The Effect of p-Type Doping of Polysilicon for PMOS Applications

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Abstract – This paper presents the effect of p-type doping of polysilicon for BF_2^+, boron, gallium and indium at various doping concentration from 10^{11} to 10^{20} (atoms/cm^3) for PMOS device using SILVACO TCAD (*Technology Computer Aided Design*) software. It is seen that the effect of p-type doping at certain level of dose significantly effects the performance of the PMOS device. The threshold voltage of polysilicon obtain from I_D-V_{GS} curve was analyzed. The results show that BF_2^+ at dose 10^{14} to 10^{19} (atoms/cm^3) and gallium at dose 10^{13} to 10^{20} (atoms/cm^3), both are giving the better characteristics of the PMOS and give almost the same threshold voltage at 1.0V to 1.3V, but the most effective for both doping are concentration at dose 10^{14} (atoms/cm^3). The resistivity of the polysilicon is gradually decreased as a concentration of doping increase, while the conductivity is reciprocal of the resistivity. Furthermore, the smaller leakage current is wanted to achieve a better device, where the BF_2^+ and gallium doping has result less leakage current.

Keyword: P-type doping; Doping concentration; Polysilicon; Threshold voltage; Resistivity; Conductivity.

1.0 INTRODUCTION

The development of polysilicon technology was driven by the use of polysilicon as a gate electrode or as an intermediate conductor in two-level structure for integrated circuits [1]. Once it was developed, polysilicon technology has found use in the p-channel Metal Oxide Semiconductor Field Effect Transistor (PMOS) applications. In PMOS devices, the polysilicon gate or simply poly gate must be doped to render it conductive and this is done with either diffusion or ion implantation [2]. The deposited polysilicon can be doped with p-type dopant for the PMOS devices. The PMOS transistor is built with an n-type substrate and has regions of p-type semiconductor adjacent to the gate called the source and drain, as shown in Fig.1 below.

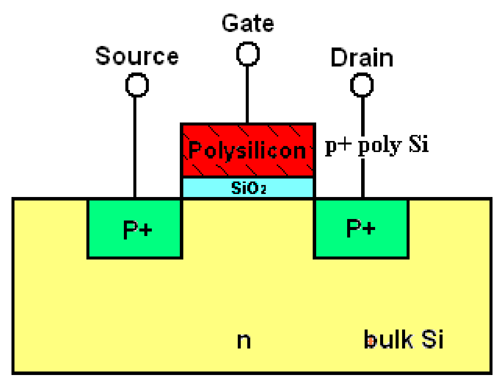

Fig.1 PMOS transistor.

Polysilicon deposited directly on silicon substrates with conformal polysilicon deposition [4]. Polysilicon when used as p-type dopant in the VLSI applications, are typically deposited on SiO_2 surface with boron or BF_2^+ as dopants [5]. The structure of polysilicon is strongly influenced by dopants, impurities, deposition temperature and post-deposition heat cycles [3]. The polysilicon can be doped with p-type or n-type impurities to create a p+ or n+ polysilicon gate.

Different types of p-type doping and doping concentration have been introduced to improve the polysilicon structure in order to get better electrical characteristics of polysilicon for PMOS applications.

In this study, the investigation has been done to show the effect of p-type doping of polysilicon for BF_2^+, boron, gallium and indium by using simulation software of SILVACO TCAD tools. The main purpose of the study is to determine the suitability of p-type doping at certain level of dose for PMOS applications. This study also explains the processing steps for build PMOS device using SILVACO's TCAD software. The polysilicon thickness was set at 0.2um and 10nm for gate oxide thickness.

2.0 PROCESS SIMULATION

In brief, the SILVACO TCAD is semiconductor process and device simulation and design tool. It consists of ATHENA and ATLAS. The simulation is begun by write the program of building the PMOS device in the ATHENA. The program's focus upon the simulation of fabrication process. Fig.2 below shows the processing steps for build PMOS structure using ATHENA.

