MAULANA ABUL KALAM AZAD UNIVERSITY OF TECHNOLOGY, WEST BENGAL

LAB REPORT

Ion Implantation(TCAD)

Work objectives

The objective of this laboratory work is to use the *Athena* semi-conductor process simulator to study the ion implantation and related thermal processes.

Amit Sarkar

Date:11-06-2021 **Signature of the Student**

Signature of the Lab Instructor

Laboratory Report

Department of Microelectronics & VLSI Technology

MAULANA ABUL KALAM AZAD UNIVERSITY OF TECHNOLOGY,WESTBENGAL

(FORMERLY KNOWN AS WEST BENGAL UNIVERSITY OF TECHNOLGY)

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Date	Topic discussed	Remarks	Signature of supervisor
05/06/2021	EXPERIMENT 1.		
05/06/2021	EXPERIMENT 2		
05/06/2021	EXPERIMENT 3		
05/06/2021	EXPERIMENT4		
05/06/2020	EXPERIMENT 5		

EXPERIMENT 1: In this experiment the implant analytical models: Gaussian (symmetrical) profile, single Pearson (amorphous implant), and SIMS Verified Dual Pearson (SVDP) method at different doping concentration or dose varied from `dose=1e12` to `dose=1e15` and at different energies are analysed.

SOFTWARE USED: Silvaco S.EDA tools

THEORY:

Ion Implantation Models

a) **Analytical model -** Gaussian Implant Model, Pearson Implant Model, Dual Pearson Model
b) **Statistical model-** Monte Carlo

COMMANDS:

Commonly used ATHENA statement for ion implantation:

```
implant phos dose=1e14 energy=40 pearson tilt=7
```

The implant statement is used modelling the implantation of ionized impurities into the Si wafer. The energy statement specifies the implant energy in keV. The dose statement allows the user to specify the dose of the implant. The units are in cm ^{2}. The pearson statement is a mathematical model (the Dual Pearson Model) used to simulate the ion implantation. The tilt statement allows the user to specify the angle normal to the wafer that the impurity was implanted at.

MOMENTS specifies moments for Pearson implant model.

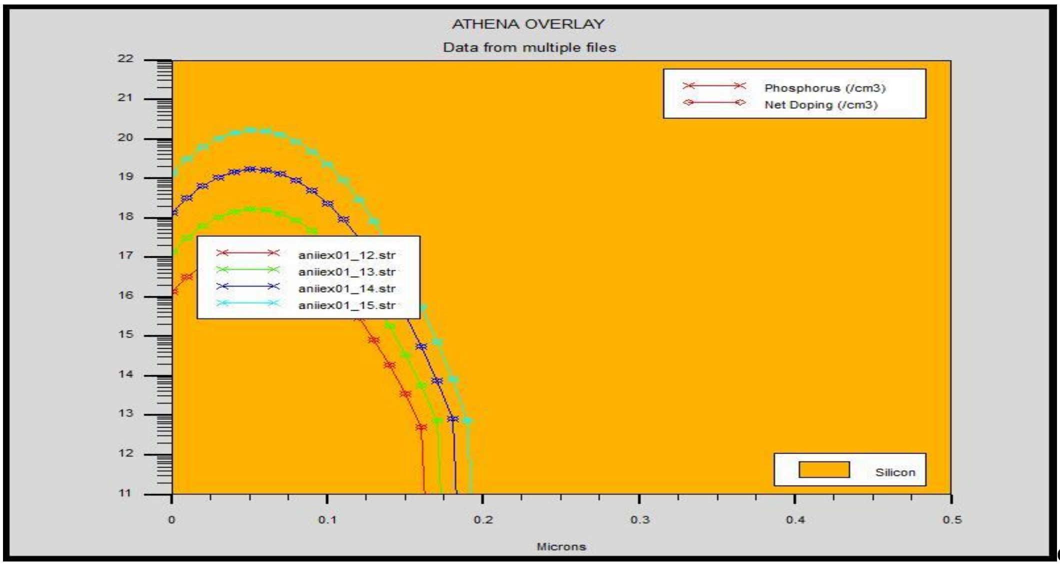
The following gives the minimum set of parameters that should be specified:

- Name of implant impurity (e.g., boron)
- Implant dose using the slider for the pre-exponential value (e.g., 4.0) and the Exp menu for the exponent (e.g., 12)
- Implant energy in KeV (e.g., 60)
- Tilt angle in degrees (e.g., 7°)
- Rotation angle in degrees (e.g., 30°)

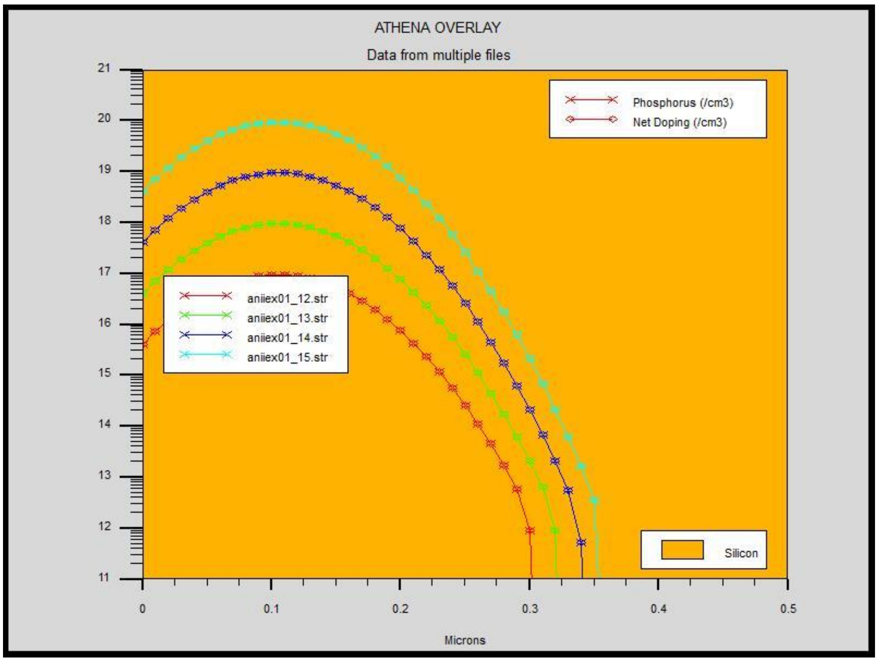
OBSERVATION:

GAUSS MEATHOD

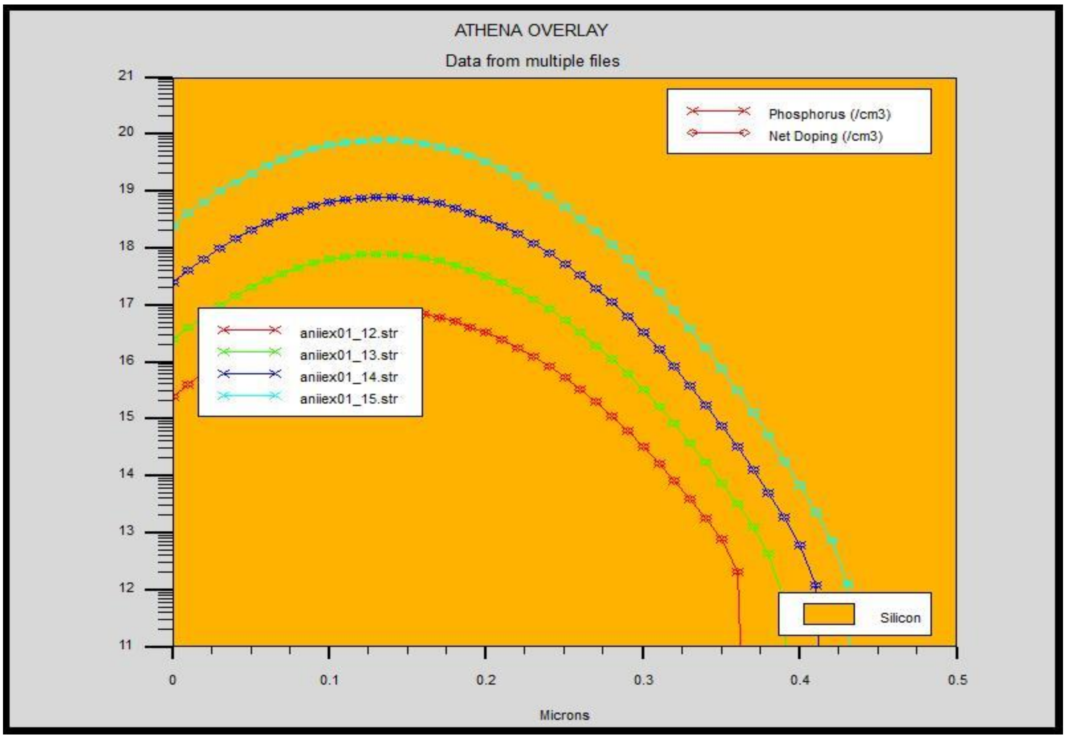
Comparison of Gauss meathod at different concentration of phosphorus at energy=40 Kev



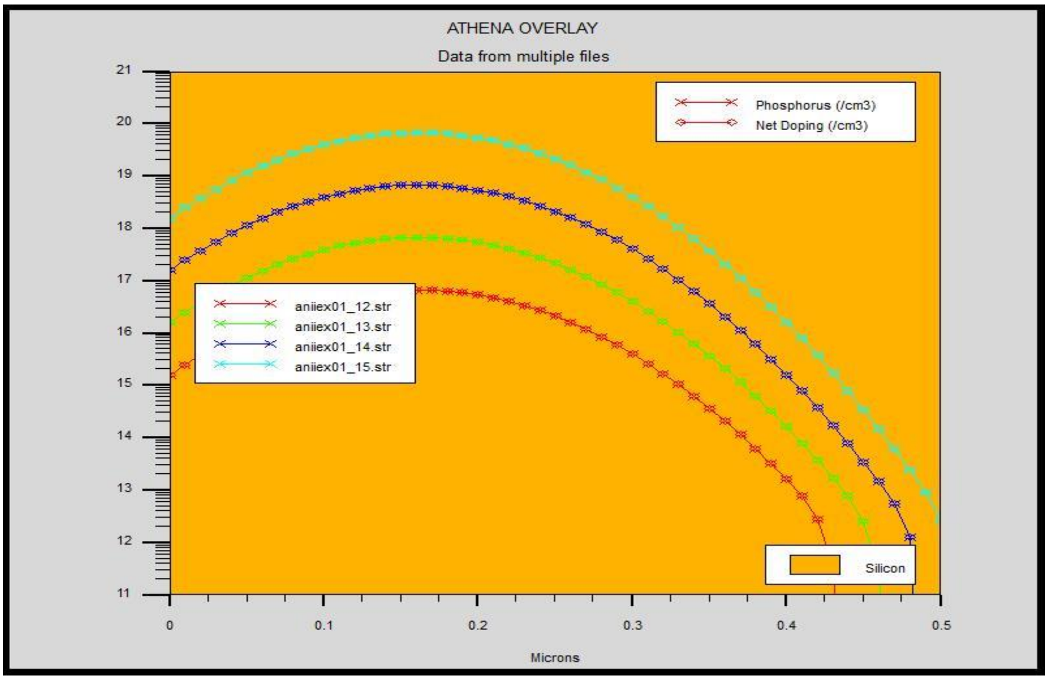
Comparison of Gauss meathod at different concentration of phosphorus at energy 80 KeV



