Behavioural Modelling of Semi-Conductor Devices based on Ion-Implantation

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Introduction

The aim of my project is to predict if a model can be built on MESFET fabrication techniques and if so build a suitable model that can be used.Virtual Metrology have been developed as a solution for advanced process modelling.It helps to predict metrology measurements based on production equipment data and previous metrology results.

A MESFET is like a MOSFET but the only difference is in the substrate that is used.

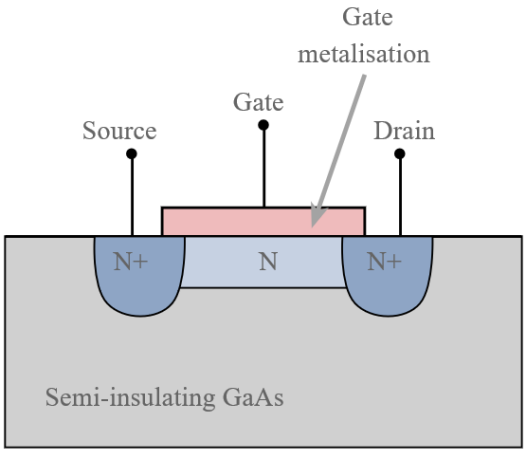
In MESFET the GaAs substrate is used.For practical uses mostly n channel MESFET is used mainly because of the high speed of electron in place of holes.

The GaAs substrate taken in Semi Insulating, but for simulation purposes we can make it lightly doped with p type.And the Gate, Source, Drain is made n type.

For GaAs p type doping is achieved with - Be, Zn, Mg(With Be most widely used) and for n type doping is done with group 14 elements like Se, Si etc (Silicon is widely used).

For MESFET fabrication, TCAD softwares were used.TCAD softwares allow the semiconductor processes to be simulated based on the different conditions, instead of performing experiments in the lab.This allows us to study the properties of these devices and study them.

For the purpose of this project CROSSLIGHT - CSuprem was used which is based on Suprem which was developed by Stanford University for Semi Conductor Process simulation.



MESFET Fabrication

To begin with MESFET Fabrication using CSuprem the task can be divided basically into 5 stages.

