International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 8, August - 2013

Modelling for Formation of Source/Drain Region by Ion Implantation and Diffusion Process for MOSFET Device

[1]Supratim Subhra Das [2]Ria Das
[1,2]Assistant Professor, Mallabhum Institute of Technology, Bankura, Bishnupur, West Bengal

Abstract

The main aim of this paper is to optimize the parameters needed to fabricate the MOSFET device using Active simulation process (simulator: MT3.00). The simulator consists of three programs hidden under one shell called MicroTech^{TM}. It is well known that to fabricate MOSFET device, one of the most important steps is the formation of Source/Drain region. The ion implantation or diffusion process with different impurities is used for formation of source/drain region of MOSFET device. A comparative study is reported here between Arsenic and Boron concentration profile with ion implantation and diffusion process using the MicroTech simulator. To fabricate the n-channel MOSFET device, it is observed that in case of 70KeV ion energy doping concentration is maximum near to the surface, as observed from boron concentration profile using ion implantation process, which is also observed in case of p-channel MOSFET. To fabricate source/drain region of MOSFET device using diffusion process, it is observed that in case of 500⁰C doping concentration is maximum near to the surface for both kinds of dopants. Ion implantation process is more effective compared to the diffusion process as observed from the doping concentration profile in case of all dopants.

1. Introduction

Integrated circuits are made in the top surface of semiconductor wafers. This is called planner technology and all the structuring of silicon, deposition of layers and the metallization takes place in the top of 2-5 µm of the silicon surface. Integrated circuits occupy up to 1-2cm^2 of the silicon surface area[1].There are process to form source and drain region,ion implantation and diffusion process for MOSFET device.The main aim of the paper is to study the process parameters to optimize the MOSFET device performance.For this purpose a two dimensional process and device simulator for Si based devices (MicroTech^{TM})are used to do the simulation.

Most common impurities used in making ICs in Si are arsenic as donor and boron as acceptor. They all have a good solubility in Si and concentration up to 10^{20}/cm^2 can be reached. The ionization energies of these atoms are very small, <0.06eV, so at a temperature of 75⁰ K 99% of impurities are ionized[1]. Arsenic(for n-channel) implantation used for highly doping contact region and boron(for p-channel)to create buried and junction of too high concentration

2. Case Study

Ion Implantation

Ion implantation is a process by which energetic impurities atoms can be introduced into a single crystal substrate in order to change its electronic properties. Implantation is carried out with ion energies in the 52500keV range. A wide range of dose from 10^{11} to 10^{17} ions/cm^2,are routinely introduced during the fabrication of a MOS device. And even a lower dose to higher dose is possible. Heavy ions like arsenic do not travel as far in the crystal as light ions like boron. If different ions are implanted with a same energy, heavy ions stop at a shallower depth. Because of the different scattering that each ion will undergo in the Si and implanted profile will result that is all most of Gaussian ship;it has a mean depth R_p, and spread $\Delta R_{p.}$ Both will depend on the energy that is used for the implant[2].The spread of the ions depends on the range travelled with deeper ranges allowing for more random stopping events .The heavy ions with the smaller range have a more narrow distribution than the light ions.

The peaks of the profiles can be described by a Gaussian formula:

$N(x)=N_{peak}\exp(-(x-R_p)^2/2\Delta R_p)$ …………. (i)

Standard deviation ,i.e. the distance from the peak concentration to concentration is equal to $0.61N_{peak}$.The implant dose and the integral of the profile can be found from,

$Q=\sqrt{2\pi}N_{peak}\ \Delta R_p\ \ cm^{-2}$ …………..(ii)

Ions(charged atoms or molecules) are created via an enormous electric field stripping away an electron .These ions are filtered and accelerated toward a target wafer, where they are buried in the wafer. The depth of the implantation depends on the ion energy(voltage).The dose is very carefully controlled by integrating the measured ion current.

Advantages

1. Very precise control of the dose.
2. Independent control of impurity depth and dose.
3. Very fast (1 6" wafer can take as little as 6 seconds for a moderate dose).
4. Can perform retrograded profiles that peak at points inside the wafer (as opposed to the wafer surface).
5. Complex profiles can be achieved by multi-energy implants.
6. It is a serial process.