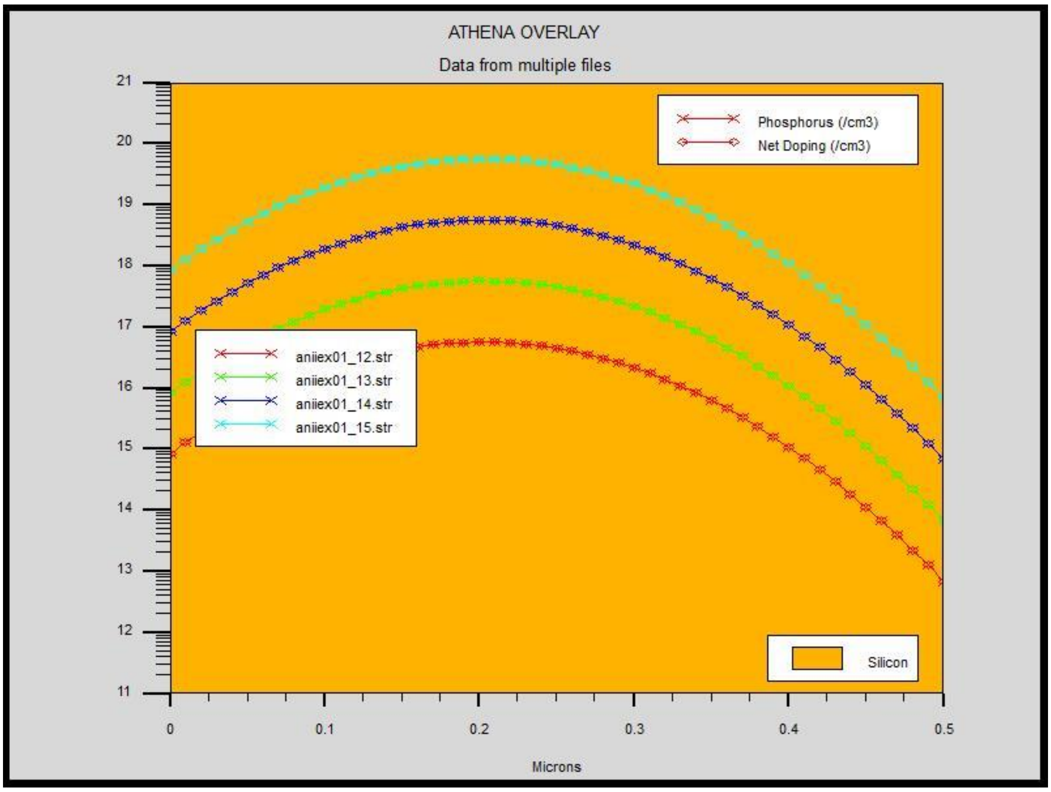
Comparison of Gauss meathod at different concentration of phosphorus at 100 KeV



Comparison of Gauss meathod at different concentration of phosphorus at energy 120 KeV

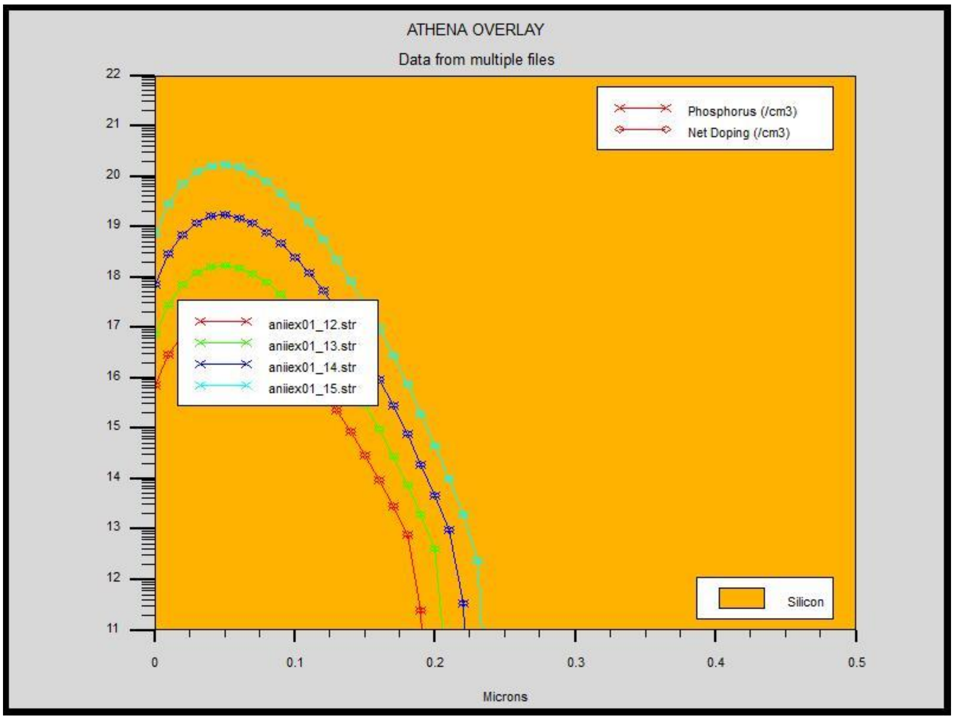


Comparison of Gauss meathod at different concentration of phosphorus at energy 150 KeV

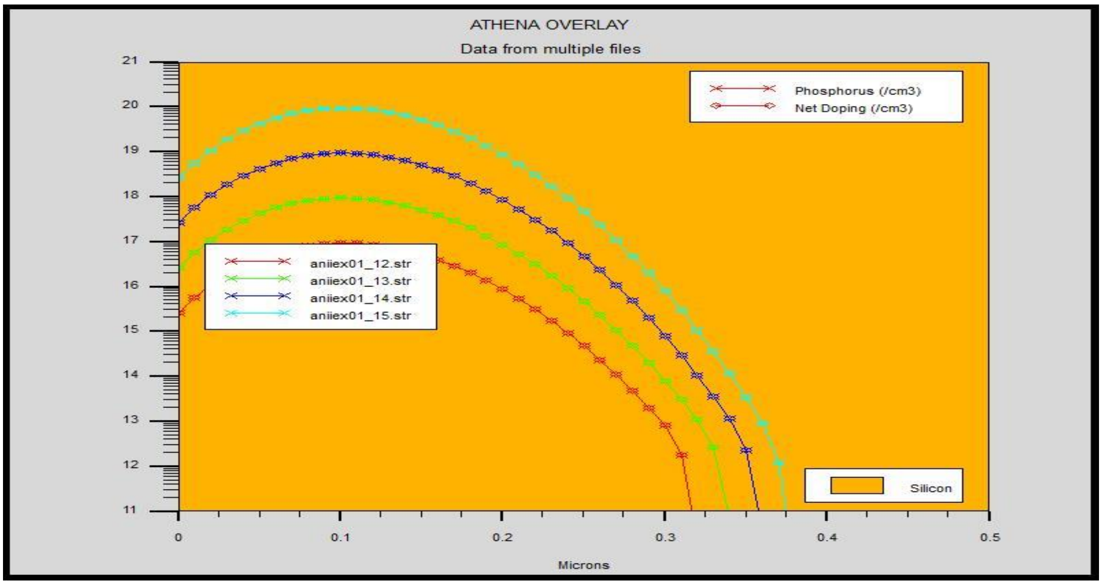


PEARSON MEATHOD

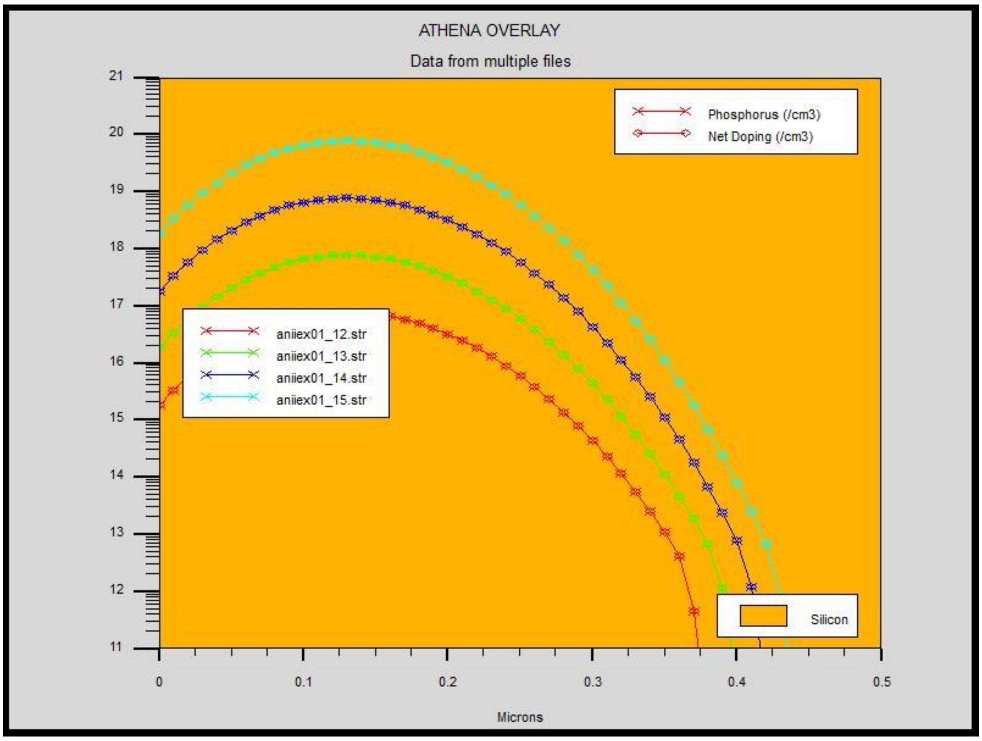
Comparison of, Pearson method at different concentration of phosphorus at energy 40 KeV



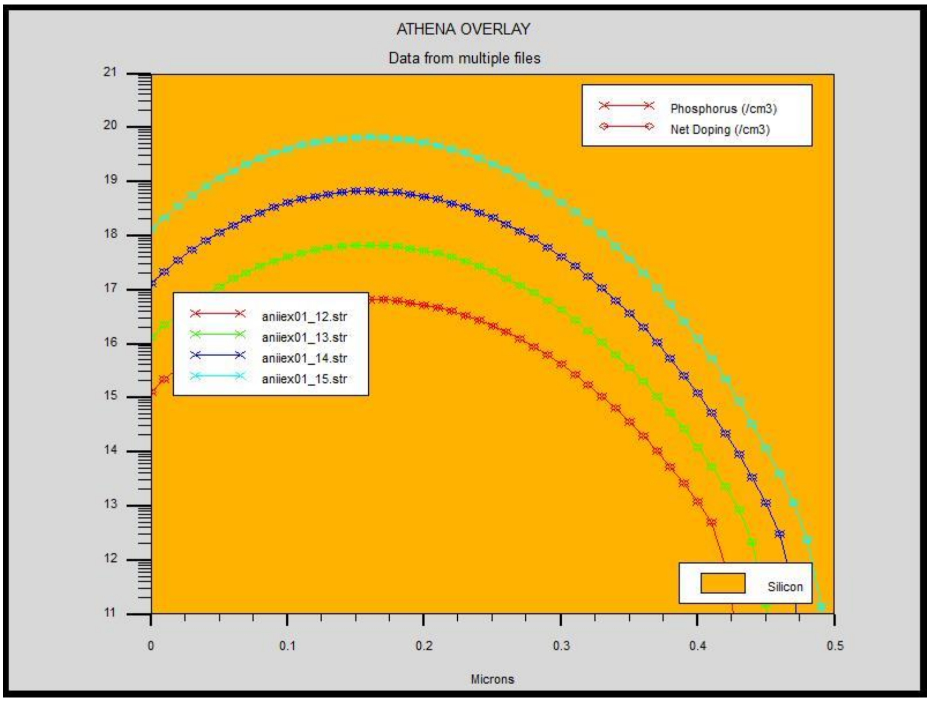
Comparison of, Pearson method at different concentration of phosphorus at energy 80KeV



