LOGIC
Journal of Engineering Design and Technology
Vol. 20 No. 1 March 2020; p. 53 - 58

p-ISSN : 1412-114X
e-ISSN : 2580-5649
http://ojs.pnb.ac.id/index.php/LOGIC

MODELLING OF PHOSPHORUS AND BORON DOPING CONCENTRATION ON SOI WAFER BASED DIFFUSION PROCESS

Anak Agung Ngurah Gde Sapteka 1),
Anak Agung Ngurah Made Narottama 2), **Kadek Amerta Yasa** 3)

1) Electrical Department,
Politeknik Negeri Bali,
Kampus Bukit Jimbaran,
Denpasar, Indonesia
2) Electrical Department,
Politeknik Negeri Bali,
Kampus Bukit Jimbaran,
Denpasar, Indonesia
3) Electrical Department,
Politeknik Negeri Bali,
Kampus Bukit Jimbaran,
Denpasar, Indonesia

Correponding email 1) :
sapteka@pnb.ac.id

Abstract. High concentration of Boron and Phosphorus elements are required in diffusion process during the fabrication of semiconductor devices such as diode and transistor based on Silicon On Insulator (SOI) wafer. Achieving high level of these elements' concentration are the entry point for further research in the field of electronics. For this reason, the concentration of the both elements was tested by flowing Boron and Phosphorus gas with flow rate of 1.5 litre per minute into the Nitrogen furnace for 5 minutes towards the surface of the SOI wafer samples at temperatures of 880, 900 and 950 degrees Celsius. This test was carried out at Michiharu Tabe Laboratory, Research Institute of Electronics, Shizuoka University, Hamamatsu, Japan. Furthermore, the resistivity measurements of samples with Boron and Phosphorus doping were carried out. The results of resistivity were then converted to obtain the concentrations of Boron and Phosphorus on the surface of SOI wafer sample. From the concentration and temperature data, it is obtained the modelling of concentration to temperature function for Boron and Phosphorus. The modelling results show that there are linear correlation between high concentrations of Boron and Phosphorus to temperature.

Keywords : Diffusion, Boron, Phosphorus, Concentration, SOI.

1. INTRODUCTION

Phosphorus and Boron are important elements in the fabrication of semiconductor devices. Both elements are used as doping material in semiconductor such as Silicon to produce certain electrical, optical and structural properties. The Phosphorus element function is to produce n-type semiconductor materials, while the Boron element function is to produce p-type semiconductor materials. To produce n-type semiconductor material, Phosphorus vapor is flowed on the surface of a Silicon wafer. Likewise, to produce p-type semiconductor material, Boron vapor is flowed on the surface of the Silicon wafer. To maintain the purity of the results, this diffusion process is carried out in a clean room using a nitrogen furnace with temperature regulation. This research is focused on the concentration of Phosphorus and Boron obtained from the diffusion process in the Silicon On Insulator (SOI) wafer layer, which is a wafer consisting of successive layers from top to bottom namely, Silicon, Insulator, and Silicon Substrate.

Research on SOI-based semiconductor devices has been conducted by several researchers. In 2015, research on tunneling transport in SOI wafer-based diodes was carried out by measuring current-voltage at several temperature levels [1], also research on negative diferential conductance in SOI-based Esaki diodes [2] and research on characteristics voltage-current with very low temperature conditions on SOI wafer-based PIN diodes [3]. In 2016, research on SOI-based lateral Esaki diodes was conducted to analyze interband tunneling currents [4]. SOI wafer-based research in 2017 was conducted on negative differential conductance in Esaki diodes with co-dopants in the Silicon channel [5], also research on the probability of donor atom distribution with Boron concentrations of 1×10^{20} cm^{-3} and 2×10^{20} cm^{-3} [6], as well as a simulation of MOSFETs with doping concentrations in the source and drain area reaching 1×10^{20} cm^{-3} [7]. In 2018 a study was conducted on SOI wafer-based electro-absorption modulators with a Boron concentration of around 10^{18} cm^{-3} [8].

Based on the research that has been carried out, this paper examines the doping concentration of Phosphorus and Boron in the SOI wafer-based diffusion process in a furnace using Nitrogen gas. This study aimed to produce a mathematical model that applies to the doping concentration of Phosphorus and Boron elements in the range of 10^{19} cm^{-3} to 10^{20} cm^{-3} in the fabrication process of SOI wafer-based electronic devices, especially in the diffusion process using furnaces with Nitrogen gas based on several experiments at temperatures different. The SOI wafer used in this study consists of a p-type Silicon substrate layer and coated by SiO_2 with a thickness of 150 nm and a Silicon layer with doping Phosphorus and Boron. High concentrations of the two elements are needed in the diffusion process in the fabrication of semiconductor devices such as diodes and transistors in nanometer dimensions based on SOI wafers. Achieving a high level of concentration is an entry point for further research in the electronics field.