Disadvantages

1. Very deep and very shallow profiles are difficult.
2. Not all the damage can be corrected by annealing.
3. Typically has higher impurity content than dose diffusion.
4. Often uses extremely toxic gas sources such as arsine(AsH3),and phosphine (PH3).
5. Expensive.

Diffusion

Diffusion is a relatively straight forward process by which impurities may be introduced into selected regions of a semiconductor, for the purpose of altering its electronic properties. Diffusion allows the formation of source and drain for MOS device. Only at very high temperature it is possible for impurity atoms to move through a crystal lattice. The force to move them can in practice be a diffusion force. The impurity atoms to generally will not be neutral (as these high temperature they certainly will have been ionized). During diffusion process one can vary the time using the same temperature and one can vary the temperature using the same time, to study the doping concentration with distance, which is essential to form the source/drain terminal for MOSFET device. Mathematically, diffusion is described by

$J=-D_N\partial N/\partial x$ …………………(iii)

Here J is the flux of atoms (cm^{-2}), N the atom concentration (cm^{-3}) and D_N the diffusivity or diffusion constant for atom type N($cm^2\ s^{-1}$). This equation is known as Fick's first law and describes in fact all diffusion phenomena in nature. If the concentration N is low compared to atom density, then D is real constant. If N becomes comparable with the atom density, then the diffusing atom 'see' each other and interest; D will be a function of N in that case. The flux is in the positive x-direction and for any position in the Si having:

$\partial N/\partial t=\partial J/\partial x$ ……………………..(iv)

This is simply a law of continuity: the flux coming into an element of lengh δx minus the flux going ou of it, i.e. δJ, remains behind in the element δx and builds up the local concentration in time. This is Fick's law and we can substitute the first one o give:

$\partial N/\partial t=D_N\partial^2N/\partial x^2$ ……………… (v)

The evaluation of concentration profile of N in the Si is a solution to the above equation

For the special condition that the source of dopants at the interface is finite with a value of Q(cm^{-2}), the solution is given by

$N(x,t)=Q/\sqrt{\pi D_N t}\exp[-(x/2\sqrt{D_N t})]$ …….. (vi)

This the Gaussian formula for the dopant concentration in time and space. If the source at the interface is infinite, which is the case if the silicon is heated in the presence of a gas containing the dopant, then the Si is

$N(x,t)=N_0\mathrm{erfc}(x/2\sqrt{D_N t})$ …………….(vii)

$\mathrm{Erfc}(x) = 1-\mathrm{erfc}(x) = 1-2\sqrt{\pi_0}\int_0^y \exp\,(x^{-2})dx$

…………. (viii)

In both cases a characteristics ‘distance’ is given by $(D_N t)^{0.5}$; erfc(1)≈0.2 so at $x=2(D_N t)^{0.5}$ the concentration of dopants is $0.2N_0$, and if $x=(D_N t)^{0.5}$, then in the case of finite source of dopants : exp(-1)≈0.37[2].

In equilibrium cases, the position of a quasi Fermi level for electron (E_{Fn}) indicates the electron concentration. And the position of a quasi Fermi level for hole (E_{Fp}) indicates the hole concentration. This is possible by defining quasi Fermi levels for electron and hole, to be used instead of the Fermi level in equations,

$$n=n_0+\delta n=N_c e^{-(E_c-E_{Fn})/KT} \quad \ldots\ldots\ldots \text{(ix)}$$

$$p=p_0+\delta p= N_c\, e^{-(E_{Fp}-E_v)/KT} \quad \ldots\ldots\ldots\ldots \text{(x)}$$

The concentration of minority carriers is much smaller compared to the concentration of majority carriers have the opposite polarity from the majority carriers, so they may produce effect that are different from the effects of the majority carriers. The position of the energy bands with respect to the Fermi level in the equation of electron and hole concentration express the doping type and level.