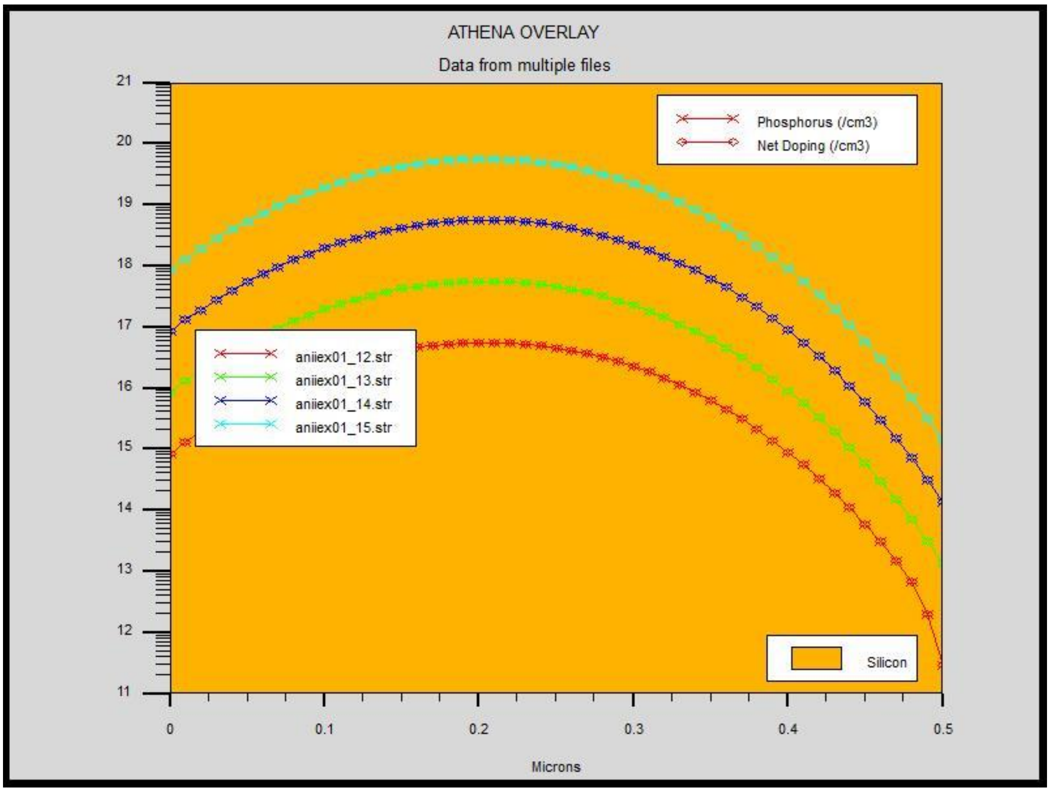
Comparison of, Pearson method at different concentration of phosphorus at energy 100 KeV



Comparison of, Pearson method at different concentration of phosphorus at energy 120 KeV

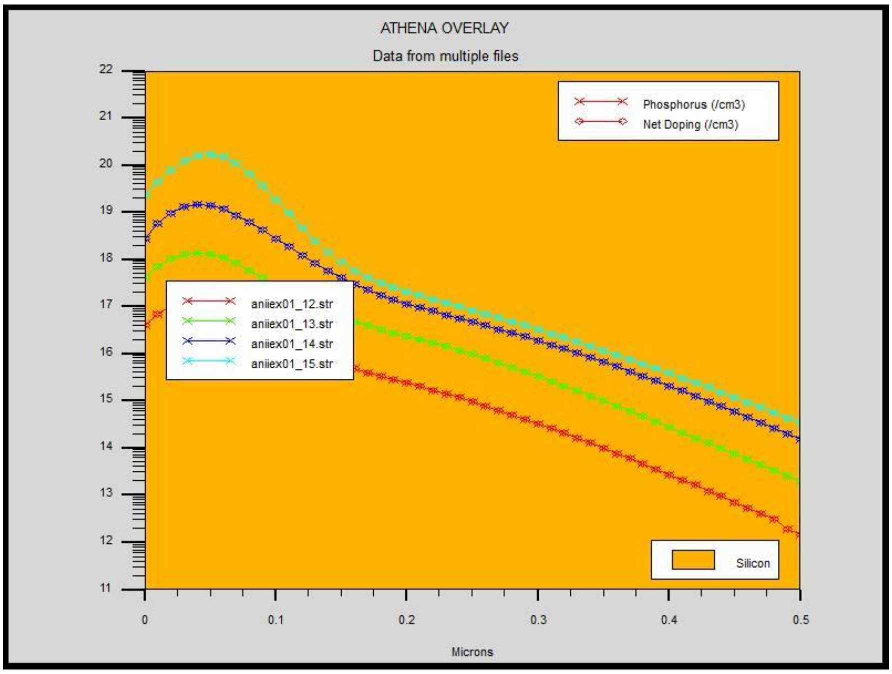


Comparison of, Pearson method at different concentration of phosphorus at energy 150 KeV

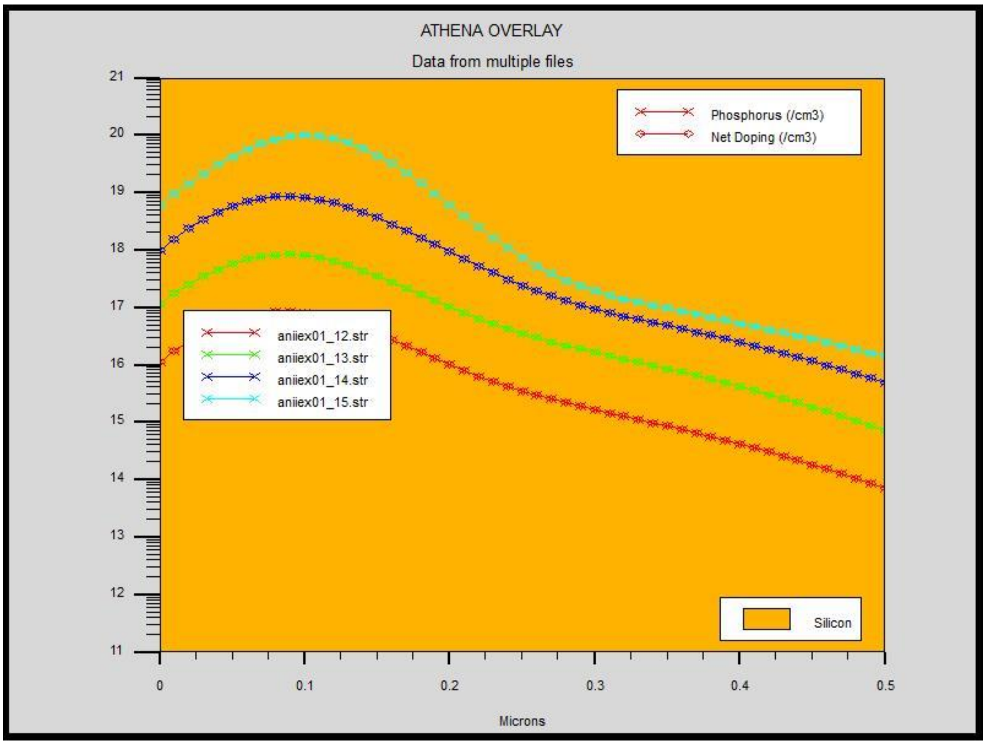


SVDP MEATHOD

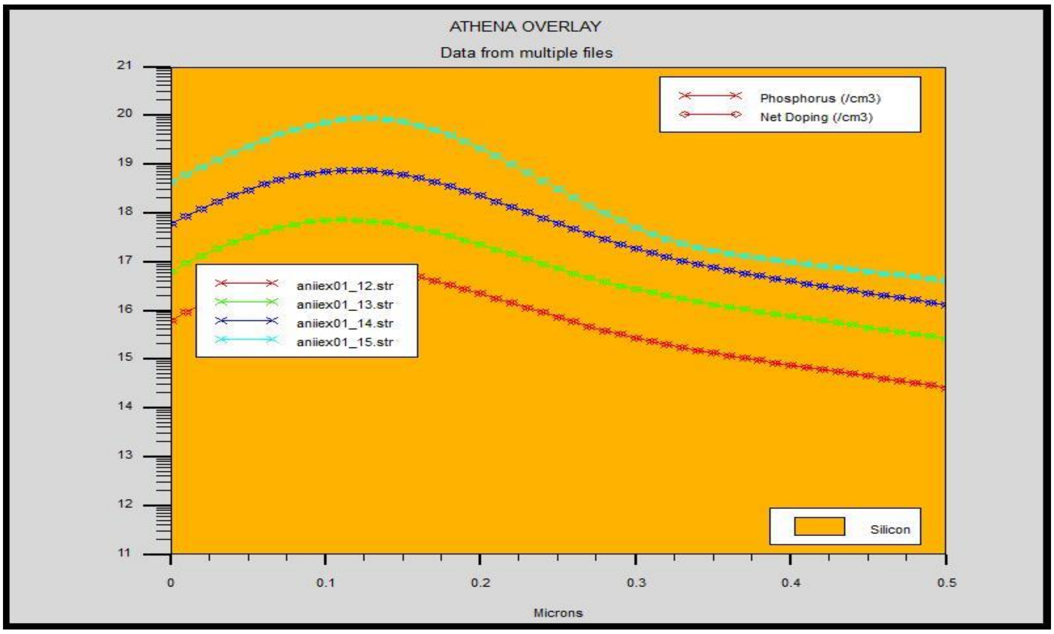
Comparison SVDP method for different concentration of phosphorus at energy 40KeV



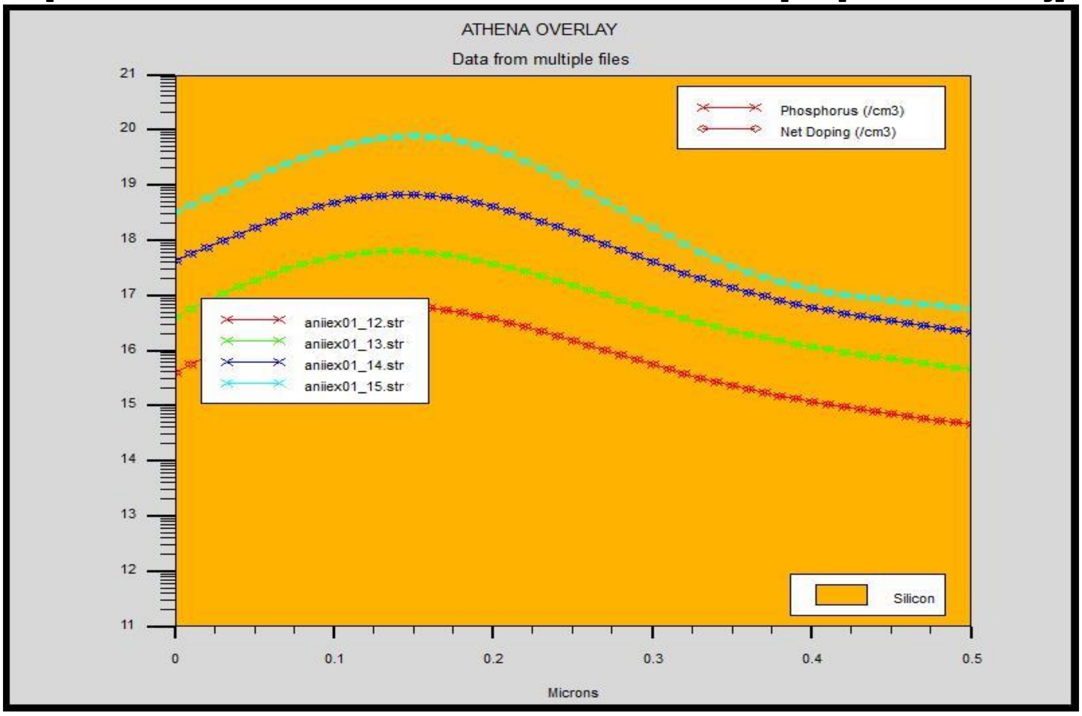
Comparison SVDP method for different concentration of phosphorus at energy 80 KeV



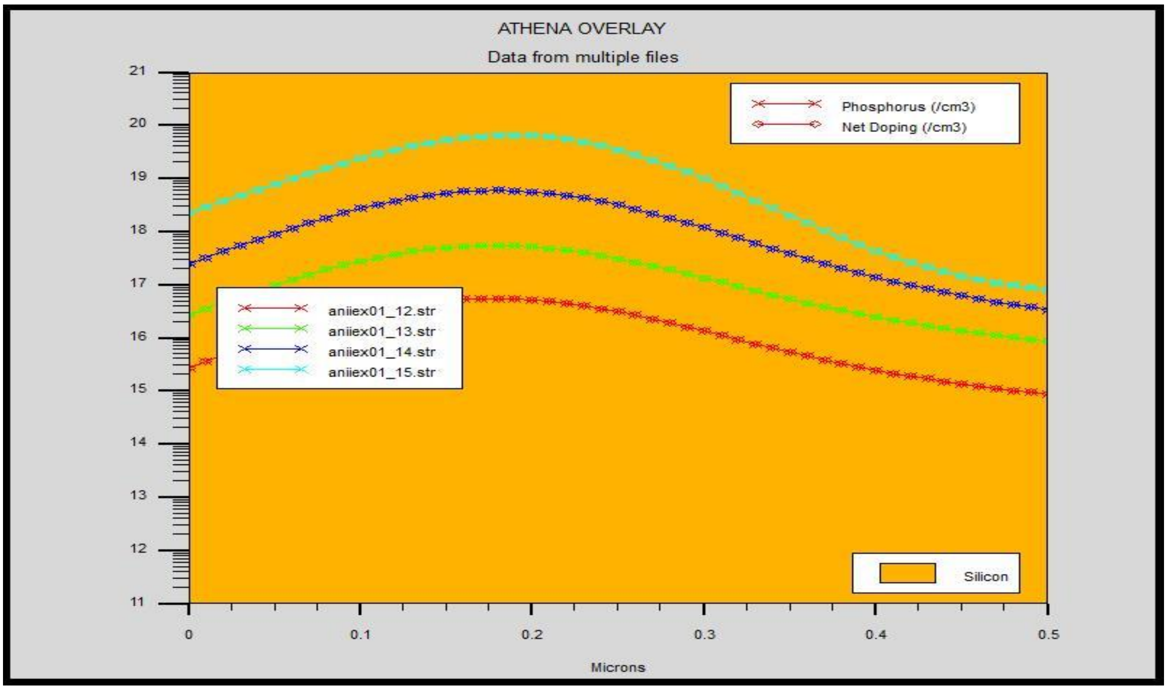
Comparison SVDP method for different concentration of phosphorus at energy 100 KeV