2. METHODS

This research is a development of research on diode fabrication located at the Michiharu Tabe Laboratory, Research Institute of Electronics (RIE), Shizuoka University, Hamamatsu, Japan. The diode fabrication process is carried out using Phosphorus gas into a diffusion furnace in Nitrogen with a 1.5 liter / minute discharge for 5 minutes to the surface of the SOI wafer sample at 880 °C, 900 °C and 950 °C. The same treatment for Boron gas using a diffusion furnace in Nitrogen. Figure 1 shows the diffusion furnace at Michiharu Tabe Laboratory.

Figure 1. The diffusion furnace at Michiharu Tabe Laboratory.

After the Phosphorus and Boron diffusion process are completed, the next step is to measure the resistivity of the silicon sample using the four-point probe method. This method is an impedance measurement technique using a pair of electrodes to measure current and a pair of electrodes to measure voltage. With this method, the resistivity measurement results are obtained in units of Ω.cm which then converted to doping concentrations of Phosphorus and Boron in cm^{-3} units using the p-Si graph for 300K room temperature in Figure 2. This is in accordance with the temperature conditions at the time of measurements were made and accordance with wafer material that uses p-type Silicon. The final step is to determine a mathematical model for the concentration of Phosphorus and Boron that can be used in various fabrication processes for devices, especially for fabrication of SOI wafer-based devices. Mathematical modeling is done through a linear fit process to determine the value of the intercept and slope and calculate the adjusted R-square value.

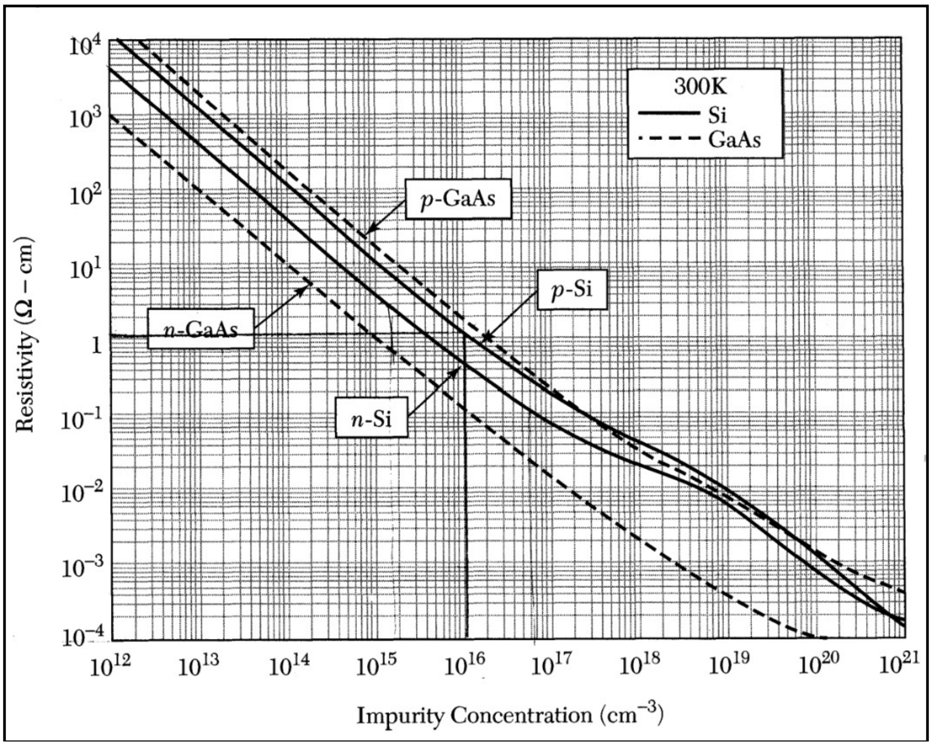

Figure 2. Impurity concentration vs resistivity [9].

3. RESULTS AND DISCUSSION

The results of resistivity measurement using the four-point probe method that has been converted to doping concentrations in cm^{-3} units of Phosphorus and Boron samples are shown in Figure 3. Phosphorus concentrations at 950 ^{o}C reach 2×10^{20} cm^{-3} while Boron concentrations at temperatures that are the same reaches 1×10^{20} cm^{-3}. From the experimental results, no good results were obtained for temperatures higher than 950 ^{o}C. Higher temperatures cause damage to the surface of the SOI wafer. Based on the Phosphorus and Boron doping concentration data in Figure 3, the linear fit process is then performed to obtain the appropriate modelling. The concentration of Phosphorus and Boron obtain the value of intercept, slope and R-square adj. as stated in Table 1 and Table 2.