$$n_0=N_c e^{\{-(E_c-E_F)/KT\}} =N_c e^{-(E_c-E_I)/KT}\, e^{-(E_I-E_F)/KT}$$

$$= n_i\, e^{-q\phi_F/KT} \ldots\ldots\ldots\text{(xi)}$$

$$p_0=N_v e^{\{-(E_c-E_F)/KT\}} = N_v\, e^{-(E_c-E_I)/KT}\, e^{-(E_I-E_F)/KT}$$

$$=n_i\, e^{q\phi_F/KT} \quad \ldots\ldots\ldots\text{(xii)}$$

Above equations can be transformed to express the electron and hole concentration in terms of the Fermi potential. If the position of quasi Fermi levels for electron and holes are expressed with reference to the equilibrium Fermi level in the intrinsic semiconductor (E_i), equation (9) and (10) takes the following forms;

$$n_0= N_c e^{\{-(E_c-E_F)/KT\}} \quad \ldots\ldots\ldots\ldots\ldots\text{(xiii)}$$

$$p_0=N_v e^{\{-(E_c-E_F)/KT\}} \quad \ldots\ldots\ldots\ldots\ldots\text{(xiv)}$$

The electric potential is not fundamentally different from potential energy (E_{pot}), because this quantities are directly related to each other through the electron charge (-q), which is a constant:

$$E_{pot}=-q\phi \quad \ldots\ldots\ldots\ldots\text{(xv)}$$

If the potential energy is expressed in eV, then the electric potential and potential energy have the same numerical values with different signs [4].

3. Software Issue

Micro Tec is a two dimensional process and device simulation for Si devices. Micro Tec are chosen as the simulator tools for MOSFET design because of the following reasons:

a) It is a fast simulator that dies finite difference analysis through the structure.
b) It has appealing plotting routines built in. File can be exported to other plotting programs.
c) It runs under windows.

Micro Tec: The Simulation Tool

The simulator consists of three programs hidden under one shell called Micro Tec TM. The first program is SiDif (Simulation of Diffusion) and is the process simulator. For an input file defined in the setting of the project, an output file is produced that contains the doping profile of the simulated domain. These files are numbered automatically. The second program, MergeIC (Merge to an IC)is an intermediate program between the process and device simulator and allows one to construct a device from fragments that are produced by SiDif. The output of SiDif is selected as similar as input file of MargeIC. The third program is SemSim which does the the device simulation. It uses the output of MergeIC as input or it works from analytically defined doping profile. In the former case all three programs have to be run consecutively and in the latter only a SemSim solution is enough to obtain the I-V characteristics of a particular device.

Process Simulation

A process simulator is a computer tool that calculates impurity profiles and oxide thickness. The simplest simulator will do a 1D calculation; 2D and 3D simulator are much more complicated. The computer uses the iterative procedure to determine the doping concentration as a result of a particular processing sequence. For a series of steps the variable are evaluated and readjusted until the silicon has converged to a stable value. During the course of the calculation of large matrices are, manipulated and until recently these could only be done by mainframe computers.

Device Simulation

A device simulator is a computer program that determines the current distribution and the voltage distribution inside the device. It can only do so if the device is discretised, i.e. divided up to small volume in which for its volume element t he parameters are considered constant. The program calculates the steady state solution when all devices equations are satisfied for the whole system of volume elements: current match both the electric field that exists between neighboring elements and concentration gradients within the elements. The program uses mathematical routines to discretise the device equation over the volume elements. It can use what are called finite difference or finite elements as the discretisation base.

4. Results

I. Boron Concentration Varies With Ion Energy

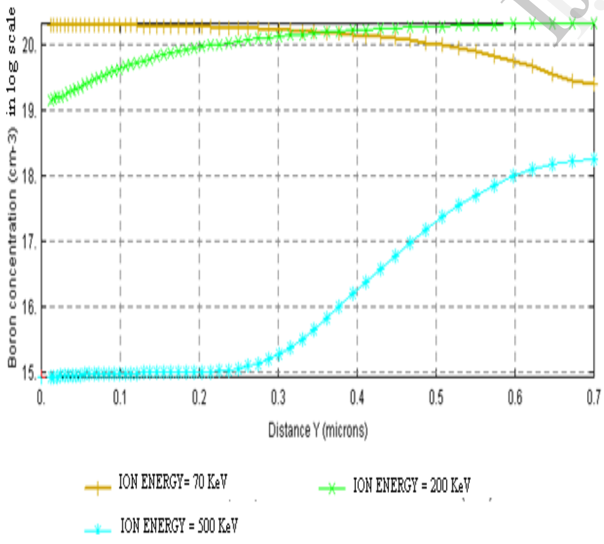

Fig 1: Boron concentration profile with different energy in silicon substrates for ion implantation process using MicroTec^{TM}

In fig1, the boron concentration profiles with different ion energy are shown here. During ion implantation process one can vary the ion energy using the same dose, to study the doping concentration with distance, which is essential to form the source/drain terminal for MOSFET device. For small amount of energy, ion cannot be penetrating deeply into the silicon. When energy increases ion can be penetrated deeply into the silicon. Maximum boron concentration is observed for 70keV ion energy with ion dose $1X10^{16}cm^{-3}$at a distance 0.2 µm from the surface of the substrate.