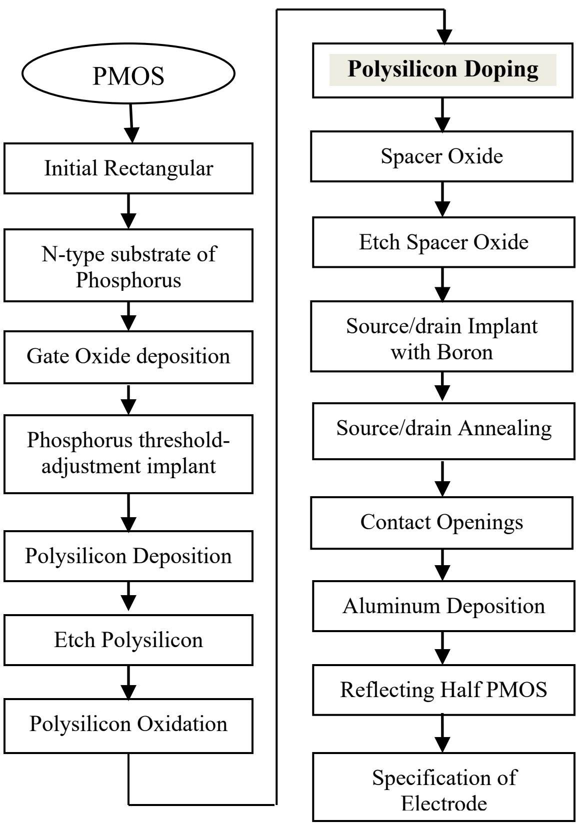

Fig.2 Processing steps for build PMOS structure using ATHENA.

3.0 DEVICE SIMULATION

Once the device is built with ATHENA and by changing the p-type doping with different level of dose in the ATHENA, ATLAS can be used to simulate the I-V curves for the PMOS. To obtain the I_D-V_{GS} curve, the drain voltage, V_{DS} was setting to -0.1V. In this simulation part, the device parameters such as threshold voltage, sheet resistance and leakage current can be extracted from this curve. To obtain I_D-V_{DS} curve, the gate voltage, V_{GS} was setting to -1.1V, -2.2V, -3.3V and -4.4V respectively. The values can be seen in the netlist in the SSUPREM4, while the figures and curves can be seeing in the TonyPlot. The TonyPlot is used for creating visual representation of the coded simulations. Fig.3 below shows the complete PMOS structure from TonyPlot.

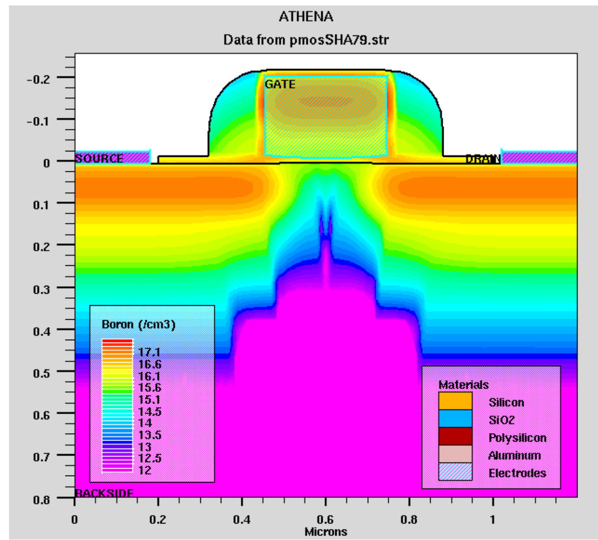

Fig.3 Complete PMOS structure from TonyPlot.

The relationship of the current and voltage for PMOS was measured for I_D-V_{GS} and I_D-V_{DS} curves. Fig.4 shows the I_D-V_{GS} curve for BF_2^+ doping at dose 10^{15} (atoms/cm^3). Fig.4 below show, the drain current started to decrease linearly with gate voltage when the V_G is less than -1.125V. This phenomenon happened because the current is allowed to flow from source to drain after gate voltage exceeds threshold voltage. In this case, since the negative gate voltage was injected into the device, so the more negatively gate voltage is needed to ON the device.