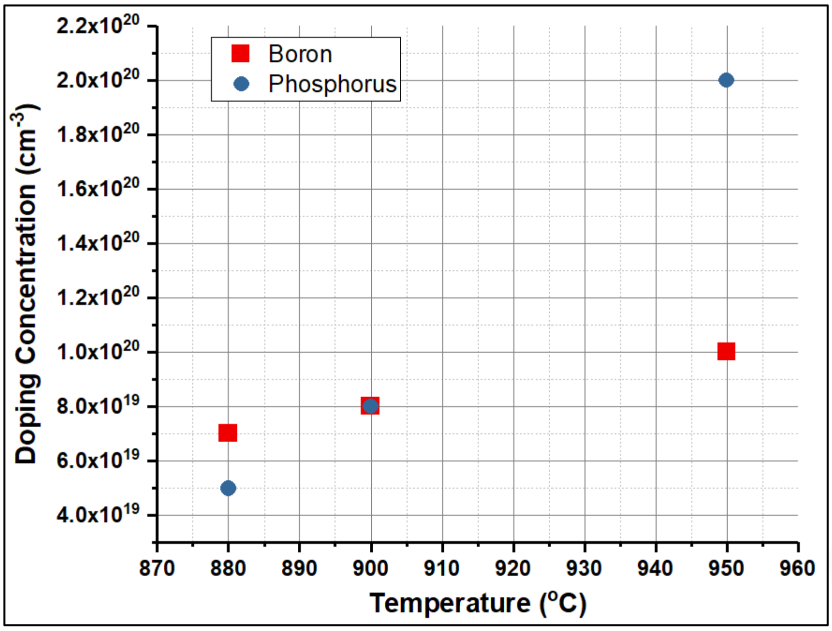

Figure 3. The results of Phosphorus and Boron concentration.

Table 1. Value of Intercept, Slope and Adj. R-square for Phosphorus

Sample	Intercept		Slope		Adj. R-square
	Value	Standard Error	Value	Standard Error	
Phosphorus	-1.885×10^{21}	1.8196×10^{20}	2.19231×10^{18}	1.99852×10^{17}	0.98352

Table 2. Value of Intercept, Slope and Adj. R-square for Boron

Sample	Intercept		Slope		Adj. R-square
	Value	Standard Error	Value	Standard Error	
Boron	-3.01667×10^{20}	2.02178×10^{19}	4.23077×10^{17}	2.22058×10^{16}	0.99451

From the results of primary data processing in Table 1 and Table 2, it is known that the concentration of Phosphorus doping has a linear correlation with temperature (T) accompanied by intercept, slope and adjusted R-square values of -1.885×10^{21}, 2.19231×10^{18}, and 0.98352 respectively. While Boron doping concentration has a linear correlation with temperature (T) accompanied by intercept, slope and adjusted R-square values of -3.01667×10^{20}, 4.23077×10^{17}, and 0.99451 respectively. Thus a linear equation for doping concentration of Phosphorus (CP) and Boron (CB) is obtained according to Equations (1) and (2) as shown in Figure 4. CP and CB are stated in cm^{-3} and T are stated in °C.

$$\mathrm{CP} = 2.19231 \times 10^{18} \times \mathrm{T} - 1.88500 \times 10^{21} \quad (1)$$

$$\mathrm{CB} = 4.23077 \times 10^{17} \times \mathrm{T} - 3.01667 \times 10^{20} \quad (2)$$

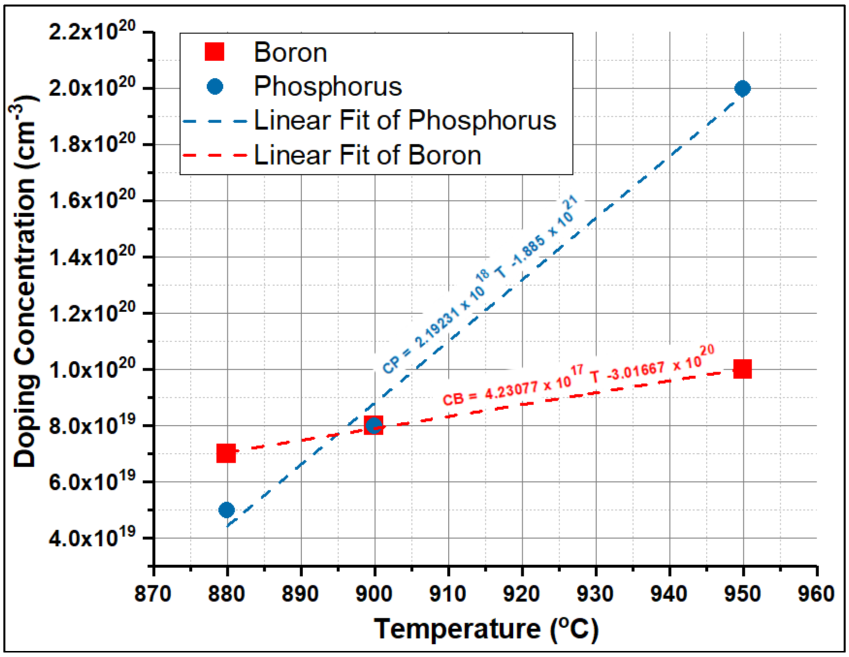

Figure 4. The Linear Equation of Doping Concentration and Temperature.

