SiGe Optical Modulator with NPN Configuration Over Varies Doping Type

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***Abstract*—This project proposed the design of SiGe optical modulator with NPN configuration by using Silvaco application. The accurate design is required to develop the best performance of optical modulator device. The designs are develop using instruction in DECKBUILD using 3 different doping type of material which are Boron, Aluminum and Indium for P+ doping while Antimony, Phosphorus and Arsenic for N+ doping. A different performance when varying doping material is expected to be developed. The parameter which has been analysis are refractive index and absorption loss. From the simulation and analysis, it was observed that doping material using Antimony as N+ and Indium as P+ give the highest reflection index change compare to other material. While doping material using Phosphorus as N+ and Boron as P+ give the lowest absorption loss compare to other material.**

***Index Terms*— NPN; SiGe Optical Modulator; Silvaco.**

I. Introduction

Optical modulator is a device which is used to modulate a beam of light. Optical modulators may be categorized into amplitude modulators, phase modulators or polarization modulators. Similar to other optical device, the performance of modulator is very important in order to improve the signal transmitted. As for optical modulator, the performance is depends on doping material. Each doping material has different doping level to each other. Improving the doping level for N+ and P+ will increase the speed as well as increasing the performance of device [1-4].

SiGe films are ideal candidate material for photo receivers at optical communication wavelengths because of their high optical absorption compatibility with existing Silicon technology. Consequently the integration of SiGe photo detectors on Silicon substrate has been an active area of research. It has potential of offering increased carrier mobility over pure silicon [1], [5-6].

Therefore, in this project SiGe optical modulator with NPN configuration is design and the performance-using variable of doping type is investigate. The scope of this project limited to 3 type of doping material which are Boron, Aluminum and Indium for P+ doping while Antimony, Phosphorus and Arsenic for N+ doping for SiGe optical modulator with NPN configuration. The development of this project includes the design of metal contact, doping material and SiGe layer. The device has an NPN structure where three side doping regions are joined as a common anode or cathode. A different performance when varying doping material is expected to be developed.

II. Methodology

This project involves software application or simulation using Silvaco. There are two modules that are used during this project which are ATHENA and ATLAS. ATHENA is one of software application that specifically builds to design the fabrication process of optical modulator. ATHENA has advantage of capability to create impressive simulation analysis, which can be implementation as real fabrication as in industry.

This research is about to develop variation of doping type for SiGe optical modulator with N-P-N configuration to investigate the performance of optical device. It involves several modules in Silvaco software to design the device. The data code and tasks that includes etching, diffusion, metallization, calculation algorithm, storing, plotting structure and plotting result are stored in the DECKBUILD as its data.

The optical modulator is design using silicon substrate with 16 micrometers length and 7 micrometer thick. There are 3 side doping regions combine together as command anode or command cathode. The structure of optical modulator is shown in Figure 1. It involved Silicon, SiGe and Aluminum in order to design this optical modulator waveguide structure.

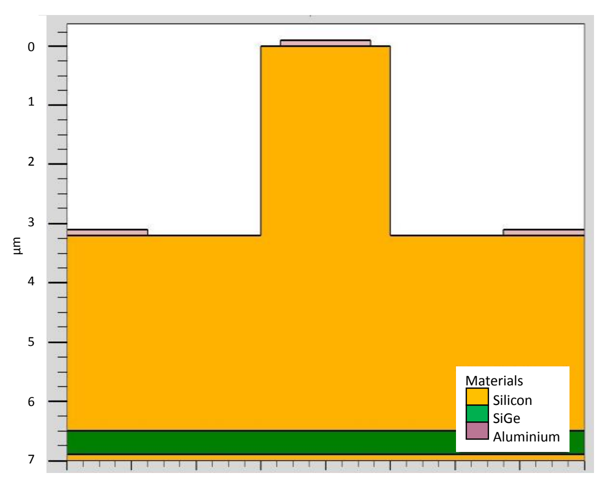

Figure 1: Optical modulator waveguide structure

III. Results and Discussion

The performance result will take part in ATHENA under DECKBUILD. ATLAS is a physically based two-dimensional device simulator. It predicts the electrical behavior of specified semiconductor structures and provides insight into the internal physical mechanisms associated with device operation.