1)Setting up the GaAs Mesh

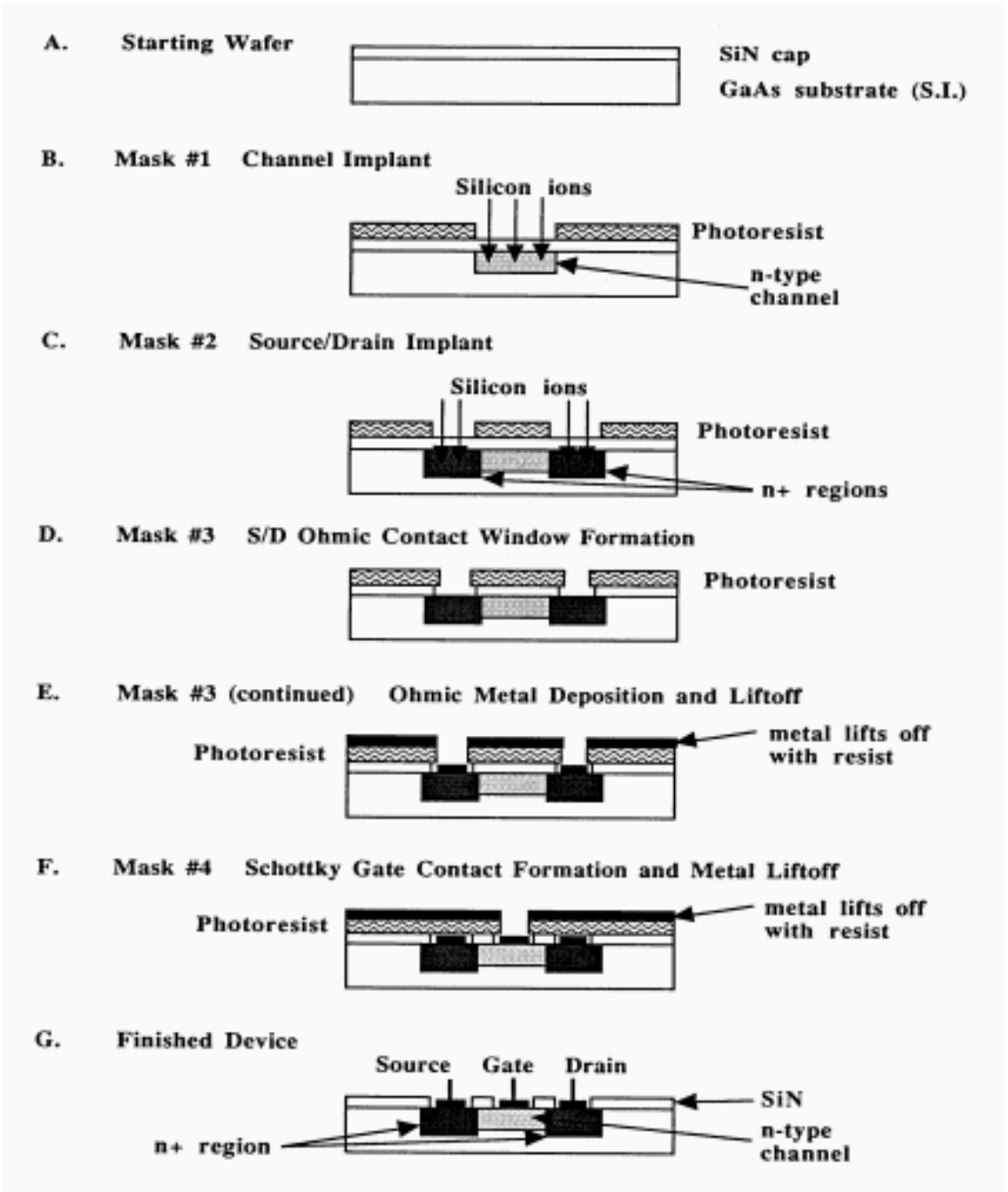
2)Depositing Nitride

3)Mask process to make the photoresist

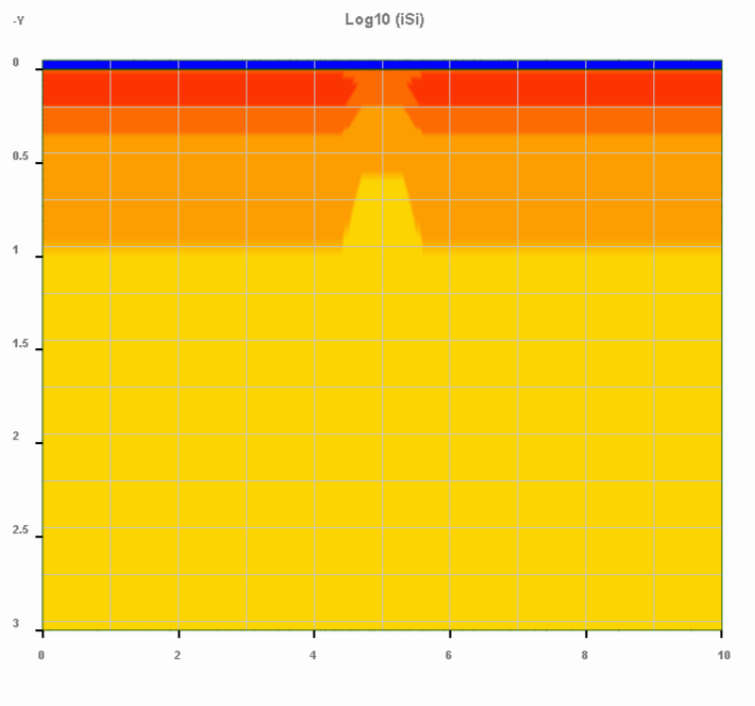
4)Implant of Silicon.