Comparison SVDP method for different concentration of phosphorus at energy 120 KeV



`Comparison SVDP method for different concentration of phosphorus at energy 150 KeV`



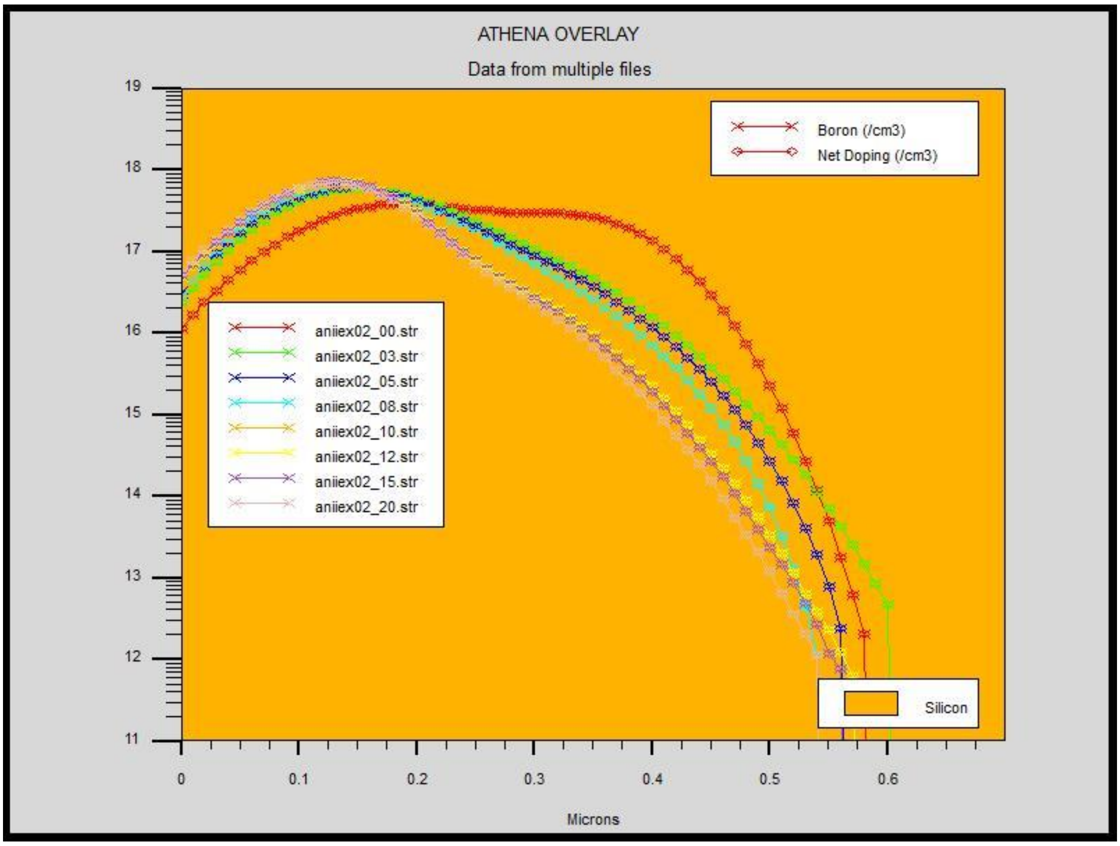
Conclusion: As we increase energy depth of penetration of doping increases and the peak also increases with increase in doping . SVDP has more depth of penetration among the three meathod.

EXPERIMENT 2: This experiment shows how 35 keV boron implant profile depends on the tilt angle as it is varied from 0,3,5,8,10,12,15,20 degrees and the SIMS Verified Dual Pearson (**SVDP**) method is used.

SOFTWARE USED: Silvaco S.EDA tools

THEORY: When implantation is performed in a single crystal Si and the direction of the penetrating ion beam is aligned with a major crystal orientation, the impurities can penetrate deeper than predictedby theory. This effect is called *"ion channelling"* and is due to the regularity of the position of the Si atoms in the crystal. To avoid channeling, ions are typically implanted at an angle off any major crystal axis of the Si wafer. Usually in practice, the ions beam is tilted by 7…10º from the (100) or the (111) directions.

OBSERVATION:



Conclusion :

As it can be seen the boron distribution is very sensitive even for a small variation in the tilt angle. The channeling effect can be clearly seen at angle less than 3° and that channeling is progressively decreased with increasing tilt angle. For a tilt of 8°, channeling is reduced significantly.

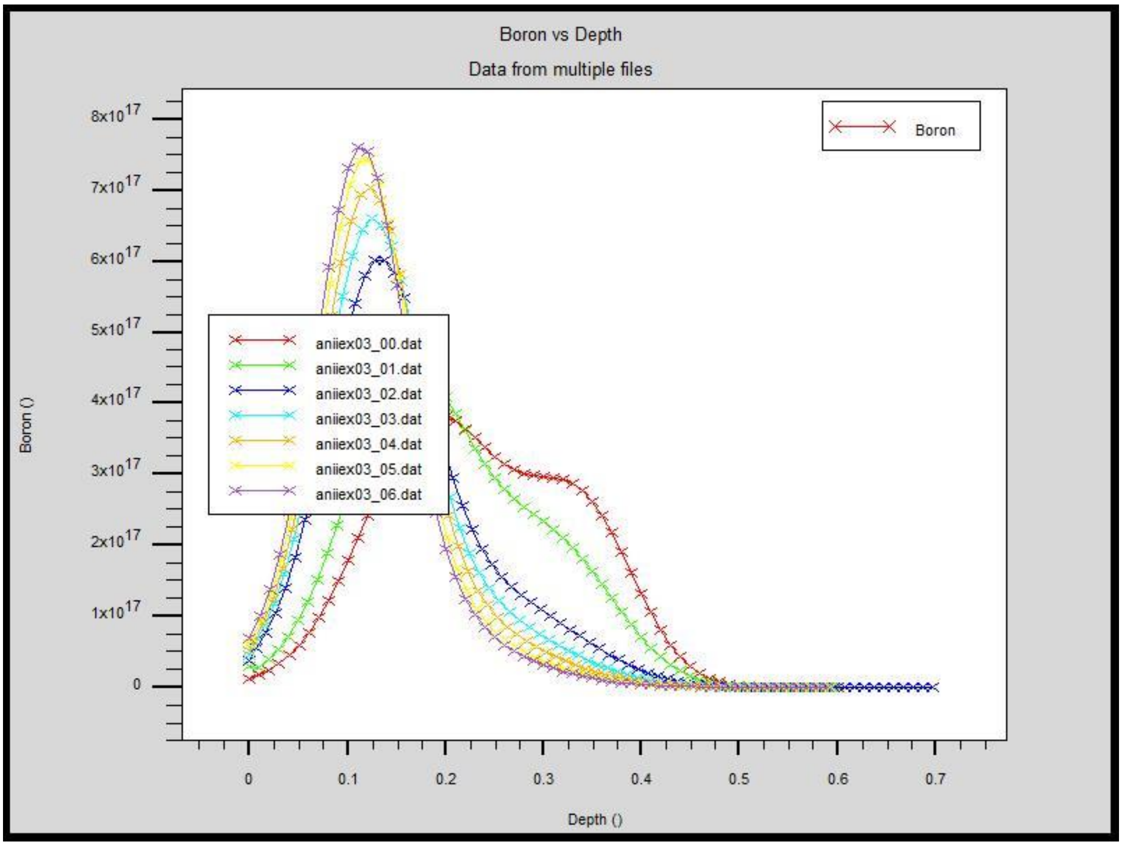
EXPERIMENT 3: This experiment shows how a 35 keV boron implant profile depends on the thickness of the surface oxide. Oxide is grown in DRY ambient at a temperature of 850 C to 1100 C. Oxidation time varies from 5 min to 200 minutes .The values of oxide thickness are extracted and then substituted into the S.OXIDE parameter of the IMPLANT statement. The SIMS Verified Dual Pearson (SVDP) method allows us to properly predict this effect.

SOFTWARE USED: Silvaco S.EDA tools

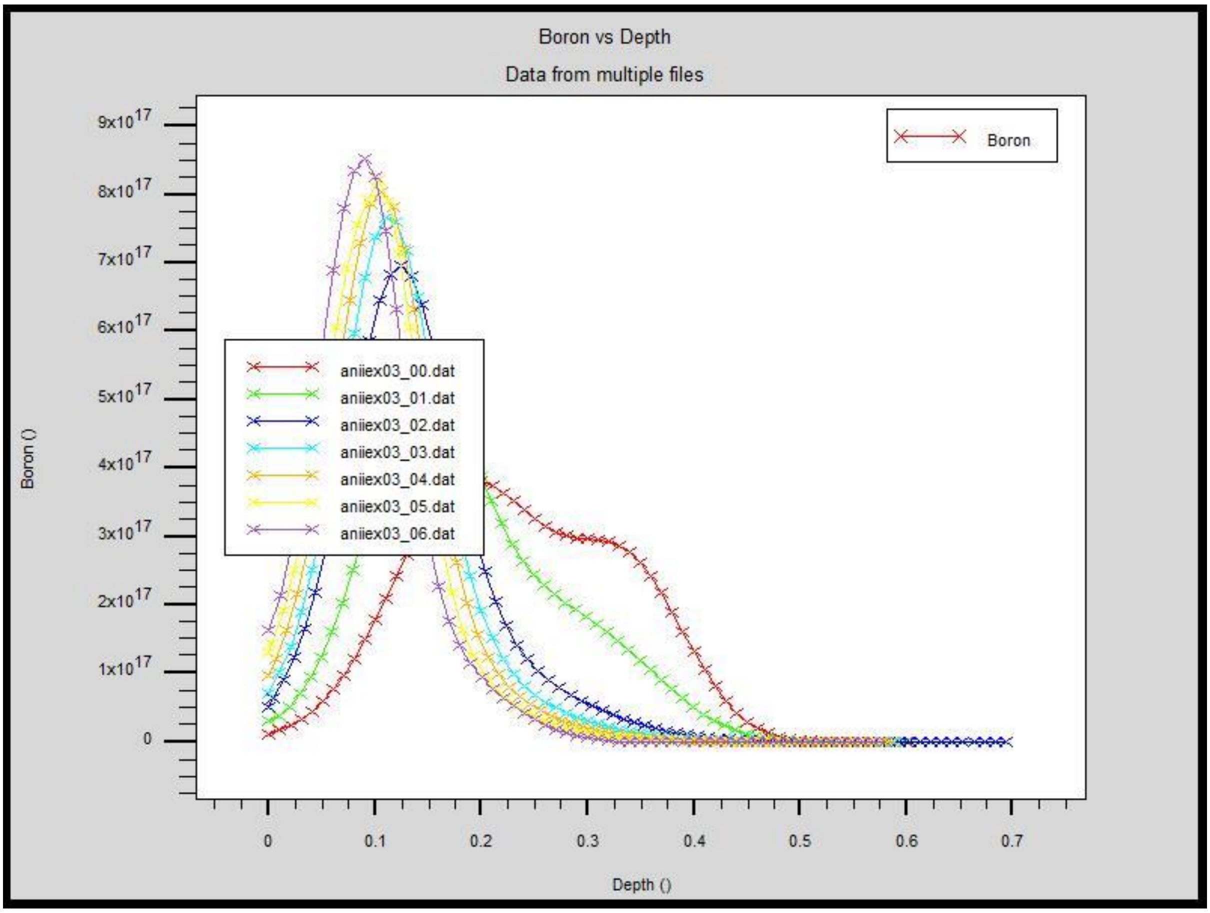
THEORY: SIMS-Verified Dual Pearson (SVDP) ModelBy default, Athena uses SIMS-Verified Dual Pearson (SVDP) implant models. These are based on the tables from the University of Texas at Austin. These tables contain dual Pearson moments for B, BF2, P, and As extracted from high quality implantation experiments are also conducted by the University of Texas at Austin.