Fig.5 shows the I_D-V_{DS} curve for BF_2^+ doping at dose 10^{15} (atoms/cm^3). It shows the level of saturation current allowed in the device for the PMOS at applied gate of -1.1V, -2.2V, -3.3V and -4.4V respectively. In Fig.5, the current is zero for gate voltage below threshold voltage. But as the increasing of the negative gate voltage the threshold voltage increases, it's happened due to the fact that increasing negative gate voltage induces more and more negative charges, thereby allowing more current, I_D to flow through the p-channel for a given voltage V_{DS} and the saturation will occurs at higher drain voltage, V_{DS}.

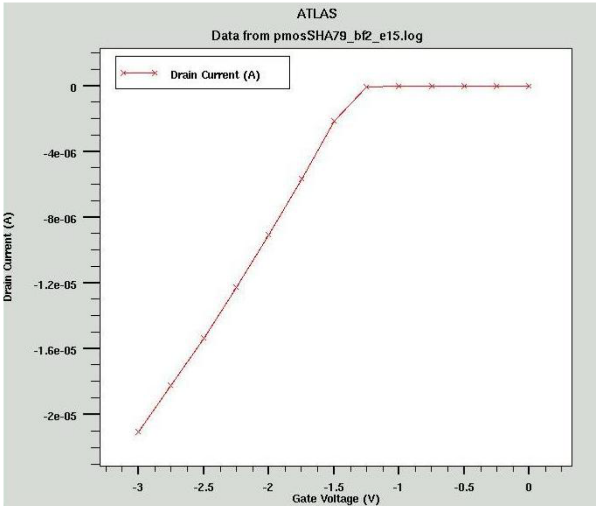

Fig.4 I_D-V_{GS} curve for BF_2^+ at dose 10^{15} (atoms/cm^3).

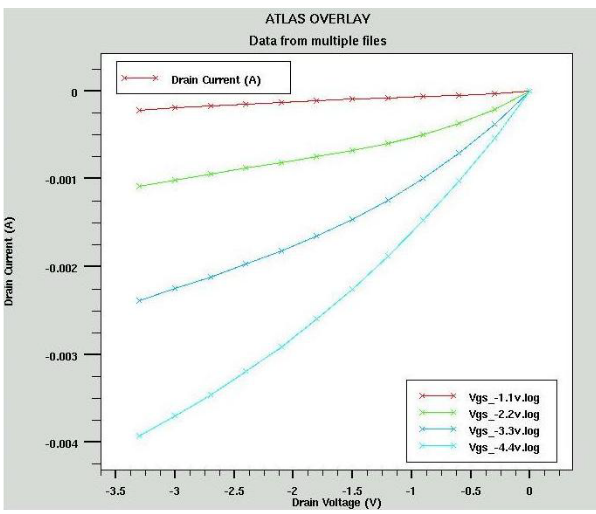

Fig.5 I_D-V_{DS} curve for BF_2^+ at dose 10^{15} (atoms/cm^3).

4.0 SIMULATION RESULTS AND DISCUSSION

By changing p-type doping with various concentration at range from 10^{11} to 10^{20} (atoms/cm^3), has influence the characteristics of PMOS device. These give results variation in the I-V curves, resistivity, conductivity and leakage current. The results of all tests were plotted and viewed using TonyPlot.

4.1 I-V Characteristics.

In order to find better characteristics of PMOS in SILVACO TCAD tools, the different p-type doping with various concentration was performed to get the suitability of the level of dose for PMOS applications.

Fig.6 shows the I_D-V_{GS} curve for BF_2^+ at dose 10^{11} (atoms/cm^3). It shows that BF_2^+ doping have produced inverted curve then the expected curve, same also to others doping types for boron, gallium and indium. It can be conclude that, all p-type doping for ions dose at 10^{11} (atoms/cm^3), are cannot be used to doped the polysilicon. Which mean the number of atoms are not enough to cover the area which are implanted in the polysilicon.