Table 1 summarize the effect of variation in N+ and P+ doping material over various parameters such as electron and hole concentration, refractive index change, absorption change and loss and the estimated length. The voltage is set to 0.6, 0.7, 0.8, 0.9 and 1.0 V and the simulated results are compared.

Table 1
Summarize effect of variation in doping material over parameters.

	VOLTAGES (V)														
	N Doping Phosporous, P Boron					N doping Arsenic, P Aluminium					N doping Antimony, P indium				
PARAMETERS	0.6	0.7	0.8	0.9	1.0	0.6	0.7	0.8	0.9	1.0	0.6	0.7	0.8	0.9	1.0
Electron cons, ΔNe	$2.0x10^{9}$	$5.5x10^{9}$	$1.6x10^{10}$	$4.2x10^{10}$	$1.0x10^{11}$	$1.6x10^{9}$	$4.2x10^{9}$	$1.2x10^{10}$	$2.8x10^{10}$	$7.0x10^{10}$	$1.5x10^{9}$	$3.8x10^{9}$	$9.5x10^{9}$	$2x10^{10}$	$4x10^{10}$
Hole cons, ΔNh	$1.0x10^{17}$	$3.0x10^{17}$	$9.6x10^{17}$	$2.2x10^{18}$	$9.0x10^{18}$	$1.8x10^{17}$	$5x10^{17}$	$1.5x10^{18}$	$3.5x10^{18}$	$5.5x10^{18}$	$2.8x10^{17}$	$7x10^{17}$	$1.8x10^{18}$	$4x10^{18}$	$6x10^{18}$
Refractive Index Change, Δn	0.0003	0.0008	0.0021	0.004	0.0077	0.0005	0.0012	0.003	0.0058	0.0084	0.0008	0.0016	0.0034	0.0065	0.009
Absorption change, $\Delta\alpha$	0.6	1.8	5.76	13.2	30	1.08	3	9	21	33	1.68	4.2	10.8	24	36
Estimated length, $L\pi$	$2.6x10^{-10}$	$6.3x10^{-10}$	$1.6x10^{-9}$	$3.1x10^{-9}$	$5.9x10^{-9}$	$4.2x10^{-10}$	$9.5x10^{-10}$	$2.2x10^{-9}$	$4.5x10^{-9}$	$6.5x10^{-9}$	$5.9x10^{-10}$	$1.2x10^{-9}$	$2.6x10^{-9}$	$5x10^{-9}$	$6.9x10^{-9}$
Absorption loss, $\alpha\pi$	$2x10^{-9}$	$1.1x10^{-8}$	$9.2x10^{-8}$	$4.1x10^{-7}$	$1.8x10^{-6}$	$5x10^{-9}$	$2.9x10^{-8}$	$2.1x10^{-7}$	$9.5x10^{-7}$	$2.1x10^{-6}$	$1x10^{-8}$	$5.9x10^{-8}$	$2.9x10^{-7}$	$1.2x10^{-6}$	$2.5x10^{-6}$

The electron and hole concentration when Boron and Phosphorus, Arsenic and Aluminum, Antimony and Indium been use as doping material are shown in Figure 2, Figure 3 and Figure 4, respectively.

For all cases the value of concentrations is set to 5x and the background doping concentration is set to 1x. The refractive index n of an optical medium is a dimensionless number that describes propagation light across that medium. The refractive index determines how far light is refracted after going in a material. The refractive indices also determine the amount of light that is reflected when reaching the interface [7].

Figure 5 and Figure 6 show the refractive index change and absorption loss when vary the doping material for N+ type and P+ type. Refractive index change for 3 type material doping was determined by varying the voltage anode to 0.6 V, 0.7V, 0.8V, 0.9V and 1 V. From the simulation result, the highest refractive index change is plotted when using Antimony as N+ doping and Indium as P+ doping. The second highest is plotted when using Arsenic as N+ doping and Aluminum as P+ doping. Followed by using Phosphorus as N+ doping and Boron as P+ doping.

