TAGUCHI ANALYSIS ON THE PERFFORMANCE OF CARRIER DEPLETION SOI OPTICAL MODULATOR

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ABSTRACT

This thesis is about optimizing the performance of PIPIN carrier depletion optical modulator in Silicon on Insulator (SOI) using Taguchi method. The applied voltage is in reverse biased and working at 1.55µm wavelength. The ATHENA and ATLAS software from SILVACO Int was used to design the PIPIN optical modulator. In Taguchi method, the L9 orthogonal array was used to find the optimum factors and levels. The three selected factors are concentration of doping, applied voltage and energy. The parameter that the optimum device are concentration of doping is 5e21cm^{-3}, voltage is -2.94V and energy is 10eV. Then, the most significant factors that affect the modulators performance are the concentration of doping with 64.65%.

ABSTRAK

Penulisan kajian ini adalah tentang mengoptimumkan prestasi PIPIN pembawa kekurangan pemodulat optik „Silicon On Insulator" (SOI) menggunakan kaedah Taguchi. Voltan yang digunakan adalah secara terbalik iaitu negatif voltan dan beroperasi pada lebar jalur 1.55µm panjang gelombang. Perisian SILVACO Int yang mempunyai ATHENA dan ATLAS telah digunakan untuk mereka bentuk PIPIN pemodulat optik. Dalam kaedah Taguchi, L9 tatasusunan ortogon digunakan untuk mencari faktor-faktor yang optimum dan berlainan tahap. Ketiga-tiga faktor yang terpilih ialah bahan pendopan, negatif voltan dan tenaga. Parameter untuk optimum bahan adalah bahan pendopan iaitu 5e21cm^{-3}, voltan adalah -2.94V dan tenaga adalah 10eV. Kemudian, faktor yang paling penting yang memberi kesan kepada prestasi pemodulat adalah bahan pendopan adalah sebanyak 64.65%.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In this project, Taguchi method was used to optimize the performance of carrier depletion SOI PIPIN optical modulator. Then, this project is focused on optical modulation in silicon on insulator (SOI).

Silicon on insulator (SOI) is comprised of a thin silicon uppermost layer and a thicker silicon lowermost layer with an insulating material like silicon dioxide forming the middle layer between these silicon layers. Subsequently, silicon on insulator (SOI) substrates for silicon photonics provides various benefits like lower energy wastage and low power usage. Silicon is the material which is cheaper and suitable for integrated photonic.[3]

Optical modulator is a device that is used to modulate a beam of light. In addition, refractive index changes when modulation occurs. Figure 1.1 shows that the structure of SOI PIPIN which is P consists of boron and N consists of phosphorus.

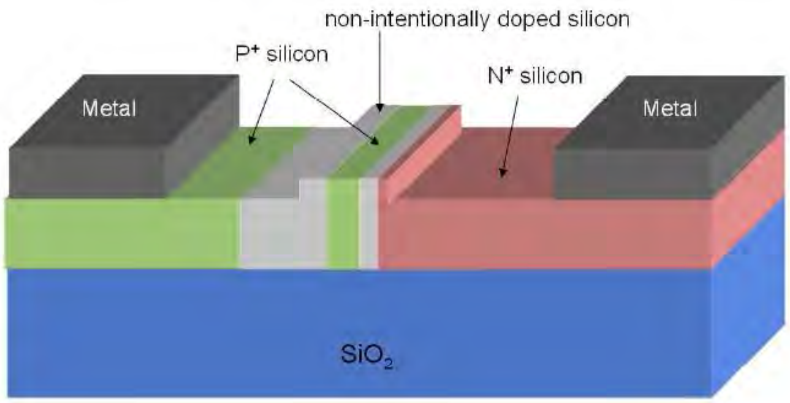

Figure 2.1: Structure of SOI PIPIN modulator [5]

This project utilized simulation of ATHENA and ATLAS from Silvaco Int. ATHENA was used to design while ATLAS was used to generate the electrical characteristics.

For this project, Taguchi method was applied to optimize the performance. Taguchi method approach a systematic application for designing and analyzing the product quality at the design stage. Then, the L9 orthogonal array was used to find the optimum factors and levels in Taguchi method. Table 1.1 shows that the L9 orthogonal array that contains nine experiments and three factors.

Table 1.1: L9 Orthogonal Array

Experiment	Factor A	Factor B	Factor C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

1.2 Problem statement

Engineering designs involve setting values of a large number of decision variables. Then, the optimization of a device is crucial so difficult to optimize the performance. So, statistical tool that is Taguchi method was used. Taguchi method is a structured approach for determining the best performance.