II. Boron Concentration Varies With Ion Dose

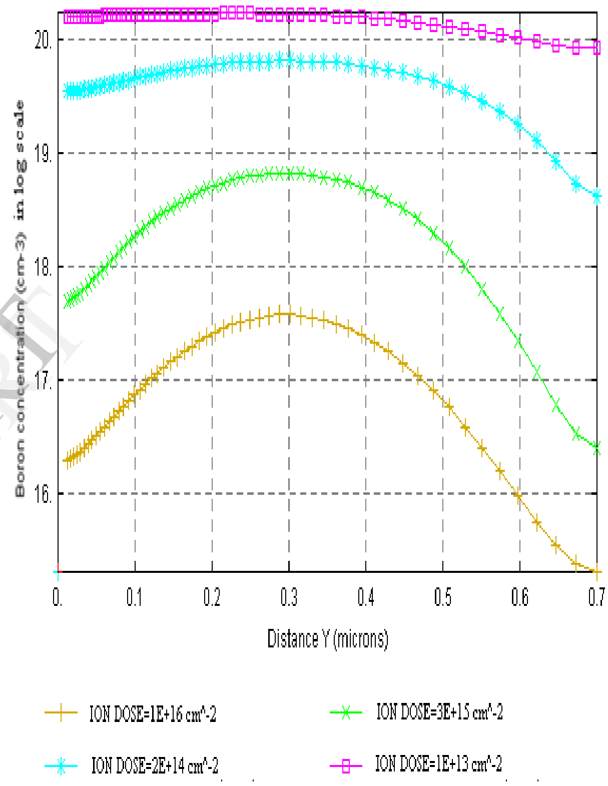

Fig 2: Boron concentration profile with different dose in silicon substrates for ion implantation process using MicroTec^{TM}

In fig2, the boron concentration profiles with different ion dose are shown here. During ion implantation process one can vary the ion dose using the same energy, to study the doping concentration with distance, which is essential to form the source/drain terminal for MOSFET device. For small amount of dose, ion cannot be penetrating deeply into the silicon. When dose increases ion can be penetrated deeply into the slicon. Maximum boron concentration is observed for $1X10^{13}/cm^3$ ion dose with ion energy 100 keV at a distance 0.15 µm from the surface of the substrate.

III. Arsenic Concentration Varies With Ion Energy

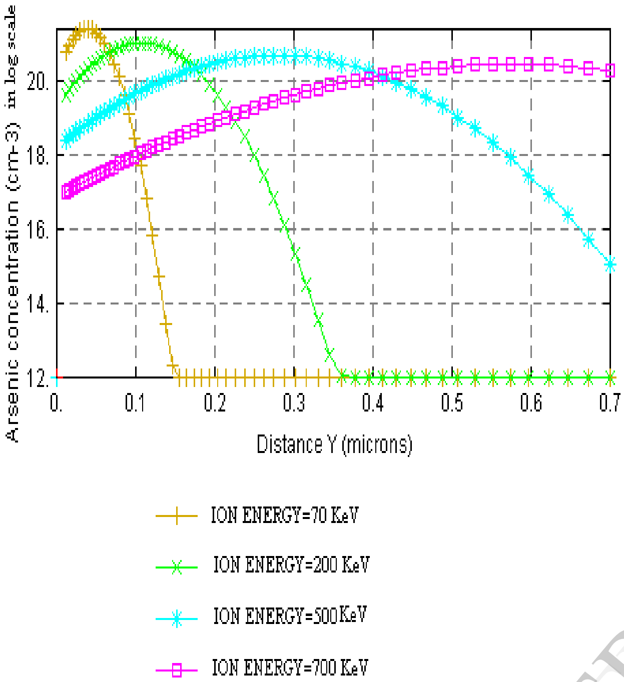

Fig 3: Arsenic concentration profile with different energies in silicon substrate for ion implantation process using MicroTec™

In fig 3, the arsenic concentration profiles with different ion energies are shown here. During ion implantation process one can vary the ion energy using the same dose, to study the doping concentration with distance, which is essential to form the source/drain terminal for MOSFET device. For small amount of energy, ion cannot be penetrating deeply into the silicon. When energy increases ion can be penetrated deeply into the silicon. Maximum arsenic concentration is observed for 70 keV ion energy with ion dose $1X10^{16}cm^{-3}$at a distance 0.05 µm from the surface of the substrate.

