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PERFORMANCE ANALYSIS OF MMI COUPLERS FOR MODULATORS ON SOI

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ABSTRACT

The emerging research conducted on silicon photonics has emphasized its potential to utilize low cost, mature and mass productive CMOS processes. Among all of the silicon photonics devices, the silicon modulator is one of the important components in optical communication network. In this paper, Multimode Interference (MMI) device is used to develop the Mach Zehnder Interferometer (MZI) structure of the optical modulator. The electrical part of the modulator utilizes the forward biased P-I-N structure. The effects of varying the waveguide's width of the MMI couplers to the performance of the MZI optical modulator on Silicon-On-Insulator (SOI) were investigated. The analyses were done on the insertion loss (IL), extinction ratio (ER) and modulation efficiency ($V_\pi L$) of the device. The investigated waveguide's widths were 3, 4 and 5 µm. Largest waveguide's width of the MMI, which was 5 µm demonstrated the best performance with IL of 3.63 dB, ER of 28.81 dB and $V_\pi L$ of 0.0315 Vcm.

Keywords: optical modulator, SOI, MZI, waveguide's width of the MMI.

INTRODUCTION

Silicon photonics have spurred a growing interest in recent years, mainly because of its unique applicability in optical interconnects that are considered as a promising alternative to replace conventional electrical interconnects. Transmission of digital information over the communication network using photons in place of electrons is deemed helpful for achieving high bandwidth, low power consumption, low noise, data transfer with minimal crosstalk and high interconnection density[1, 2].

A primary factor driving the high level of research interest in the silicon photonics platform originates from this system's intrinsic compatibility with CMOS electronics. Silicon wafers have the lowest cost (per unit area) and the highest crystal quality of any semiconductor material. Microprocessors with hundreds of millions of components, all integrated onto a thumb-size chip, and offered at such a low price that appear in consumer electronics is able to produce by industry.

Another motivation is the availability of high-quality Silicon-on-Insulator (SOI) wafers, an ideal platform for creating Planar Light wave Circuit (PLC). The SOI structure also possesses unique optical properties owing to the large refractive index difference between silicon (n = 3.45) and SiO2 (n =1.45). The strong optical confinement offered by the high index contrast between silicon makes it possible to scale photonic devices to the hundreds of nanometer level 3, 4. Over the years, numerous research and development on PLC have been demonstrated [1], [5-9].

One of the principal components required within any optical communication link is the optical modulator, which serves the function of encoding an optical carrier wave with a high speed electronic data signal. In this paper, the Multimode Interference (MMI) device with the length of 4283µm is used to realize the optical beam splitting and combining in the MZI structure of the optical modulator. The MMI demonstrates reasonable bandwidth, compact size, high fabrication tolerances and good power balance [10, 11].

BACKGROUND

The underlying principle of the MMI devices is self-imaging theory12.In MMI devices; the input field profile is periodically reproduced in single or multiple images in the propagation along the waveguide. The length of the MMI region, requires careful design to suitably image the light from the input port onto the output ports. The self-imaging increases quadratically with and a symmetric two-fold self- image length, by 2-D approximation, is given by

$$L\pi = \frac{\pi}{\beta_0 - \beta_1} \cong \frac{4 n_0 W_e^2}{3\lambda_0} \qquad (1)$$

where W_e is the effective width of the multimode waveguide, n_0 is the effective refractive index and λ_0 is the vacuum's wavelength [13].

In this paper, the effect of varying waveguide's width of the MMI to the insertion loss (IL), extinction ratio (ER) and modulation efficiency (VπL) were carried out.

The IL takes into account the loss optical power when the optical modulator is inserted in the photonic circuit. Researches on IL of carrier dispersion modulators vary between 7.4 dB to 20 dB [14, 15]. Meanwhile, the ER is defined by the ratio of maximum transmission intensity (I_{max}) to the minimum transmission intensity (I_{min})

$$10 \log (Imax/Imin) \qquad (2)$$

where Vπ is the voltage that is required to gain π phase shift and L is the phase modulator's length that is required to gain π phase shift [8]. The lower value of VπL indicating the device is more efficient.

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DESIGN AND METHODOLOGY

The design of the optical modulator consists of two parts. The first part concentrates on the electrical structure of the optical modulator also known as the phase modulator. The phase modulator utilizes the forward biased P-I-N structure. The interactions of the electrons and holes changes the refractive index of the SOI substrate hence will be able to modulate the propagated optical signal in the waveguide area. The structure and parameter values of the PIN structure are depicted in Figure-1 and Table-1 respectively. The design was done utilizing Athena and Atlas software, from SILVACO international.

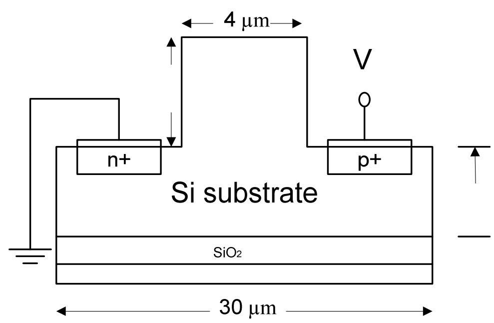

Figure-1. Structure of the phase modulator.