1.3 Objectives

1. To design and simulate SOI PIPIN optical modulator by using ATHENA and ATLAS from Silvaco.
2. To optimize the performance SOI optical modulator by using Taguchi method.

1.4 Scope

1. This project is conducted by using Silvaco simulation tools which is ATHENA and ATLAS. The wavelength involved is 1.55µm.
2. This project in focused to optimize the performance of carrier depletion SOI PIPIN optical modulator by using Taguchi method.

1.5 Project Outline

This thesis have five chapters. Chapter 1 includes the introduction of the project, problem statement, objective and scope. Chapter 2 contains literature review, background and theory for this project. Meanwhile, chapter 3 consists of discussion about methodology and software that use for this project. In addition, this chapter also includes a flow chart to show the process from the beginning of design until got the result. Chapter 4 includes the result and discussion for this project. The results will be discussed based on the calculation and simulation from the Silvaco Int. Other than that, the result from Taguchi method also will be discussed in this chapter. Chapter 5 includes the conclusion for this project and some recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Optical modulator

An optical modulator is a device that is used to modulate a beam of light. A extensive range of optical modulators are utilized in dissimilar application areas for example, in optical fibre communications. Figure 2.1 shows that the kind of optical modulators for example amplitude, phase or even polarization modulators depending on which property of light is controlled.. Optical modulator also the device that can modulate or vary the amplitude of an optical signal in a controlled manner and its generates desired intensity, color in the passing light by changing optical parameters such as the transmission factor, refractive index and reflection factor according to the modulating signal. [1]

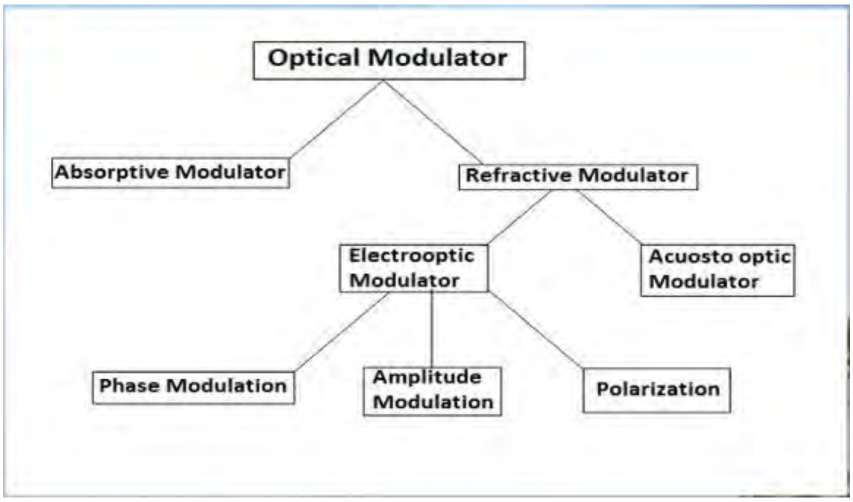

Figure 3.1: Types of optical modulator [1]

2.2 Silicon on Insulator (SOI)

Silicon-On-Insulator (SOI) is a semiconductor manufacture methods produced by IBM, which employs pure crystal silicon and silicon oxide for integrated circuits (IC) and microchips. Silicon on Insulator (SOI) microchip processing speed is normally thirty percentage faster compared today's complementary metal-oxide semiconductor (CMOS) based chips and power consumption is reduced by eighty percentaege, which makes them suited for cellular devices. SOI chips also reduce the soft error rate, which is data corruption caused by cosmic rays and natural radioactive background signals. [3]

Transistors are constructed on a silicon layer unwind on an insulating layer of silicon dioxide (SiO2) in Silicon On Insulator (SOI) fabrication technology. To oxidize the silicon thereby creating a uniform buried layer of silicon dioxide, the insulating layer created by the oxygen flowing onto a plain silicon wafer and then heating the wafer. There are lots of benefits of the technology for instance simplify fabrication steps, improve density and reduce parasitic capacitance. The result is usually around thirty percent lower power consumption, twenty percent higher performance and fifteen percent higher density than traditional bulk CMOS at the same feature size.

Currently, the application of optical data are usually in long distance communications. These connections form the backbone of the communications infrastructure for their ability to send substantial amounts of data at the quikest rate probably. Commonly, the materials of the kind of optical devices developed result in larger costs. The existing technology using electrical signals transmitted along copper wires to transfer data between high-speed fiber optic connection and user using the data that is being transfer.. Unfortunately, method to send large amounts of data is to use an electrical signal which has a lot of connections and achieve the best performance of copper.