Based on Sze [9], Phosphorus (P) element has linear diffusion coefficient with slope is greater than Boron (B) element in bulk Silicon as shown in Figure 5. At higher temperature, with a higher diffusion coefficient will result higher doping concentration. This is consistent with the results of this study, in SOI wafer, the Phosphorus element produces doping and slope concentrations greater than the Boron element.

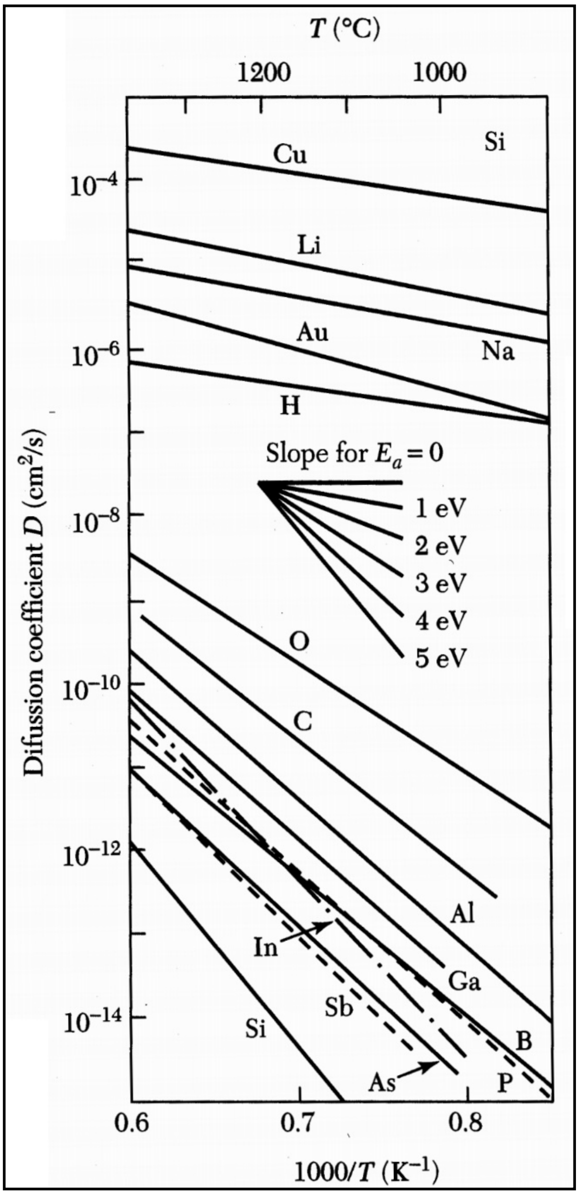

Figure 5. Diffusion coefficient in Silicon.

4. CONCLUSION

This research has shown that the concentration of Boron and Phosphorus in the SOI wafer-based penetration process has a linear correlation to the temperature at temperatures from 880ºC to 950ºC. The research conducted at the Michiharu Tabe Laboratory, Research Institute of Electronics (RIE), Shizuoka University, Hamamatsu, Japan shows that the concentration of Phosphorus reaches 2×10^{20} cm^{-3} and Boron reaches 1×10^{20} cm^{-3} at 950ºC by entering gas Phosphorus and Boron gas separately in the Nitrogen furnace with a debit of 1.5 liter / minute for 5 minutes to the surface of SOI wafer sample. The linear correlation between doping concentration of Phosphorus with temperature is shown in Equation (1) with an adjusted R-square value of 0.98352. Meanwhile the linear correlation between Boron doping concentration and temperature is shown in Equation (2) with an adjusted R-square value of 0.99451.

5. ACKNOWLEDGMENT

We express our thanks to Prof. Dr. Michiharu Tabe, Prof. Dr. Djoko Hartanto, Dr. Daniel Moraru, Dr. Arief Udhiarto, Dr. Sri Purwiyanti, Mr. Takeshi Mizuno, Mr. H. N. Tan, Mr. Yuuki Takasu, and Mr. Ryosuke Unno for guidance, support and assistance in conducting research at Shizuoka University.

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