Table-1. Parameter values for phase modulator

Parameter	Values
Silicon refractive index	**3.45**
Silicon's background carrier (cm^{-3})	$1x10^{14}$
Holes' lifetime, τ_p (s)	$2x10^{-6}$
Electrons' lifetime, τ_n (s)	$2x10^{-6}$
Temperature (K)	300
Holes injection (cm^{-3})	$5x10^{17}$
Electrons injection (cm^{-3})	$5x10^{17}$

The second part of the design consists of developing the optical structure of the optical modulator. The MZI were used as the interferometric structure. Meanwhile the two MMI devices which act as a splitter and a combiner were utilized to build the MZI structure as shown in Figure-2 with the parameter's values tabulated in Table-2. The waveguide's width of the MMI was varied to study the variation effects to the IL, ER and modulation efficiency. In the meantime, since the MMI's length is subject to the beat length of the device, equation (1) was utilized to determine the suitable length of the MMI. The OptiBPM and OptiSys software were used for the optical structure design and optical characterization purposes.

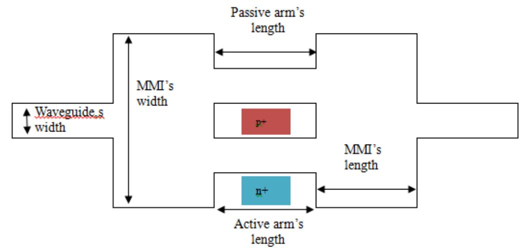

Figure-2. Schematic of the MZI optical modulator.

Table-2. Parameter values for MZI modulator.

Parameter	Values (µm)
MMI's width	**38**
MMI's length	4283
Waveguide's width	3,4,5
Passive arm's length	1180
Active arm's length	1000

RESULTS

The relationship between the IL, ER and modulation efficiency with waveguide's width of the MMI used in the modulator are depicted in Figure 3, 4 and 5.

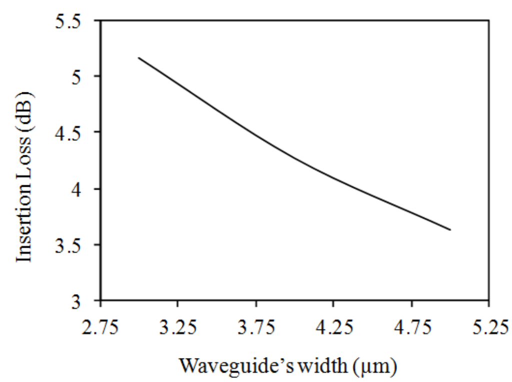

Figure-3. Graph of the IL vs waveguide's width of the MMI.

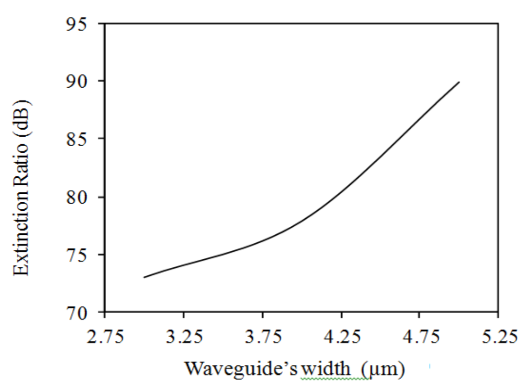

Figure-4. Graph of the ER vs waveguide's width of the MMI.

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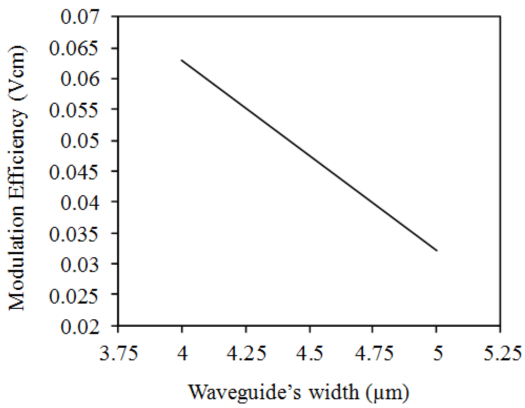

Figure-5. Graph of the modulation effciency vs waveguide's width of the MMI.

Figure-3 shows that the IL decreases with larger waveguide's width of the MMI. This might due to the fact that bigger waveguide's width enables larger propagated optical signal thus reducing the insertion loss. Meanwhile, Figure-4 depicts that the ER of the modulator rises as the waveguide's width is getting larger. The reason for the circumstances is that larger waveguide's width of the modulator results in more balanced output power. As for the modulation efficiency, larger waveguide's width demonstrates more efficient device as observed in Figure-5. Larger waveguide's width permits greater optical modes in the waveguide allowing more interaction with the injection area.

Table-3 summarizes the performance of the modulator with different waveguide's width of the MMI. Overall, the modulator with waveguide's width of 5 µm demonstrates the best performances with ER value of 28.81 dB, higher than recorded ER for MMI splitter. The IL recorded was the lowest with 3.63 dB which is lower than previous research [14, 15]. Meanwhile, the efficiency of the modulator was at its best with 0.0315 V.cm.

Table-3. Performance of the Modulator with Different Waveguide's Width of the MMI.

Waveguide's width (µm)	**ER** (dB)	**Modulation efficiency**(V.cm)	**Insertion loss** (dB)
3	23.24	0.1800	5.17
4	23.59	0.1696	3.96
5	28.81	0.0315	3.63

CONCLUSIONS

The performance of the MZI optical modulator on SOI has been investigated by varying the waveguide's width of the MMI. The largest waveguide's width exhibits the best performance. This study serves as guidance in designing high performance MZI optical modulator on SOI.

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