The aim of the research in the silicon photonics field is to develop optical devices based on silicon material. This method looks extremely attractive due to several causes, including the large established silicon fabrication infrastructure and the somewhat inexpensive and the material is high.

2.2.1 Mach- Zehnder Modulator

A digital signal is enforced on light through one of two techniques which is the direct and exterior modulation. In direct modulation, the light source entered is usually consisting switches on and off, while in exterior modulation the continuous beam is blocked or forced to interfere the modulation. Figure 2.2 shows that the silicon modulator is an exterior modulator based on the design of a Mach-Zender interferometer, where an incoming beam of light is usually separated in half and the two resulting beams travel through two different arms of the interferometer. When voltage is applied, the Kerr effect encouraged along these arms and the Franz-Keldysh affect carrier injection. The change in the refractive index gives similar results in these three mechanisms. The phase of the light might be altered by controlling the refractive index. For different phase, the two waves are converted to an amplitude modulation when both arms are recombine.[2]

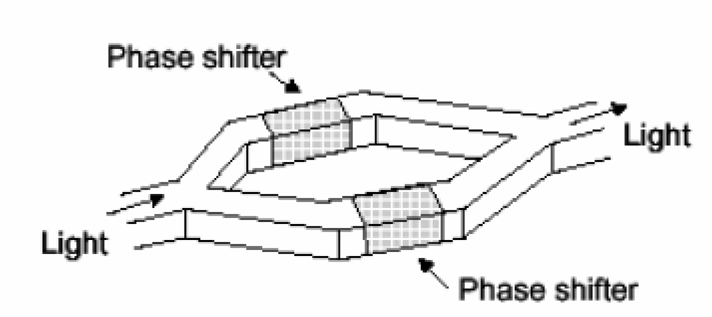

Figure 2.2: Schematic of a Mach- Zender interferometer modulator with two phase shifter sections [1]

Mach-Zehnder Interferometers utilized in a wide variety of applications within optics and optical communications. A Mach-Zehnder modulator is utilized for controlling the amplitude of an optical wave. The input waveguide is divided into two waveguide interferometer arms. When a voltage is applied across one of the arms, a phase shift is induced for the wave passing through that arm. When the two arms are recombined, the phase difference between the two waves is converted to an amplitude modulation. Figure 2.3 shows that the brief pieces associated with silicon photonic-crystal nanostructures are incorporated in the two arms of the MZI to alter the phase of the light. One arm is controlled by the exterior oscillating electrical signal applied across two electrodes so that the phase of light is modulated in time. When light from the two arms combines at the exit of the MZI, the time-varying phase of one arm brings the combined light intensity to undulate. [4]

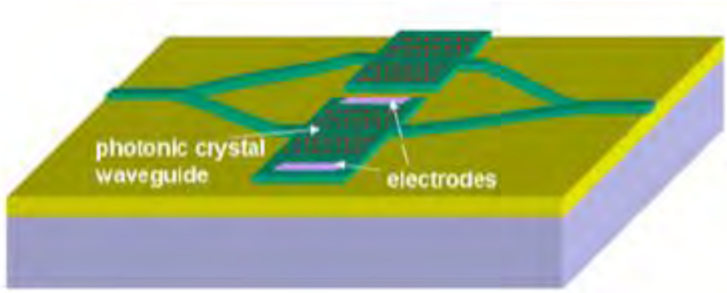

Figure 2.3: Sketch of the silicon Mach-Zehnder modulator on a SOI chip[4]

According to Graham T. Reed and et al[5] when large refractive index, light can be mostly restricted in submicron waveguide between silicon and buried silicon oxide. Apart from that, a high performance optical modulator should demonstrate low insertion loss, large extinction ratio and high frequency operation.

2.3 Carrier Depletion

Generally, carrier depletion operated in a reverse bias. Figure 2.4 shows that the schematic of PIPIN. The PIPIN diode is the best compromise for high speed and low insertion loss. P-doped region is introduced as a source of free holes in the core of the intrinsic region of the diode. At balance, when a reverse bias was applied the holes that are located in the middle of the diode will be holes out by the electric field as shown as figure 2.5. Changes in the refractive index are then obtained in the middle of the diode. Apart from that, the reverse current flows very slightly even in the reverse bias state in an actual diode. This electric current is called the leakage current or the drift current. In addition, when reverse bias increases, the zener breakdown and the current flow rapidly. The voltage that starts this breakdown phenomenon is called reverse direction breakdown voltage. Moreover, the areas in which the reverse current rapidly increases by the breakdown phenomenon is called breakdown areas. In the breakdown areas, the voltage change becomes small compared with the current change.