OBSERVATION:

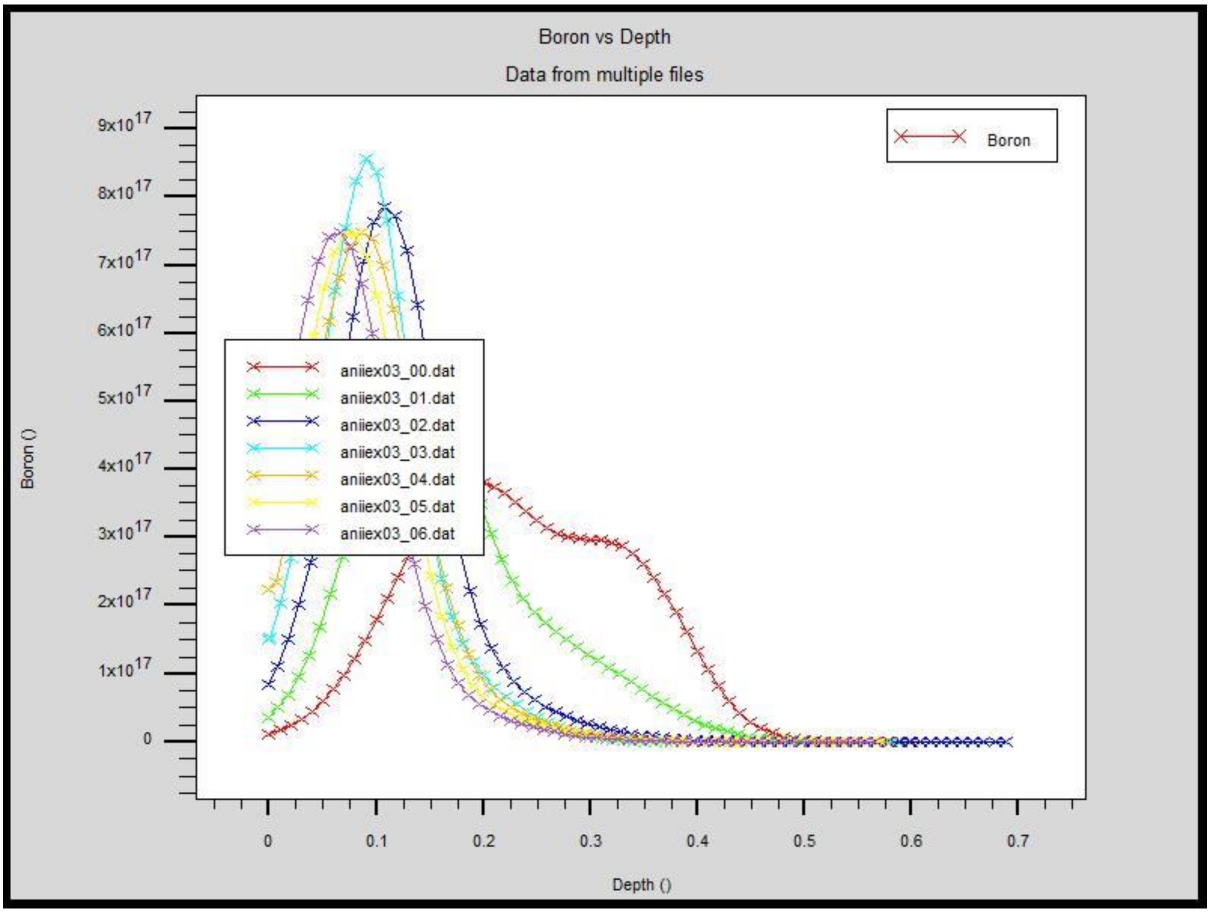
At 850 C



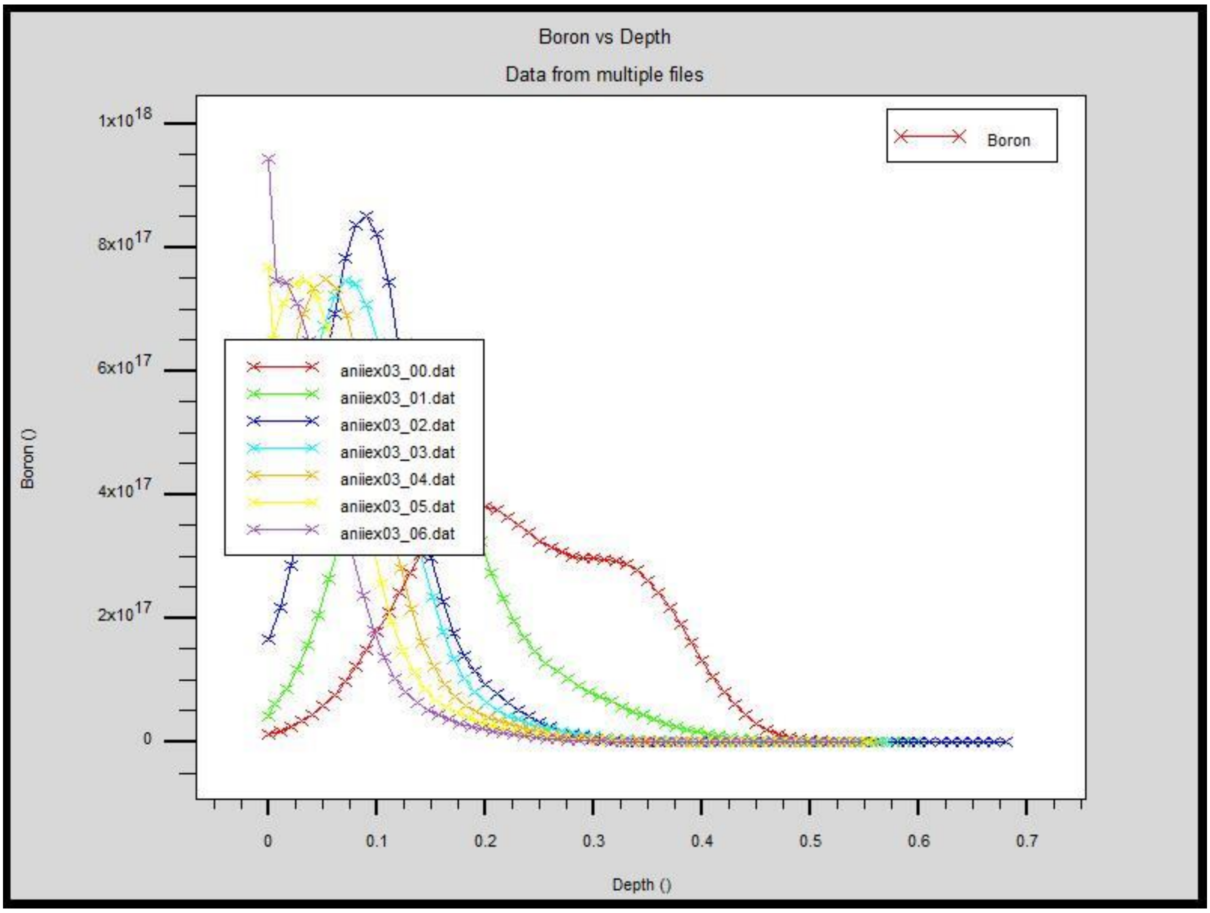
at 900 C


Boron vs Depth
Data from multiple files
Boron
aniiex03_00.dat
aniiex03_01.dat
aniiex03_02.dat
aniiex03_03.dat
aniiex03_04.dat
aniiex03_05.dat
aniiex03_06.dat
Boron ()
Depth ()

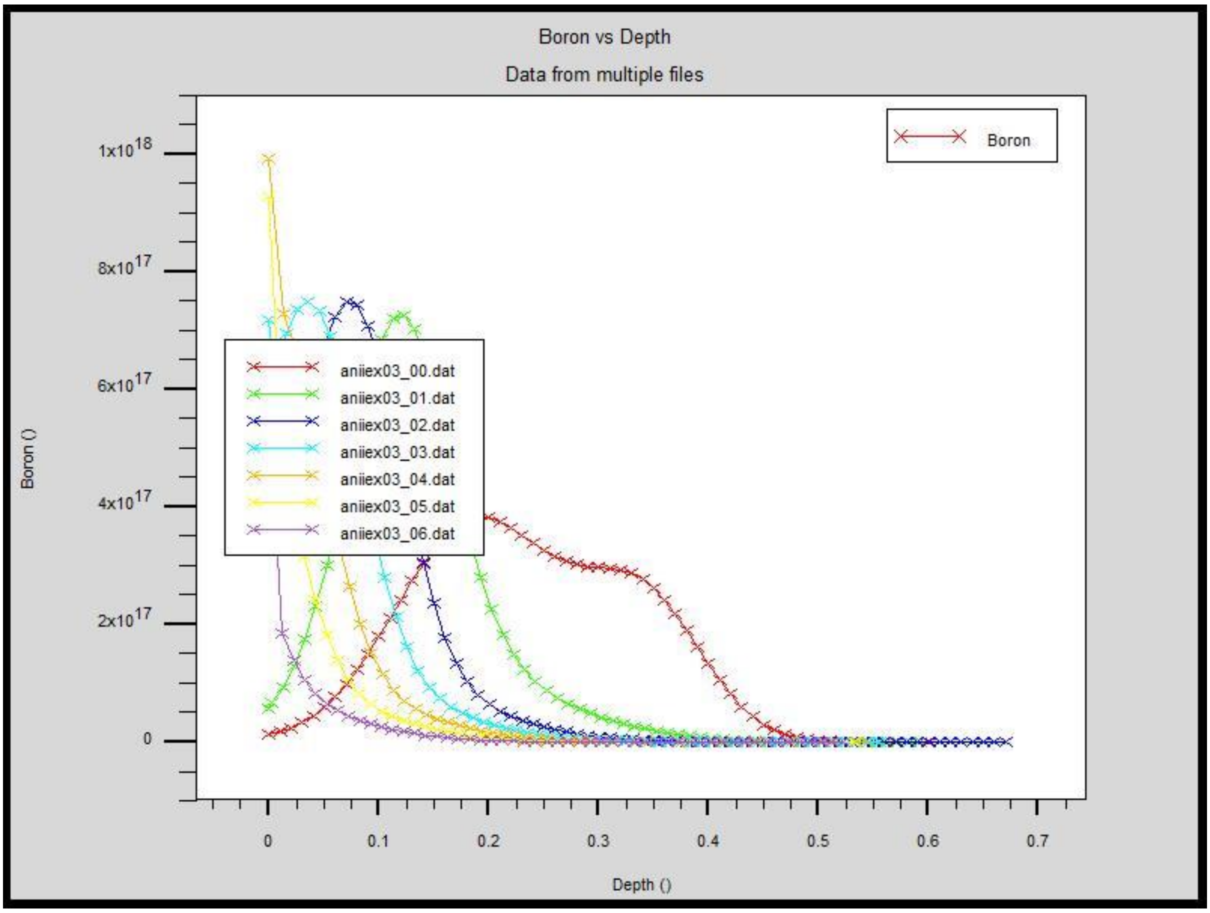
at 950 C


Boron vs Depth
Data from multiple files
Boron
aniiex03_00.dat
aniiex03_01.dat
aniiex03_02.dat
aniiex03_03.dat
aniiex03_04.dat
aniiex03_05.dat
aniiex03_06.dat
Boron ()
Depth ()
9x10^17
8x10^17
7x10^17
6x10^17
5x10^17
4x10^17
3x10^17
2x10^17
1x10^17
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