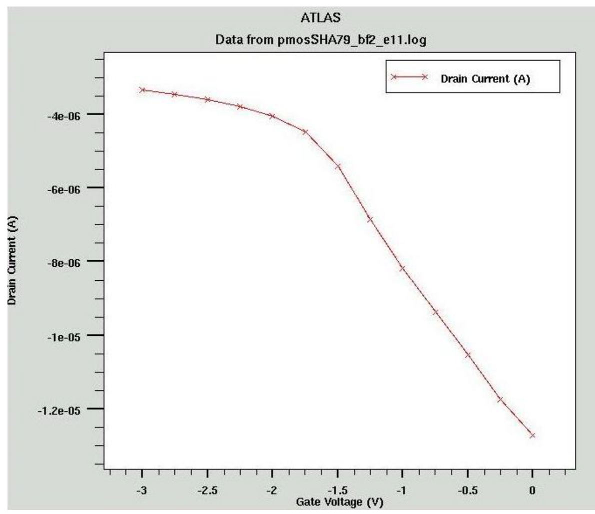

Fig.6 I_D-V_{GS} curve for BF_2^+at dose 10^{11} (atoms/cm^3).

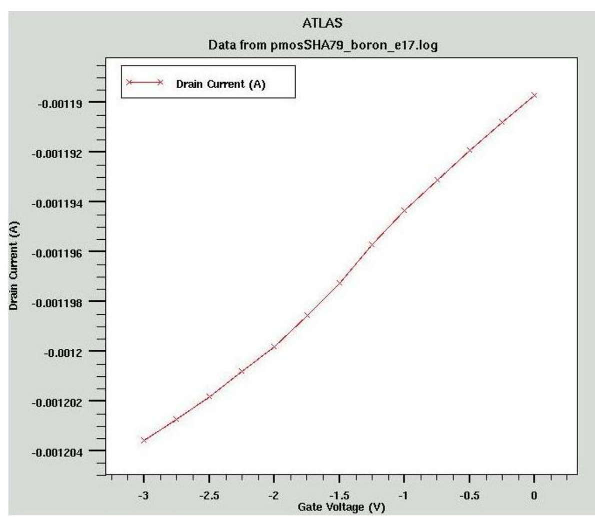

Fig.7 I_D-V_{GS} curve for boron doping at dose 10^{17} (atoms/cm^3).

Fig.7 shows the I_D-V_{GS} curve for boron at dose 10^{17} (atoms/cm^3). At this level of dose of 10^{17} (atoms/cm^3), it can be seen the boron atoms can not produced accurate curve as others doping. In addition, it shows that boron doping has produced large drain current at the same level of drain voltage that applied to all types.

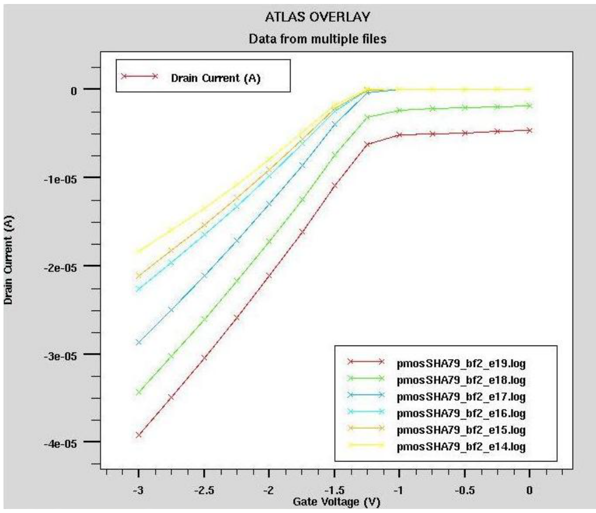

Fig.8(a) The overlay of I_D-V_{GS} curve for BF_2^+ doping at dose 10^{14} to 10^{19} (atoms/cm^3).