IV. Arsenic Concentration Varies With Temperature

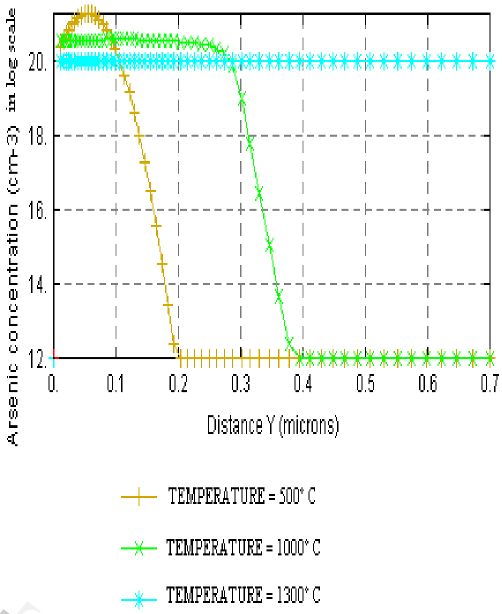

Fig 4: Arsenic concentration profile for different temperature in silicon substrate for diffusion process using MicroTec™

In fig 4, the arsenic concentration profiles with different ion temperature are shown here. During diffusion process one can vary the temperature using the same time, to study the doping concentration with distance, which is essential to form the source/drain terminal for MOSFET device. For small amount of temperature, ion cannot be penetrating deeply into the silicon. When temperature increases ion can be penetrated deeply into the silicon. Maximum arsenic concentration is observed for 500°C temperatures with time 3600s at a distance 0.05 µm from the surface of the substrate.

ISSN: 2278-0181
Vol. 2 Issue 8, August - 2013

V. Arsenic Concentration Varies With Ion Dose

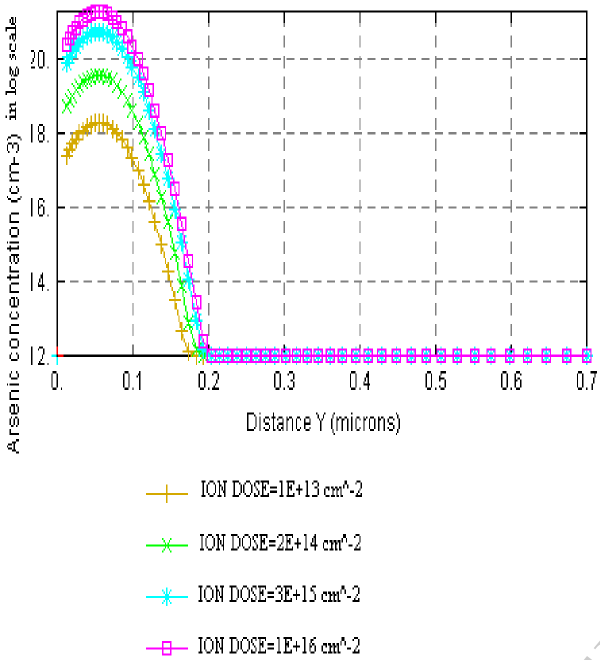

Fig 5: Arsenic concentration profile for different dose in silicon substrates for ion implantation process using MicroTec™

In fig 5, the boron concentration profiles with different ion dose are shown here. During ion implantation process one can vary the ion dose using the same energy, to study the doping concentration with distance, which is essential to form the source/drain terminal for MOSFET device. For small amount of dose, ion cannot be penetrating deeply into the silicon. When dose increases ion can be penetrated deeply into the silicon. Maximum arsenic concentration is observed for $1X10^{13}/cm^3$ ion dose with ion energy 100 keV at a distance 0.03 μm from the surface of the substrate.