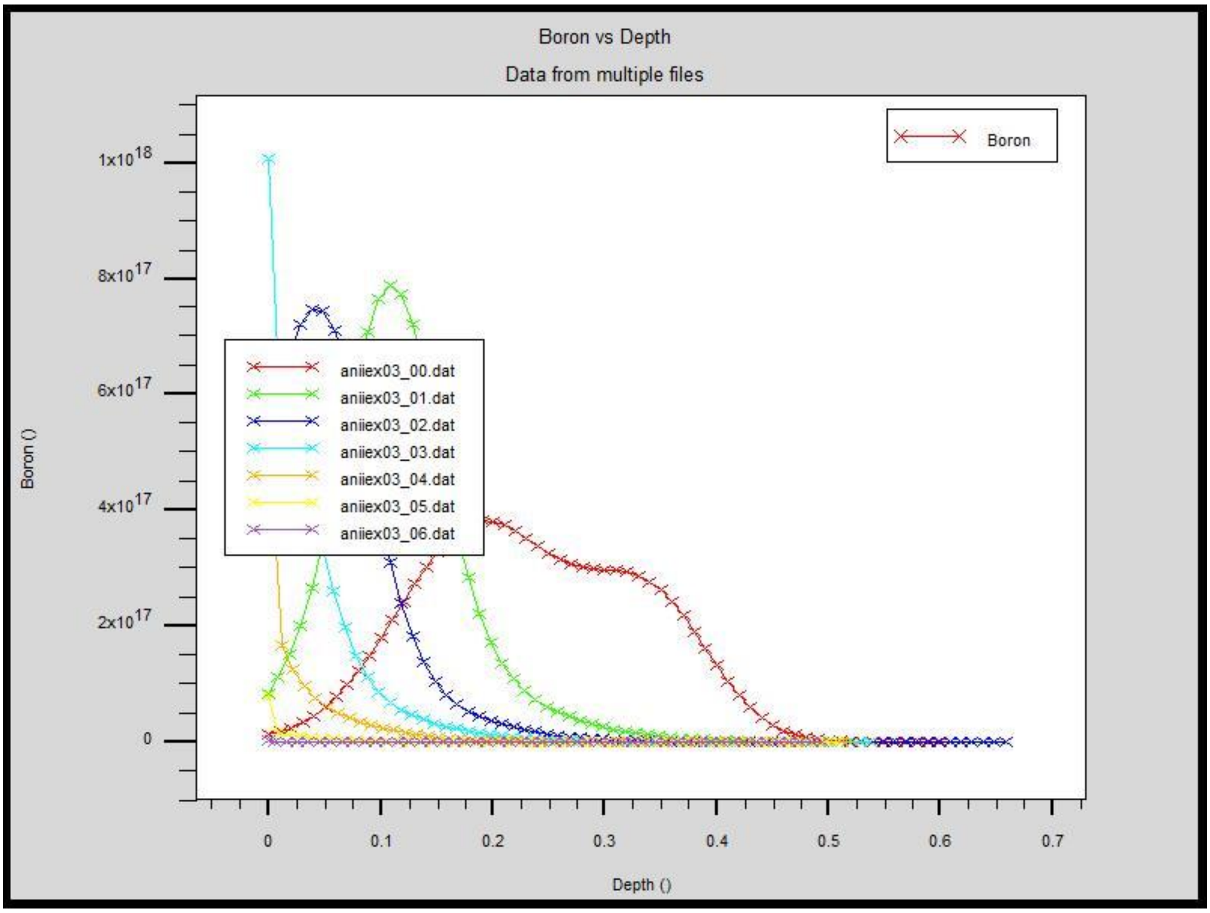
at 1000 C


Boron vs Depth
Data from multiple files
Boron
aniiex03_00.dat
aniiex03_01.dat
aniiex03_02.dat
aniiex03_03.dat
aniiex03_04.dat
aniiex03_05.dat
aniiex03_06.dat
Boron ()
Depth ()
1x10^18
8x10^17
6x10^17
4x10^17
2x10^17
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

at 1050 C


Boron vs Depth
Data from multiple files
Boron
aniiex03_00.dat
aniiex03_01.dat
aniiex03_02.dat
aniiex03_03.dat
aniiex03_04.dat
aniiex03_05.dat
aniiex03_06.dat
1x10^18
8x10^17
6x10^17
4x10^17
2x10^17
0
Boron ()
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Depth ()

at 1100 C



CONCLUSION: As annealing temperature and time increase, the dopant profile front moves deeper into the Si wafer. As the junction depth increases, the peak carrier concentration must decrease so that the area under the curve can remain constant with time and temperature.

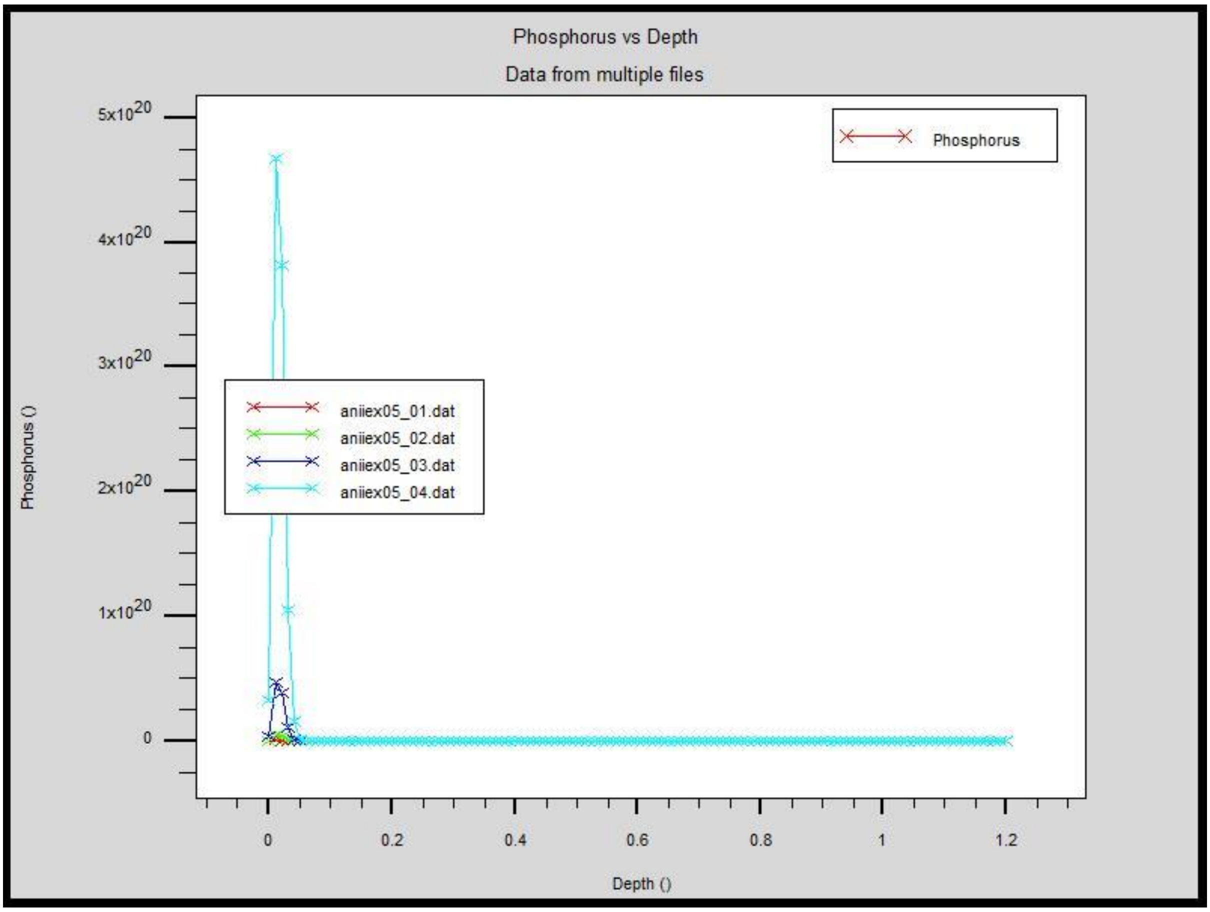
EXPERIMENT 4: This experiment shows the dose and tempreture dependence of zero-tilt P implant profiles obtained using the SIMS Verified Dual Pearson (**SVDP**) method as energy is varied from 10 KeV to 500 Kev and dose from `dose=1e12` to `dose=1e15`.

SOFTWARE USED: Silvaco S.EDA tools

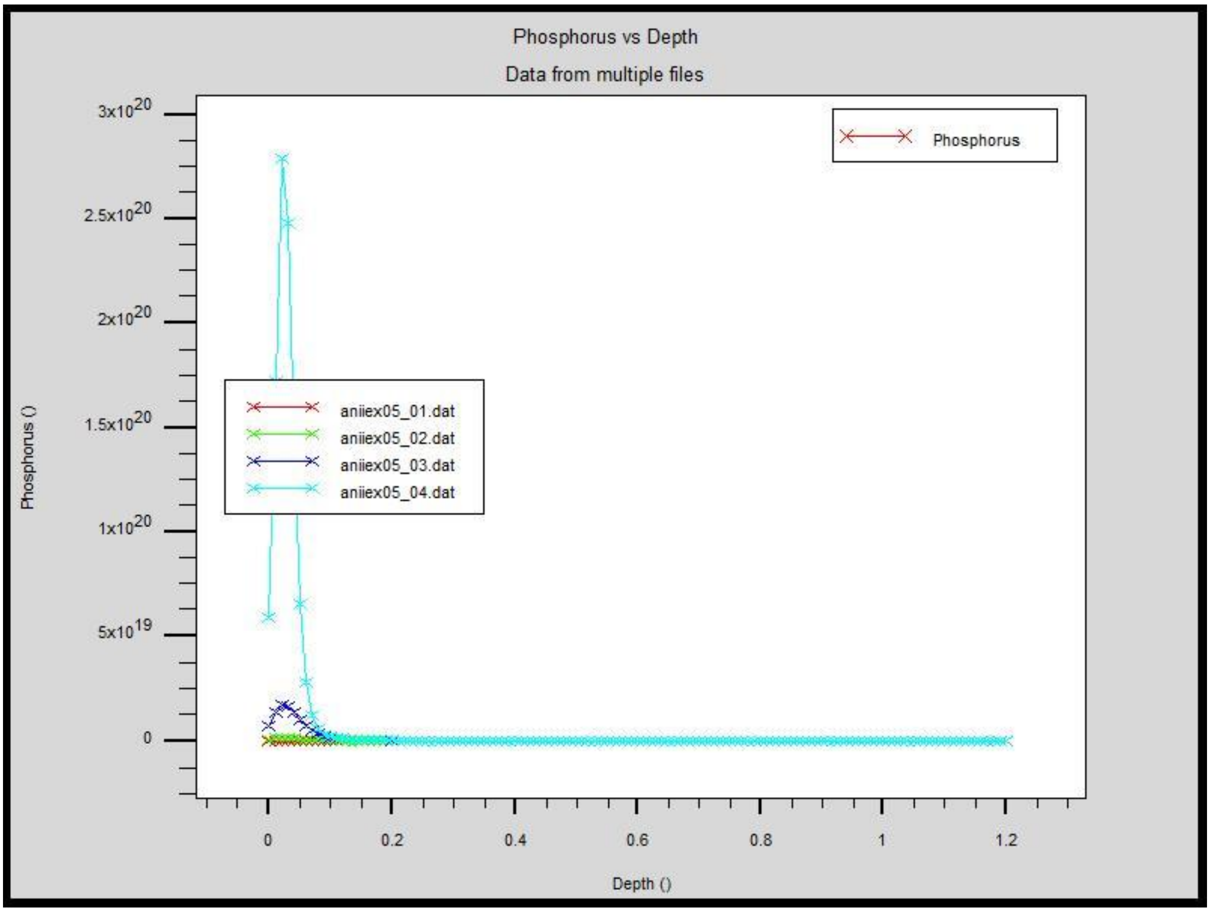
THEORY: SIMS-Verified Dual Pearson (SVDP) ModelBy default, Athena uses SIMS-Verified Dual Pearson (SVDP) implant models. These are based on the tables from the University of Texas at Austin. These tables contain dual Pearson moments for B, BF2, P, and As extracted from high quality implantation experiments are also conducted by the University of Texas at Austin.