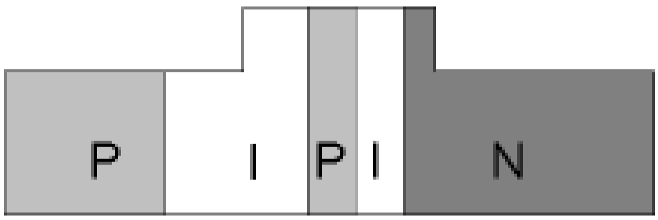

Figure 2.4: Schematic of PIPIN[12]

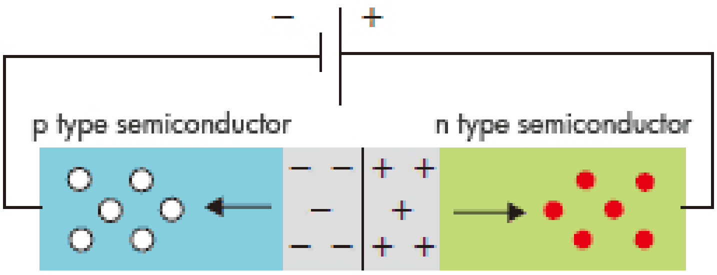

Figure 2.5: When applying reverse bias

According to Delphine Marris-Morini and et al[12] the carrier depletion can be obtained in the reverse biased PIPIN diode with a P-doped region introduced as a source of free holes in the core of the intrinsic region of the diode. In the balance, holes are placed in the middle of the diode and holes are swept out when a reverse bias is applied by the electrical field. Then, the carrier depletion appears as one of the most efficient ways to achieve high speed and high performance optical modulators. In addition, the PIPIN seems to be more flexible with the possibility to achieve targeted specifications, especially on optical loss and cutoff frequency.

Laurent Vivien and et al[13] do the paper about the optical modulation by carrier depletion in a silicon PIN diode. When in balance, in the P+ layer have localize holes that are electrostatically. Apart from that, when a reverse bias voltage was applied to the diode, expands through the space charge of the device. Then, holes are swept out from the active area. In addition, carrier density variations are responsible for refractive index variations, and thus for a phase shift of the optical guided mode propagating through the device.

2.4 Taguchi Method

Taguchi method was first introduced by Dr. Genichi Taguchi to AT&T Bell Laboratories in 1980. Taguchi method is a new engineering design for optimization to improves the quality of existing products and processes and at the same time reduces their costs with minimum engineering resources and human development. Taguchi method achieves this by making the product or process performance is not sensitive to variations in factors such as materials, manufacturing equipment, workmanship and operating conditions.

In addition, Taguchi method is a standardized approach for determining the best combination of inputs to produce a product or service that is based on a Design of Experiments (DOE) methodology for determining parameter levels. DOE is an important tool for designing processes and products. [12]

Pursuant to P.S. Menon and et al[9] the optimizing PIN photodiode using Taguchi method. The four factors which are the intrinsic region length, photoabsorption layer thickness, incident optical power and bias voltage. Then, to examine the performance factors of the device and to find the optimum factors and levels, signal to noise ratio (SNR) of larger the better (LTB) was applied. The result show that the most effect is incident optical power followed by bias voltage, photoabsorption layer thickness and incident optical power.

Other than that, the selected factors that provide the best combination based on L9 orthogonal array and the signal to noise ratio (SNR) larger the best (LTB) is used to find the optimum factors and levels in Taguchi method. Generally, there are three categories of the performance characteristics to analyse the S/N ratio that is nominal the best, larger the better and smaller the better.

The larger the better characteristic is just the vice versa of the smaller the better characteristic. The type of this character, it can be recommended to maximize the results and the suitable goal value is infinity. For instances of this characteristic is maximizing the product yield from a process.

CHAPTER 3

METHODOLOGY

3.1 Flowchart Methodology

The flowchart is important in methodology as a reference and guided to complete this project. Step by step process in Silvaco should be known and analysis to avoid the wrong design of the structure. Figure 3.1 shows that the flowchart for this project. Before designing the device, a literature review was study to know about the structure of SOI PIPIN optical modulator with their application. Then, the Silvaco software that has ATHENA and ATLAS was learned. After that, the structure SOI PIPIN modulator was developed and simulated. Furthermore, the step to optimize the performance by using Taguchi method should analyze to make sure the optimization is correct. For Taguchi method, the L9 orthogonal array was chosen to observe the control factors with their levels for the different design.