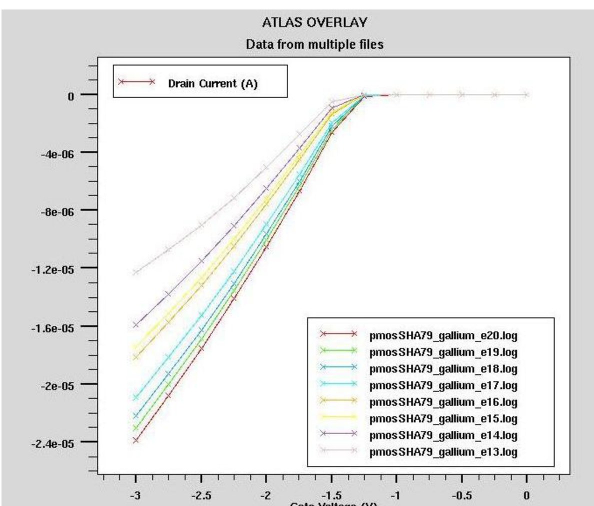

Fig.8(b) The overlay of I_D-V_{GS} curve for Gallium doping at dose 10^{13} to 10^{20} (atoms/cm^3).

Fig.8 (a) and (b) shows the overlay of I_D-V_{GS} curve for BF_2^+ doping at dose from 10^{14} to 10^{19} (atoms/cm^3) and gallium doping at dose from 10^{13} to 10^{20} (atoms/cm^3) respectively. From both figures, it shows that at dose concentration 10^{14} (atoms/cm^3) is the most effective than others doping concentrations. This level of dose is required to make PMOS device more efficient. These two types of doping has produce quite same of threshold voltage that are between the range of 1.0V to 1.3V.

4.2 *Resistivity.*

The value of sheet resistance can be extracted form the I-V curve. From the value of sheet resistance, the resistivity of the device can be obtained, according to the formula below.

The resistance of the material can be expressed as

$$R = \frac{\rho}{t} \cdot \frac{L}{W} \qquad (1)$$

Where the ρ is the resistivity, t is the thickness of polysilicon, L and W is the length and width of the material. This expression can be rewritten as

$$R = R_S \cdot \frac{L}{W} \qquad (2)$$

Where R_S is the sheet resistance and has units of Ω/square. By equalities equation (1)=(2), the value of resistivity can then be written as

$$\frac{\rho}{t} = R_S \qquad (3)$$

$$\rho = R_S \cdot t \qquad (4)$$

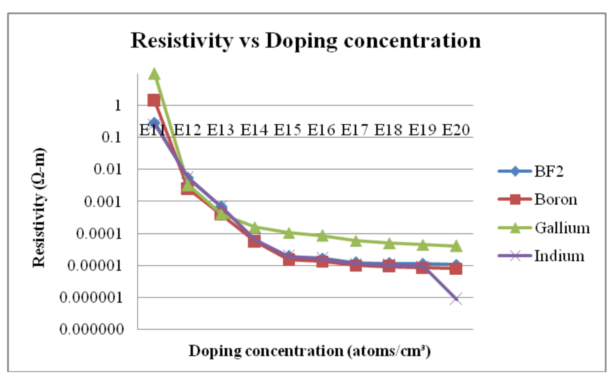

Fig.9 Resistivity at various doping concentration.

The resistivity at various doping concentration is shown in Fig.9 above. From figure 9, it shows that the resistivity,ρ will gradually decrease as a concentration of dopant increase for dose from 10^{11} to 10^{20} (atoms/cm^3). It can be concluded that, the resistivity of polysilicon will reduce by adding more dopant into it. Lower resistivity is needed in order to obtain higher conductivity, where the lower the resistivity of polysilicon, the better the conducting ability. From figure above, shows that the indium has lowest resistivity.