OBSERVATION:

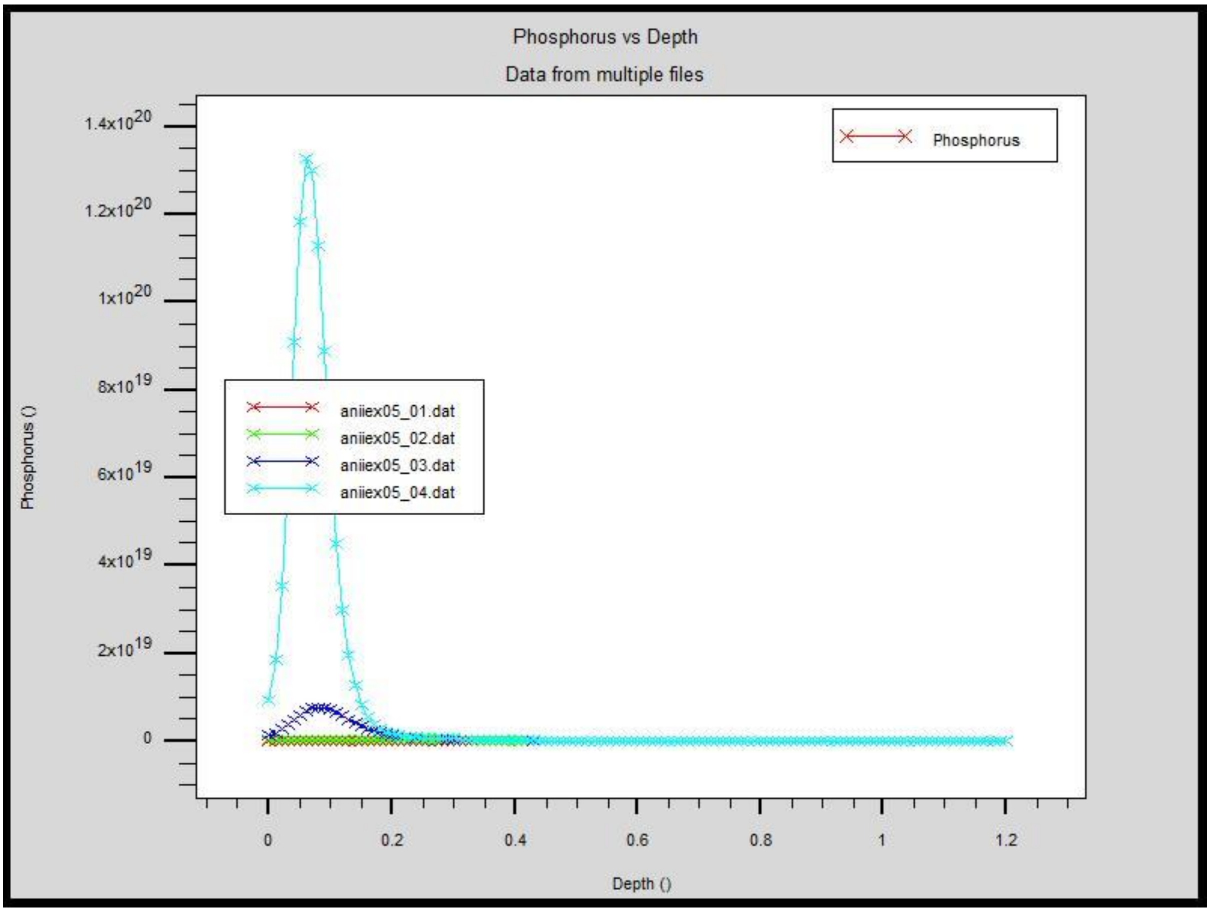
At 10 KeV



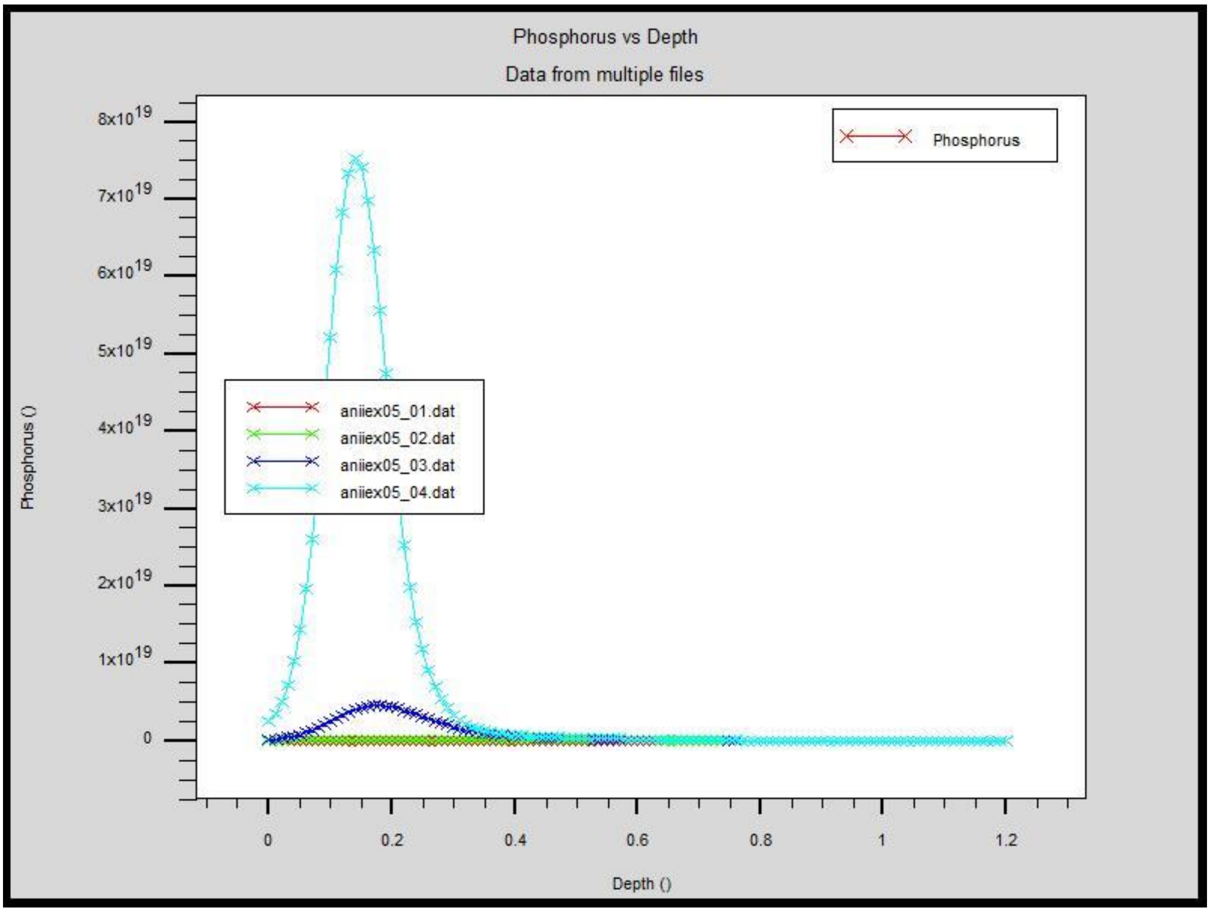
At 20 KeV


Phosphorus vs Depth
Data from multiple files
Phosphorus
aniiex05_01.dat
aniiex05_02.dat
aniiex05_03.dat
aniiex05_04.dat
3x10^20
2.5x10^20
2x10^20
1.5x10^20
1x10^20
5x10^19
0
Phosphorus ()
0
0.2
0.4
0.6
0.8
1
1.2
Depth ()

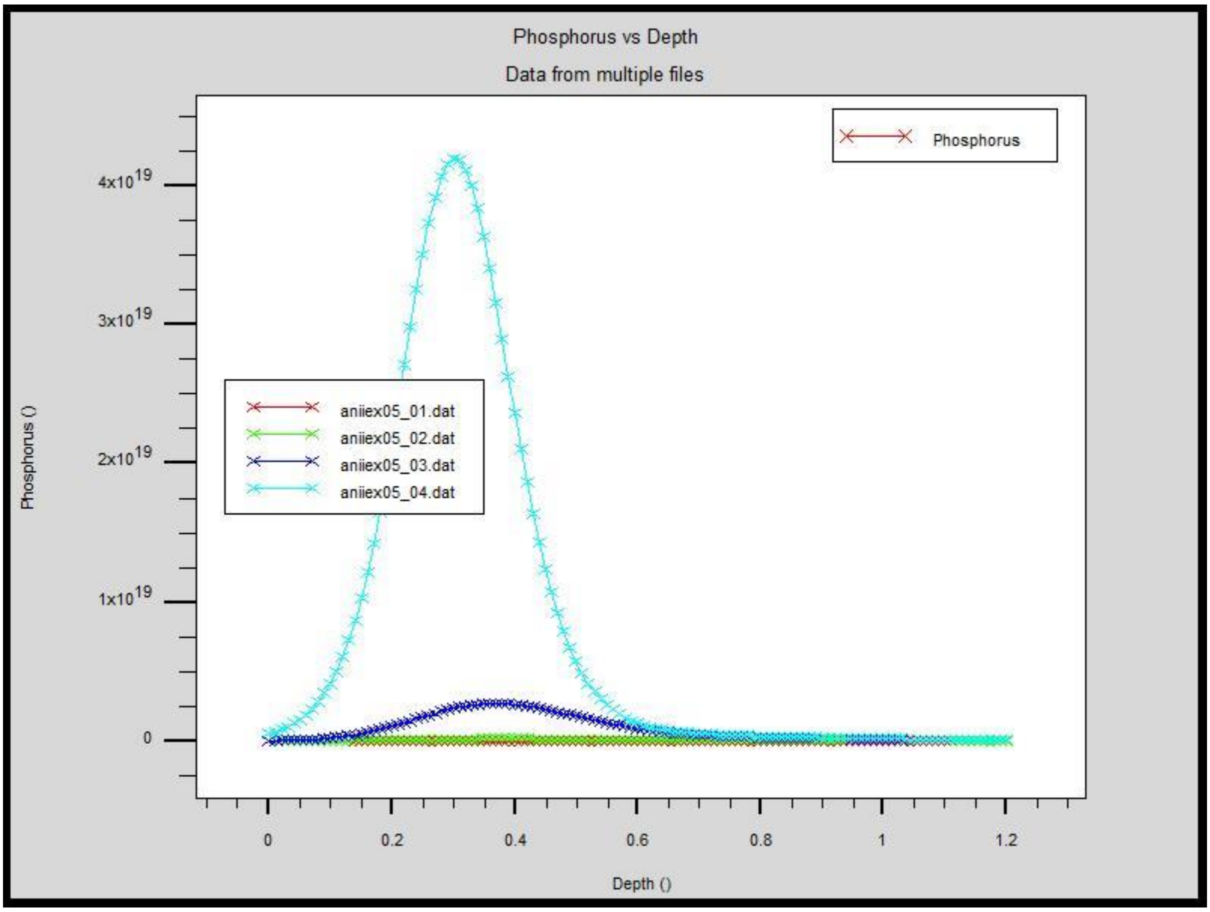
At 50 KeV


Phosphorus vs Depth
Data from multiple files
Phosphorus
aniiex05_01.dat
aniiex05_02.dat
aniiex05_03.dat
aniiex05_04.dat
Phosphorus ()
Depth ()
1.4x10^20
1.2x10^20
1x10^20
8x10^19
6x10^19
4x10^19
2x10^19
0
0.2
0.4
0.6
0.8
1
1.2