VI. Arsenic Concentration Varies With Diffusion Time

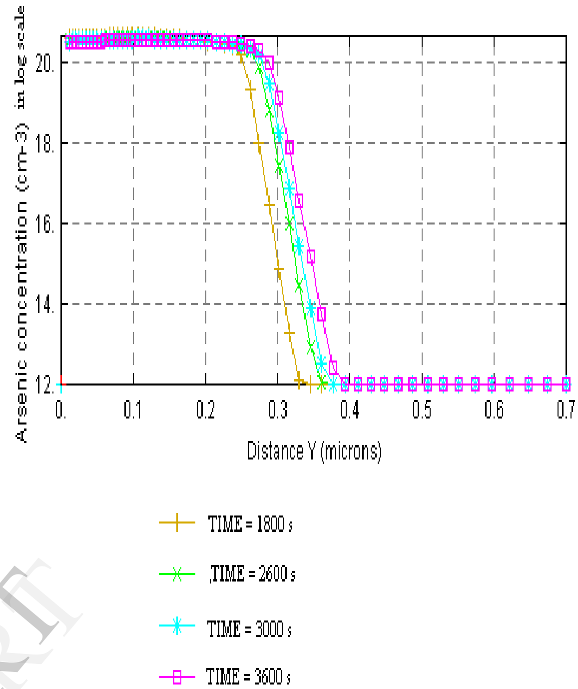

Fig 6: Arsenic concentration profile for different temperatures in silicon substrates for diffusion process using MicroTec™

In fig 6, the arsenic concentration profiles with different time are shown here. During diffusion process one can vary the time using the same temperature, to study the doping concentration with distance, which is essential to form the source/drain terminal for MOSFET device. For small amount of time, ion cannot be penetrating deeply into the silicon. When time increases ion can be penetrated deeply into the silicon. Maximum arsenic concentration is observed for 1800s with temperature 1000°C from the surface of the substrate.

VII. Boron Concentration Varies With Temperature

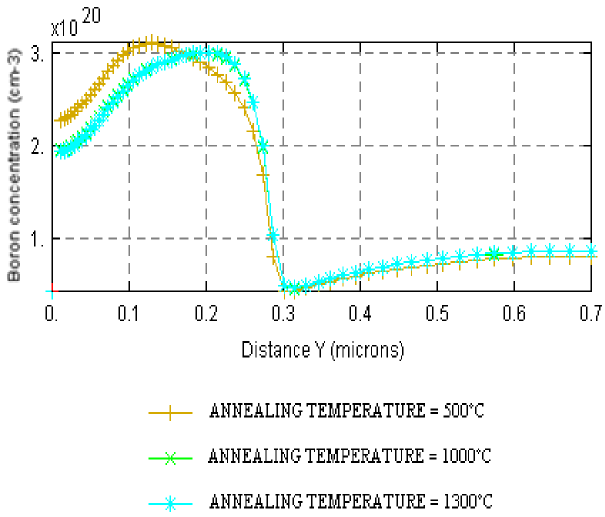

Fig 7: Boron concentration profile for different temperature in silicon substrates for diffusion process using MicroTec^{TM}

In fig 7, the boron concentration profiles with different ion temperature are shown here. During diffusion process one can vary the temperature using the same time, to study the doping concentration with distance, which is essential to form the source/drain terminal for MOSFET device. For small amount of temperature, ion cannot be penetrating deeply into the silicon. When temperature increases ion can be penetrated deeply into the silicon. Maximum arsenic concentration is observed for 500^{o}C temperatures with time 3600s with a distance 0.05 µm from the surface of the substrate.