5)Mask process for Drain Source

6)Implant of Silicon (N+).



The
approach to build is to make a mesh and then deposit a thickness of Nitride.On the nitride, etch a portion on the right side of the same and then do an ion implant.Followed by complete removal of the nitride and depositing a new nitride layer(This was done so as to remove the use of photoresist insulating layer). Then etching the portion of nitride where the implant had occurred and make a new layer of nitride.Mirroring the same about the right side so as to get the MESFET.



Generating the Data Set

For generating the data set and to use virtual metrology we studied the process of ion implant and calculated the depth of the p-n junction that is formed by the channel part.

The depth of the p-n junction depends on the following parameters

1)Energy of the implanted ion

2)Dose with which the implant is carried out.

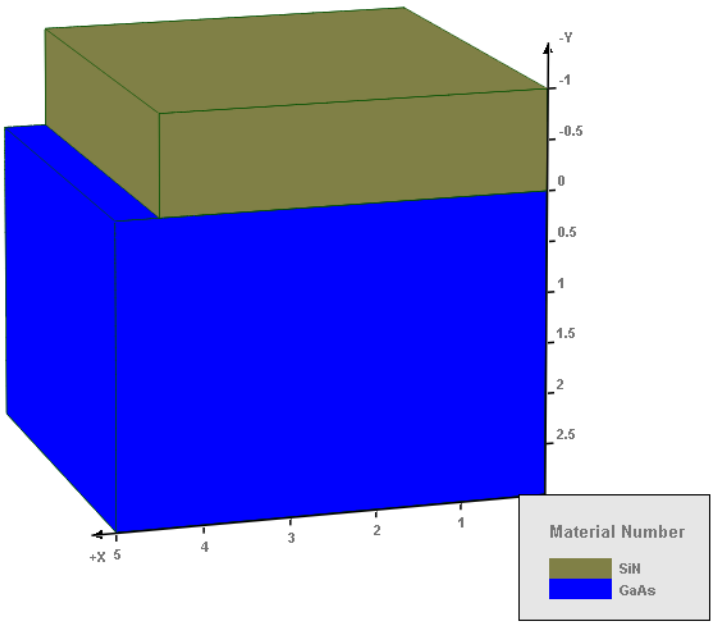
3)Angle with which incident beam is targeted on the substrate

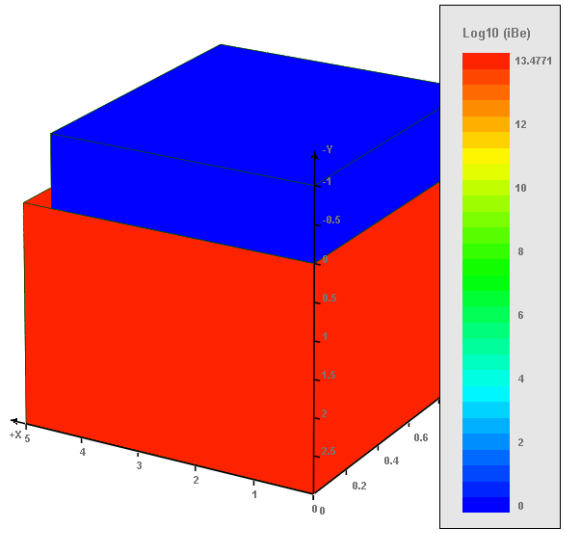
4)The implanted ion.

For the aim of this project all of the variations of these properties were studied.The Angle of rotation was varied between 0-45 degrees.The Dose was varied from 10^9 to 10^14 molecules per cm square.The Energy was varied between 1 and 125 KeV.Two types of implanted ions were used Silicon and Selenium.