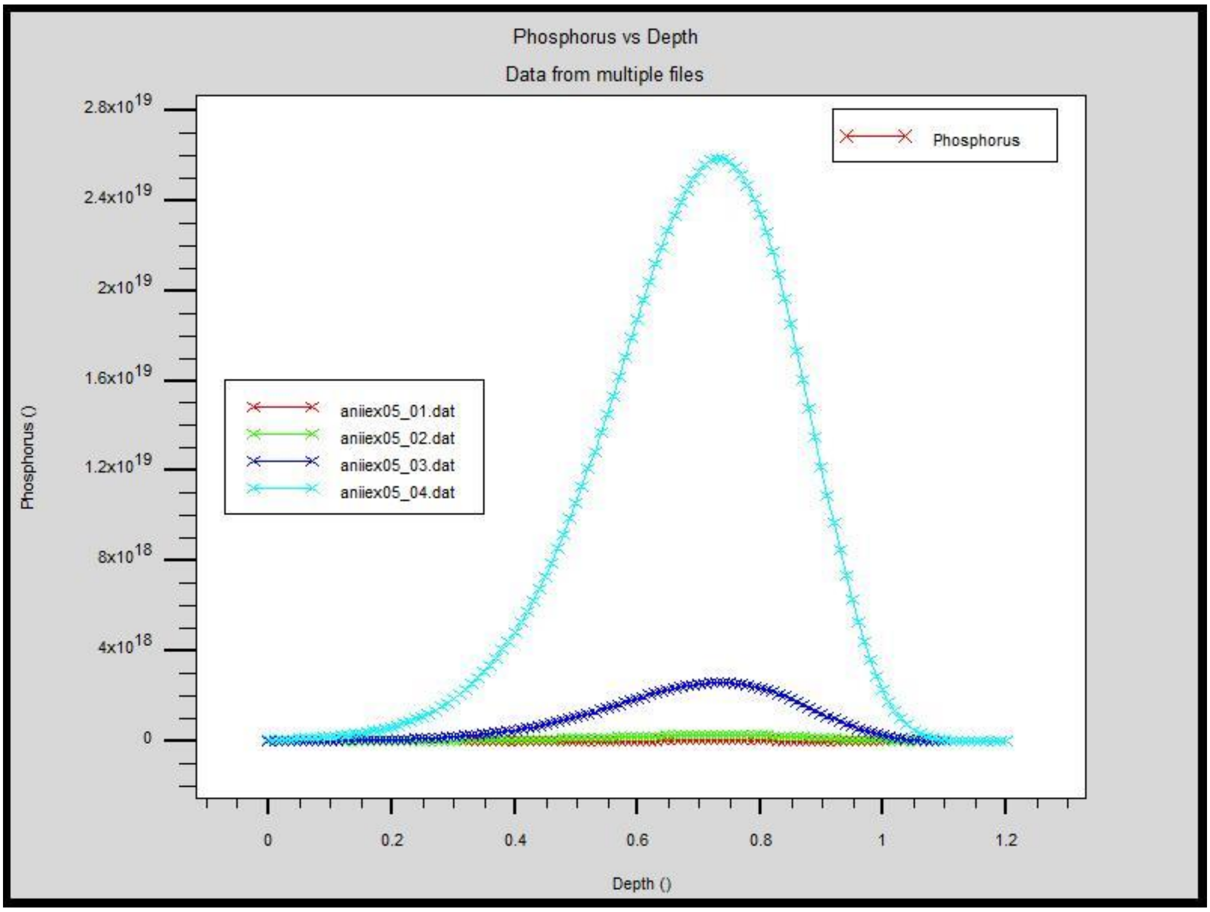
At 100 KeV


Phosphorus vs Depth
Data from multiple files
Phosphorus
aniiex05_01.dat
aniiex05_02.dat
aniiex05_03.dat
aniiex05_04.dat
Phosphorus ()
Depth ()

At 200 KeV


Phosphorus vs Depth
Data from multiple files
Phosphorus
aniiex05_01.dat
aniiex05_02.dat
aniiex05_03.dat
aniiex05_04.dat
Phosphorus ()
4x10^19
3x10^19
2x10^19
1x10^19
0
0
0.2
0.4
0.6
0.8
1
1.2
Depth ()

At 500 KeV



CONCLUSION: As the implant dose increases, more damage is caused resulting in additional dechanneling of phosphorus ions. Therefore, the profile tail shortens with increasing dose. As temperature increase, the dopant profile front moves deeper into the Si wafer .

EXPERIMENT 5: Phosphorus implant through Nitride layer as thickness is varied from 20 nm to 500 nm divided into 5 intervals and also compares Monte Carlo , DOSE.MATCH ,MAX.SCALE meathod for implantation into a multi layered structure.

SOFTWARE USED: Silvaco S.EDA tools

THEORY:

DOSE.MATCH

The Dose-Matching Method was historically the first and is the most widely used method. The Dose-Matching Method is selected by the DOSE.MATCH parameter (default) in the IMPLANT statement.

RP.SCALE and MAX.SCALE

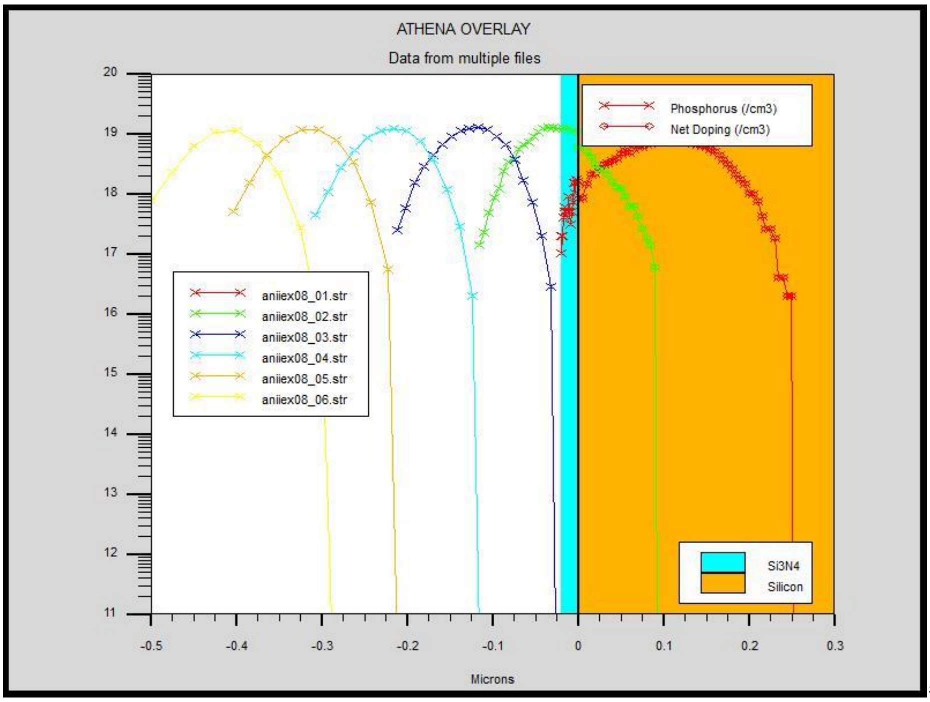
The other two methods for analytical calculation of implantation profiles in the layered structures are projected range depth scaling (set by RP.EFF or RP.SCAL in the IMPLANT statement) and maximal depth scaling (set by the MAX.SCALE parameter). These two methods differ from the dose-matching method in the way the effective depth xeff is calculated and in the normalization of the partial profiles in the layers. Like in the dose-matching method, the distribution in the first layer is calculated directly from the moments corresponding to the first layer without any corrections.

Monte Carlo Implants

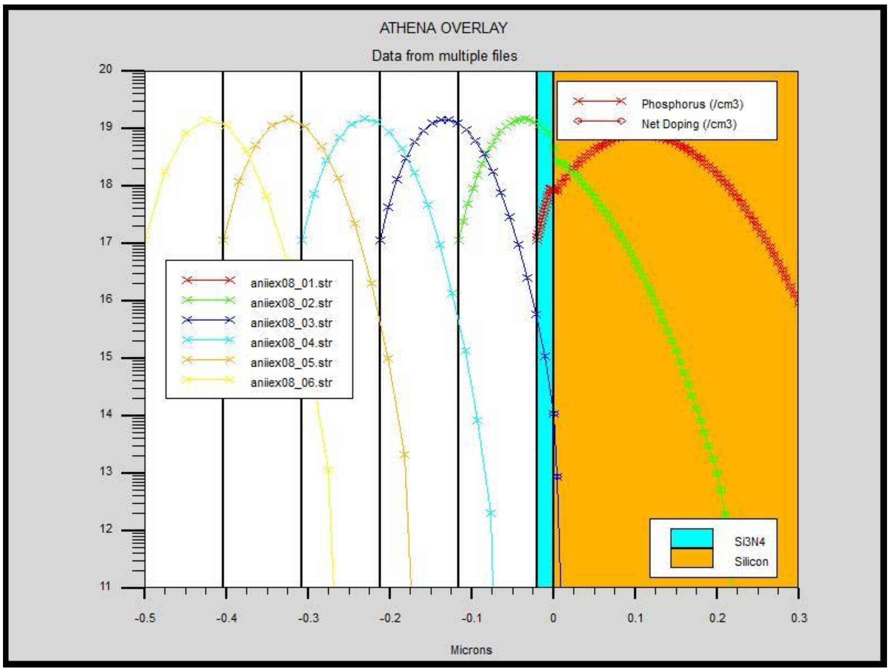
The analytical models described in the previous section give very good results when applied to ion implantation into simple planar structures (bare silicon or silicon covered with thin layer of other material). But for structures containing many non-planar layers (material regions) and for the cases, which have not been studied yet experimentally requires more sophisticated simulation models. The most flexible and universal approach to simulate ion implantation in non-standard conditions is the Monte Carlo Technique. This approach allows calculation of implantation profiles in an arbitrary structure with accuracy comparable to the accuracy of analytical models for a single layer structure.
Athena contains two models for Monte-Carlo simulation of ion implantation: Amorphous Material Model and Crystalline Material Model. Both of them are based on the Binary Collision Approximation (BCA) and apply different approximations to the material structure and ion propagation through it.

OBSERVATION:

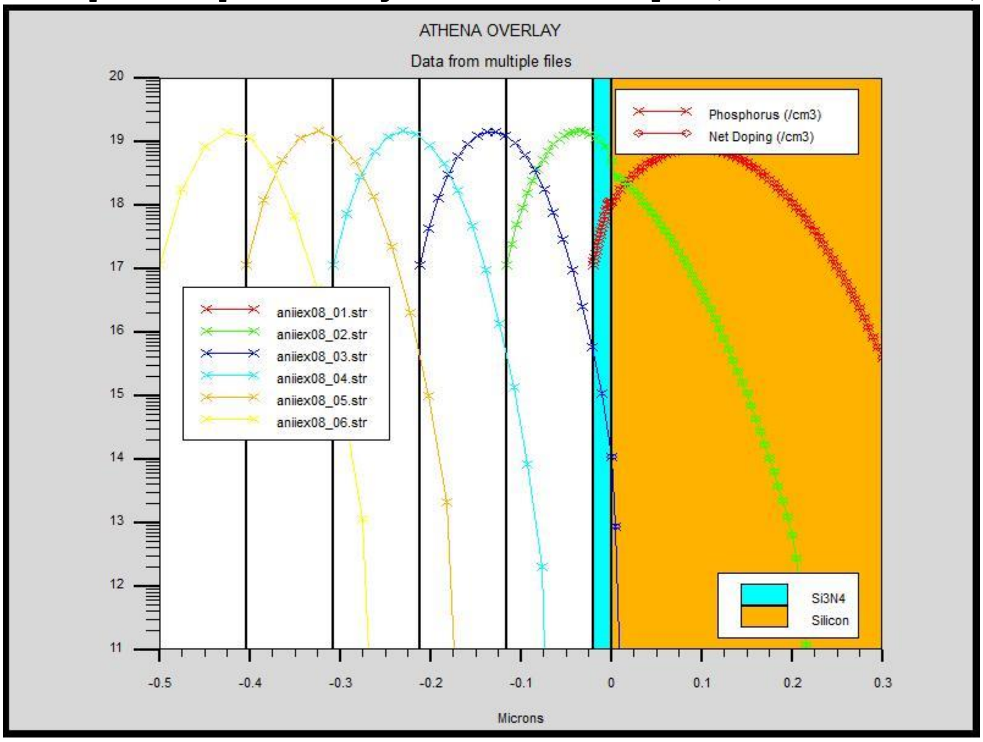
 # Phosphorus Implant through Thick Nitride Layer (Monte carlo)



 # Phosphorus Implant through Thick Nitride Layer (DOSE.MATCH MEATHOD)



 # Phosphorus Implant through Thick Nitride Layer (MAX.scale meathod)



CONCLUSION: If thickness of SiN increases peak shift to SiN whereas when thickness of SiN decreases peak shift to Si.

Amit Sarkar

DATE:11-06-2021 **SIGNATURE OF STUDENT**