The resistivity of polysilicon is higher than single-crystal silicon with similar doping levels. The high resistivity in lightly implanted polysilicon is caused by carrier traps at the grain boundaries. Once these traps are saturated with dopants, the resistivity decreases rapidly and approaches the resistivity for implanted single-crystal silicon.

4.3 Conductivity.

The conductivity is the reciprocal of the resistivity, therefore, from the resistivity, the conductivity can be determined by using the formula

$$\sigma = \frac{1}{\rho} \tag{1}$$

Where σ is the conductivity and has units of $(\Omega\text{-m})^{-1}$ and ρ is the resistivity. Fig.10 shows a correlation between conductivity at various doping concentration. The conductivity is the reciprocal of the resistivity. Therefore, as the doping concentration increases, the polysilicon conductivity increased as expected as shown in Fig.10 for dose from 10^{11} to 10^{20} (atoms/cm^3). It can be concluded that, by adding more dopant into polysilicon will leads to higher conductivity. Therefore, the higher conductivity is needed in order to become a better material. From figure, it shows that the indium has produced higher conductivity.

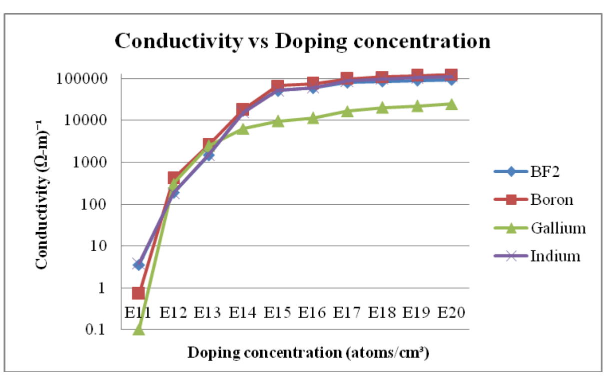

Fig.10 Conductivity at various doping concentration.

Since indium is a metal element and indium is the element that is lower position than boron and gallium in group III, therefore it has higher conductivity. This is because an electrical conduction takes place in elements and materials where the attractive hold of the protons on the outer ring electrons is relatively weak. In such a material, these electrons can be easily moved, which sets up an electrical current.

4.4 Leakage Current.

The relationship of leakage current with various doping concentration for four types doping is shown in Fig.11. From Fig.11 below, it can be seen that the leakage current of polysilicon is increases directly with the increase of level of dose from 10^{11} to 10^{20} (atoms/cm^3). The leakage current must be smaller, in order to have a good device. That's means, the BF_2^+ and gallium doping are suitable doping used to dope polysilicon, since it has produced smaller leakage current as shown in figure below.

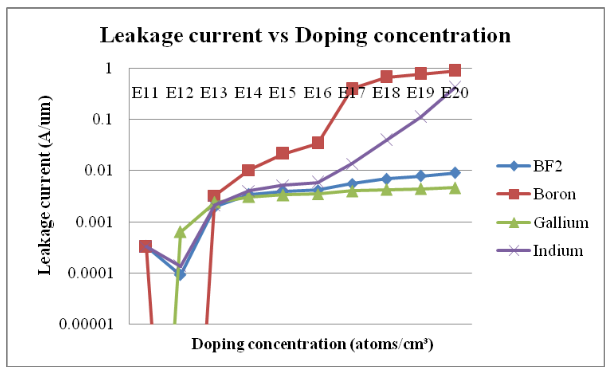

Fig.11 Leakage current at various doping concentration.

5.0 CONCLUSIONS

In this paper, the effect of different p-type doping at various concentration has been studied using SLVACO's TCAD software. The performance of the PMOS device is different, when each time the doping concentrations are changed. It is found that, the threshold voltage, resistivity, conductivity and leakage current has effect the characteristics of PMOS device. It can be concluded that, by increasing the doping concentration from 10^{11} to 10^{20} (atoms/cm^3), has result highest threshold voltage, greater conductivity, higher leakage current and lower resistivity.

6.0 REFERENCES

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