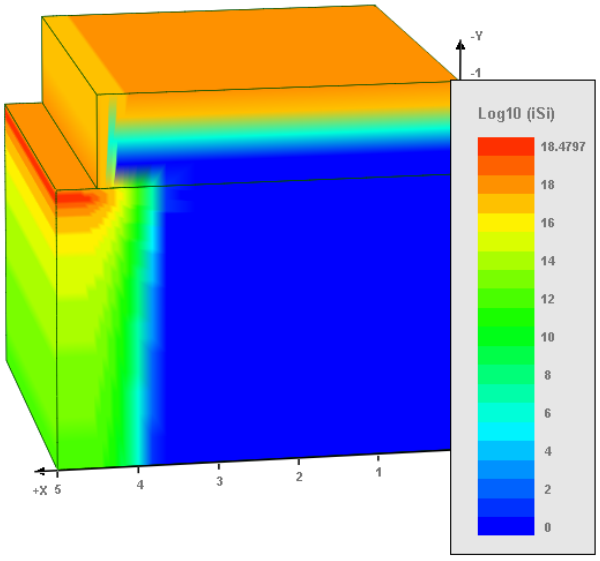
Results of Simulation

The p-n junction is formed in the first step, therefore the depth of the p-n junction is measured after the first step.The concentration of beryllium is fixed inside the substrates as 3e^13.