VIII. Boron Concentration Varies With Diffusion Time

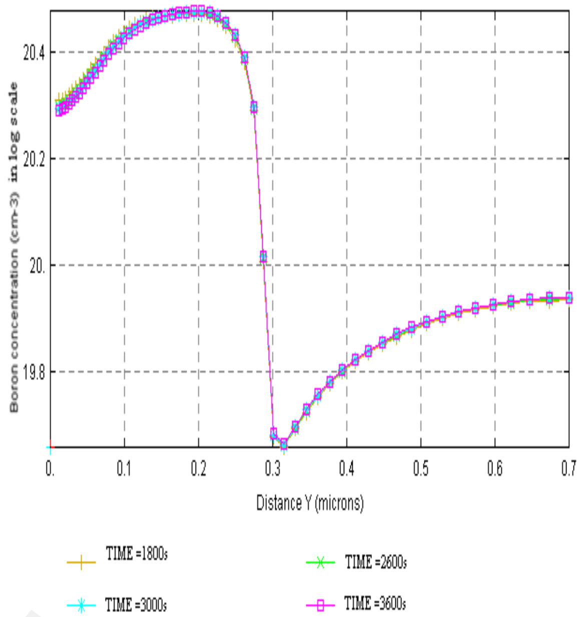

Fig 8: Boron concentration profile for different time in silicon substrate for diffusion process using MicroTec^{TM}

In fig 8, the boron concentration profiles with different time are shown here. During diffusion process one can vary the time using the same temperature, to study the doping concentration with distance, which is essential to form the source/drain terminal for MOSFET device. For small amount of time, ion cannot be penetrating deeply into the silicon. When time increases ion can be penetrated deeply into the silicon. Maximum boron concentration is observed for 1800s with temperature 1000^{o}C from the surface of the substrate.

IX. Boron Concentration Varies With Arsenic Concentration

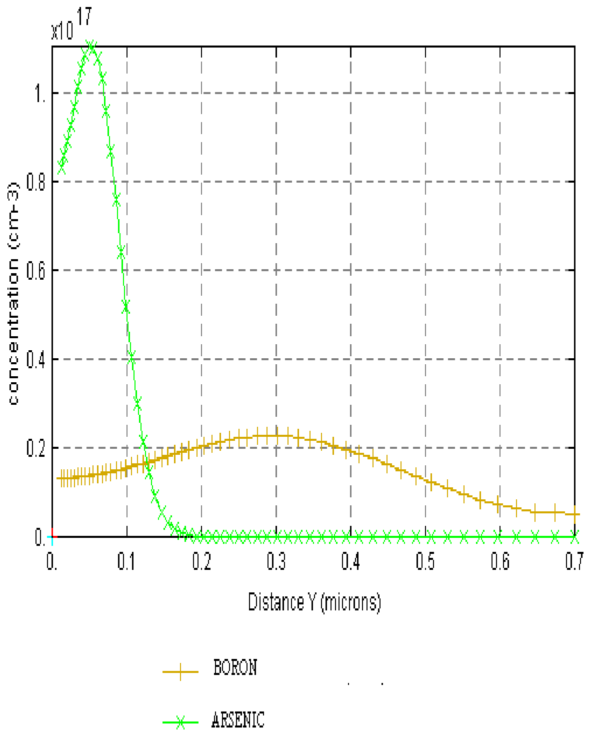

Fig 9: Comparison of boron and arsenic profiles with distance in silicon substrates for ion implantation process using MicroTec™

In fig 9, Arsenic and Boron implant profiles are shown here. There is a different profile for same energy and dose. The arsenic implant in the figure which is performed above a buried lightly doped boron layer. Arsenic ion is heavier than boron. So it has smaller range and has a more narrow distribution at same implantation energy than light boron ion. Arsenic and boron concentration is observed for $1X10^{12}/cm^3$ ion dose with ion energy 100 keV.

5. Conclusion

Our experimental output given above helps us to observe which one is the better atom for ion implantation and diffusion and what value gives the better result. For ion implantation process two different impurities are used: boron and arsenic. To fabricate n-channel and p-channel MOSFET device it is observed that in case of 70 keV ion energy doping concentration is maximum near to the surface, as observed from boron and arsenic concentration profile using ion implantation process. For diffusion process, to fabricate source/drain region of MOSFET device it is observed that in case of 500°C doping concentration is maximum near to the surface, as observed from both boron and arsenic concentration profile. Ion implantation process is more effective compared to the diffusion process as observed from the doping concentration profile in case of all dopants.

6. References

1. Sung-Mo Kang, Yusuf Leblebici; "CMOS digital Integrated Circuits"; Third edition; 2003.
2. Ton Mouthaan; "Semiconductor Devices Explained"; sixth edition.
3. James D. plummer, Micheal D. Deal, peter B. Griffin; "Silicon VLSI Technology": First edition; 2001.
4. Sima Dimitrijev; "Principal Of Semiconductor Device".