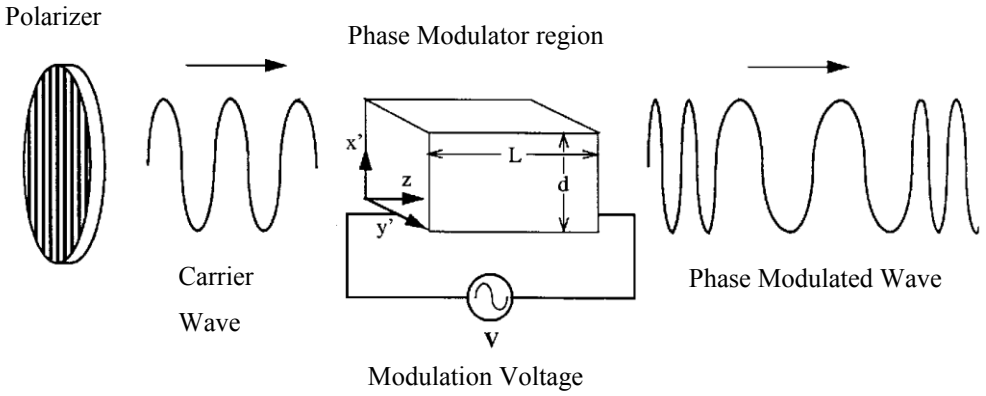

Figure 2.2: Waveform of the phase modulator.

Silicon been used for the phase modulator material can be realized by using the free carrier dispersion effect. After investigate and do some modification on several parameter on phase modulator it is proven that MZI optical modulator can perform very high performance in [1]. Moreover, when combining the phase modulation and an optical interferometer or directional coupler it can provide optical switching. Effect from that, phase modulator more versatile, less heating and wavelength sensitivity. Figure 2.3 show the phase modulator changing waveform for optical modulator.

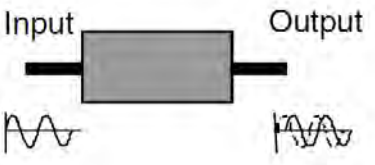

Figure 2.3: phase modulator for optical modulator device.

Research shows that the phase modulator have an ability to inject a free carriers from the p-n junction configuration to guide light effectively. It can function in both condition either in forward-bias or reverse bias. When in forward bias it will increase the efficiency of the phase modulator through the speed characteristics. While in reversed bias phase modulator can perform in high-speed characteristics with limited device capacitance. It happen because the free carrier away from the junction and make electric field produce between the depletion areas. Hence from that, the refractive index and the phase of propagating signal wave will be changed [2].

Through the carrier injection mode the properties of phase modulator can be investigate when applied some voltage supply. Phase modulator device can be integrated in the silicon-on-insulator (SOI) rib waveguide by using P-I-N diode structure [5]. Performance of phase modulator depending on the value of drive current ($I\pi$) is also can be used to find the π phase shift.

2.3 Mach-Zehnder Interferometer (MZI) Modulator

They are few devices for optical modulator but due to the special property of MZI, it had attracts many researcher about it. Interference happens when two or more optical waves are present simultaneously in the same area [6].

Interferometer also defined as an optical devices that have ability to splits the signal into two signal by using the beam splitter and then can to recombine it together by another beam splitter and detect it through the intensity of their superposition.