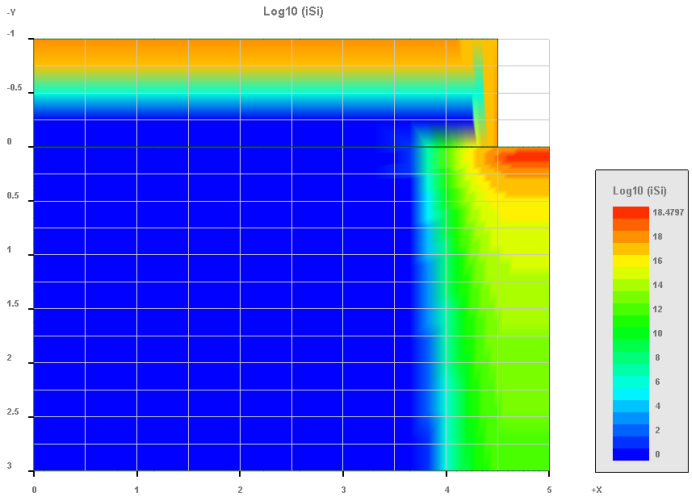


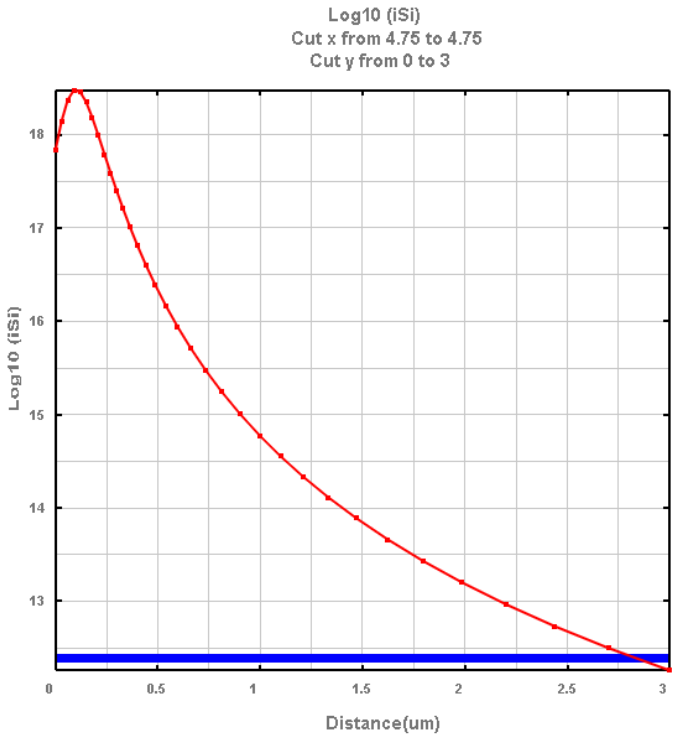


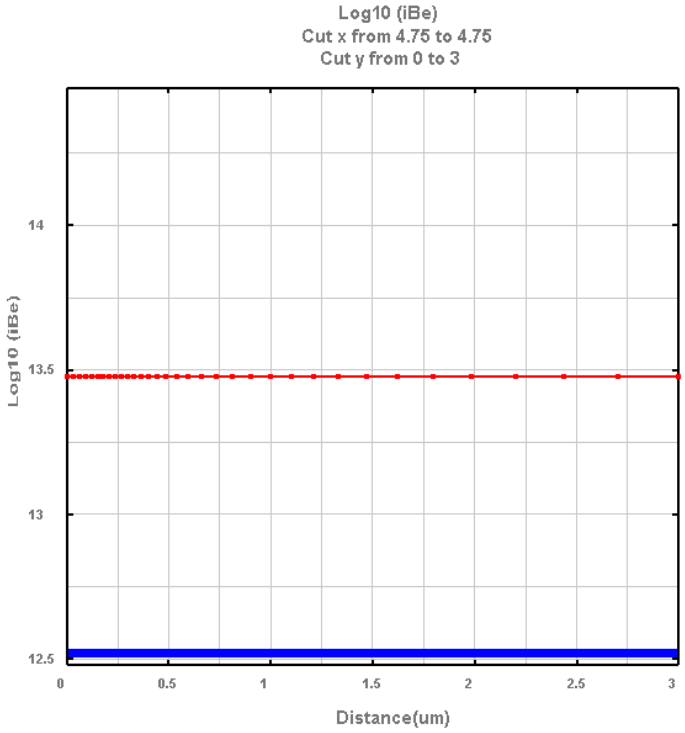
The profile of the Be after deposit of uniform concentration 3e13.



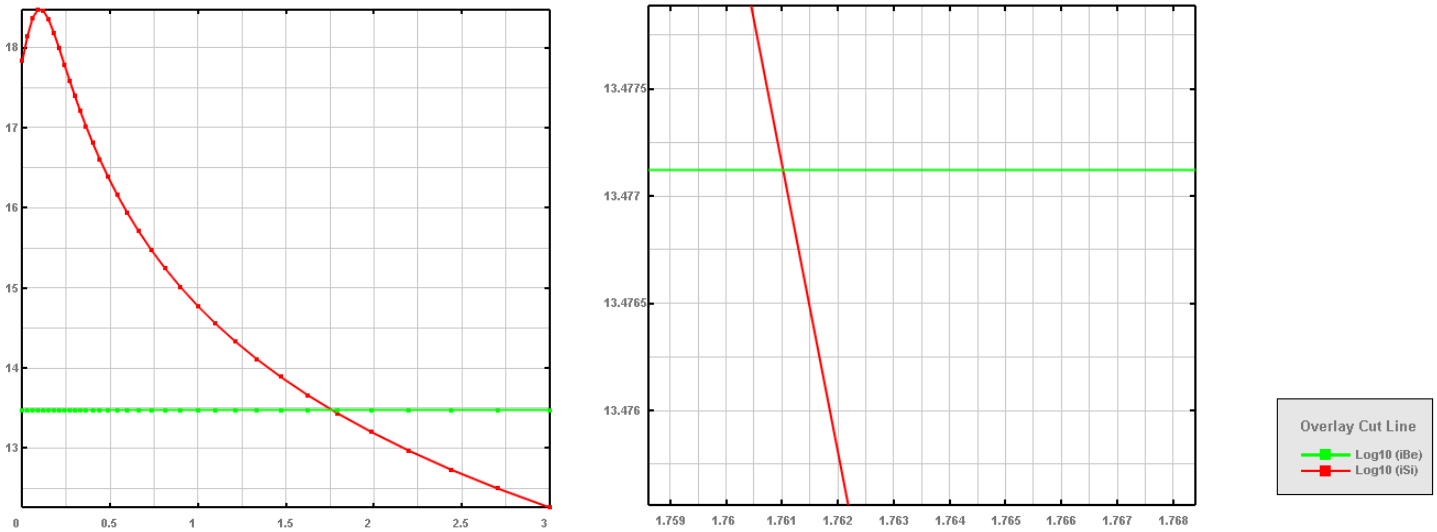
Silicon Concentration after Ion Implant(Dose=10^13.7 Energy=99 Angle=8.5)







Silicon and Beryllium Concentration profile on 1-D cut through x=4.75



Overlaying plots of Beryllium and Silicon

Thus concluding that the point if intersection or the depth of p-n juction is at 1.7615.