The refractive index change for the Antimony/Indium doping is 1.6 times higher than of refractive index change for Arsenic/Aluminum doping and 2.6 times higher than of refractive index change for Phosphorus/Boron doping at 0.6 V. The refractive index change for the Antimony/Indium doping is 1.3 times higher than of refractive index change for Arsenic/Aluminum doping and 2 times higher than of refractive index change for Phosphorus/Boron doping at 0.7 V. The refractive index change for the Antimony/Indium doping is 1.1 times higher than of refractive index change for Arsenic/Aluminum doping and 1.6 times higher than of refractive index change for Phosphorus/Boron doping at 0.8 V.

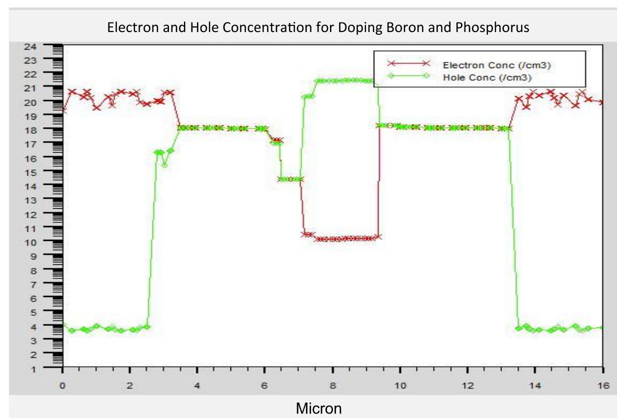

Figure 2: Electron and hole concentration for Boron and Phosporus doping

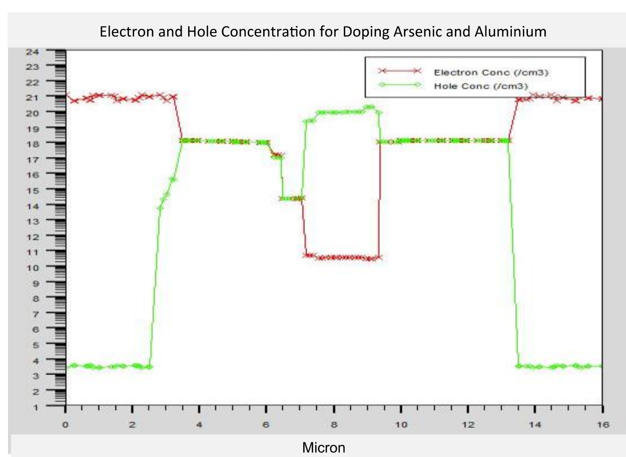

Figure 3: Electron and hole concentration for Arsenic and Aluminium doping

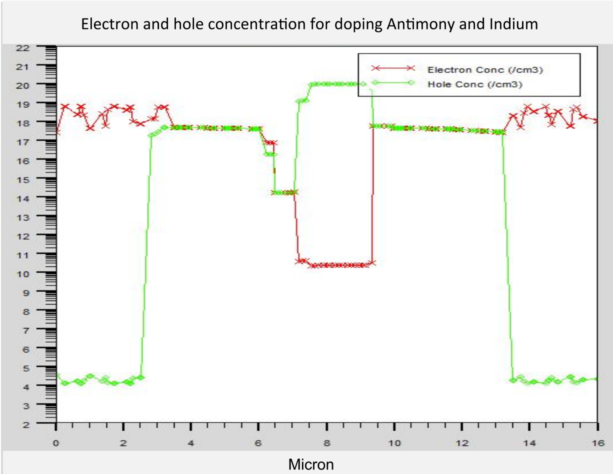

Figure 4: Electron and hole concentration for Antimony and Indium doping

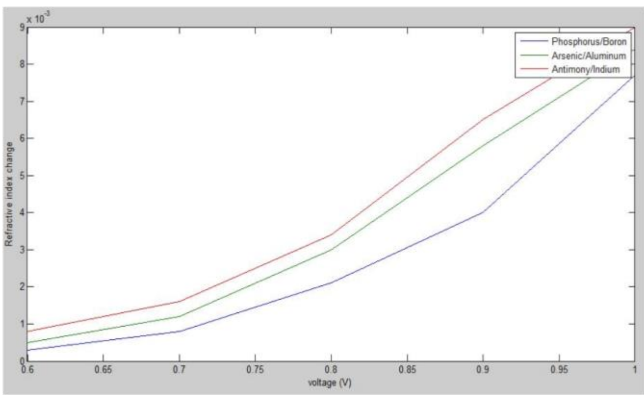

Figure 5: Refractive index for Phosphorus/Boron, Arsenic/Aluminium and Antimony/Indium.