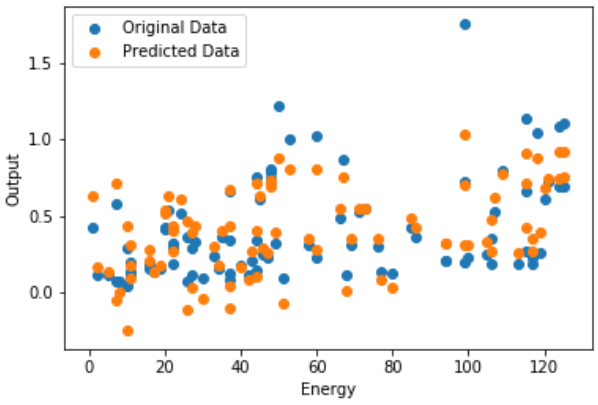
Behavioural Modelling

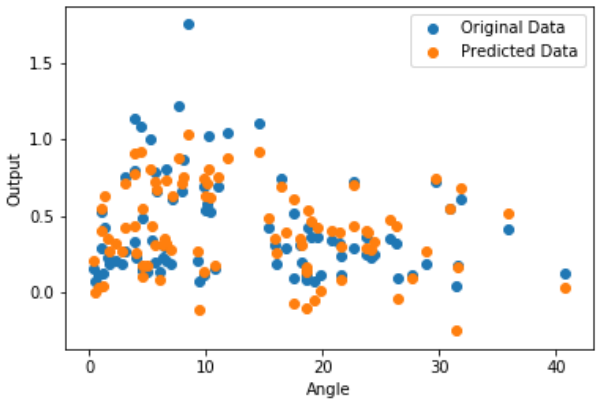
300 data sets were obtained by varying the following parameters.70% were used for training and 30% were used testing.The training is based on modern day machine learning techniques like Linear Regression, Random Forests, Neural Networks etc.

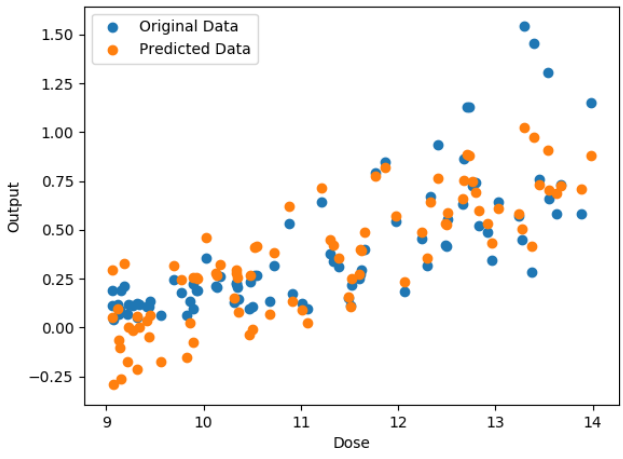
Linear Regression

This is the simplest of all machine learning tehniques.It uses Gradient descent and tries to find the best fit line so as to make the predict the outcome.It doesn't work well with non linear functions.