We can see the trend when the voltage value is increase to 0.9V and 1.0V. It can be said that material with high doping level for N+ and P+ will increase the value of cutoff frequency and improve the modulating speed of the device. Absorption occurs in optical fibers due to the presence of imperfections in the atomic structure of the fiber material, due to some basic inherent intrinsic material properties and due to some extrinsic material properties [8]. Inherent intrinsic absorption is caused by basic fiber material properties. Silica fibers possess very low intrinsic material absorption. Presence of impurities in the fiber material leads to extrinsic absorption.

Absorption loss for 3 type material doping was determined by varying the voltage anode from 0.6 V, 0.7V, 0.8V, 0.9V and 1 V. From the simulation result, the lowest absorption loss is plotted when using Phosphorus as N+ doping and Boron as P+ doping. The second lowest is plotted when using Arsenic as N+ doping and Aluminum as P+ doping. The third place is plotted when using Antimony as N+ doping and Indium as P+ doping.

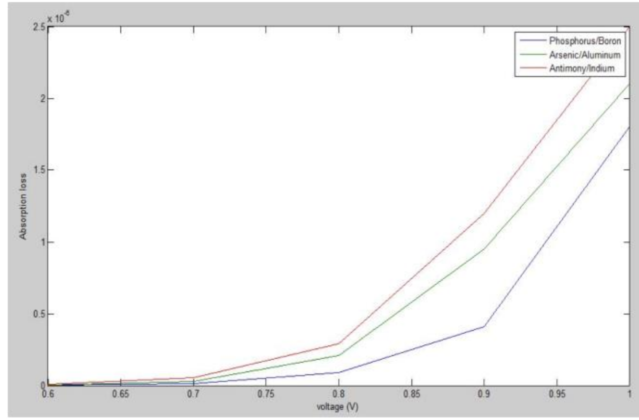

Figure 6: Absorption loss for Phosphorus/Boron, Arsenic/Aluminium and Antimony/Indium.

The absorption loss for the Phosphorus/Boron doping is 2.5 times lower than of absorption loss for Arsenic/Aluminum doping and 5 times lowers than of absorption loss for Antimony/Indium doping at 0.6 V. The absorption loss for the Phosphorus/Boron doping is 2.6 times lower than of absorption loss for Arsenic/Aluminum doping and 4.7 times lowers than of absorption loss for Antimony/Indium doping at 0.7 V. The absorption loss for the Phosphorus/Boron doping is 2.2 times lower than of absorption loss for Arsenic/Aluminum doping and 3.1 times lowers than of absorption loss for Antimony/Indium doping at 0.8 V.

The absorption loss for the Phosphorus/Boron doping is 2.3 times lower than of absorption loss for Arsenic/Aluminum doping and 2.9 times lowers than of absorption loss for Antimony/Indium doping at 0.9 V. The absorption loss for the Phosphorus/Boron doping is 1.1 times lower than of absorption loss for Arsenic/Aluminum doping and 1.3 times lowers than of absorption loss for Antimony/Indium doping at 1.0 V. Increasing doping level also increase their absorption and thus the loss of the optical modulator.

IV. CONCLUSION

The SiGe optical modulator has much advantage as the low interface induced losses and high efficiency. The SiGe optical modulator with NPN configuration has been developed using Silvaco software. The performance of optical modulator has been analyzed. The effect of 3 type doping material for P+ are Boron, Aluminum and Indium while for N+ are Antimony, Phosphorus and Arsenic on SiGe optical modulator has been compared in terms of the reflection index change and absorption loss.

Doping material using Antimony as N+ and Indium as P+ give the highest reflection index change compare to other material. While doping material using Phosphorus as N+ and Boron as P+ give the lowest absorption loss compare to other material. The equilibrium value of refractive index change and absorption loss should be considered when design and develop of optical modulator in order to select the right material for N+ and P+ doping material.

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