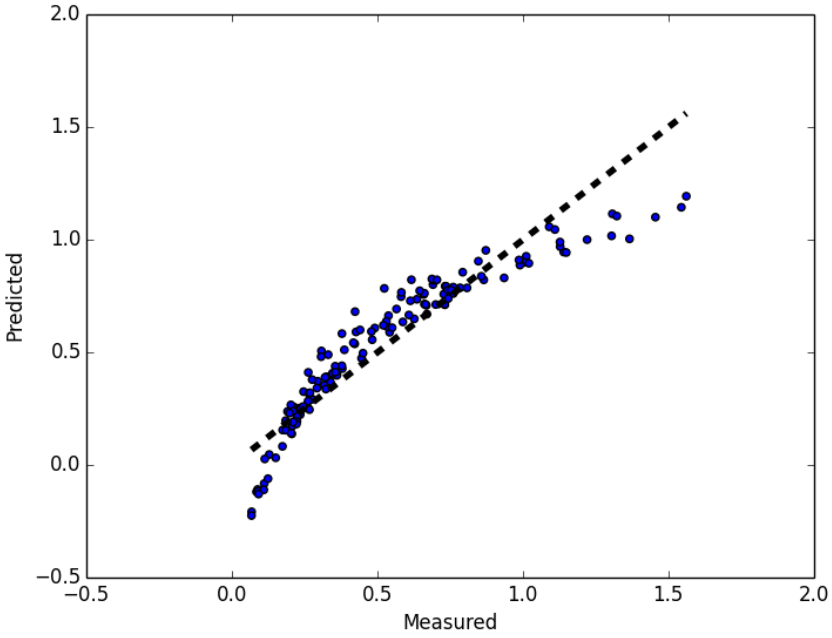
When a model was trained using Linear Regression an R2 score of 83% on the test set and a mean square error of 0.016 or Root mean square error of 12.6%







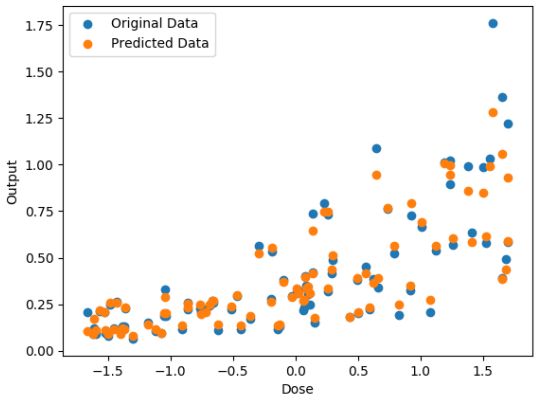
The model looks very accurate from the above.

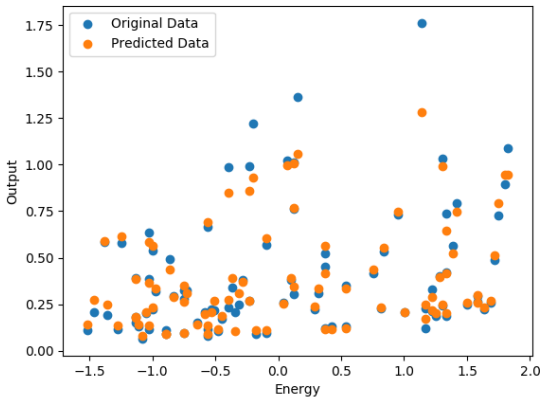


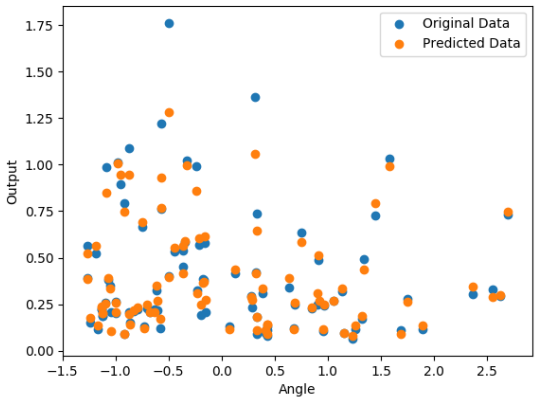
However the cross validation graphs suggested otherwise.Therefore it is essential to use other techniques instead of linear regression to train the model.

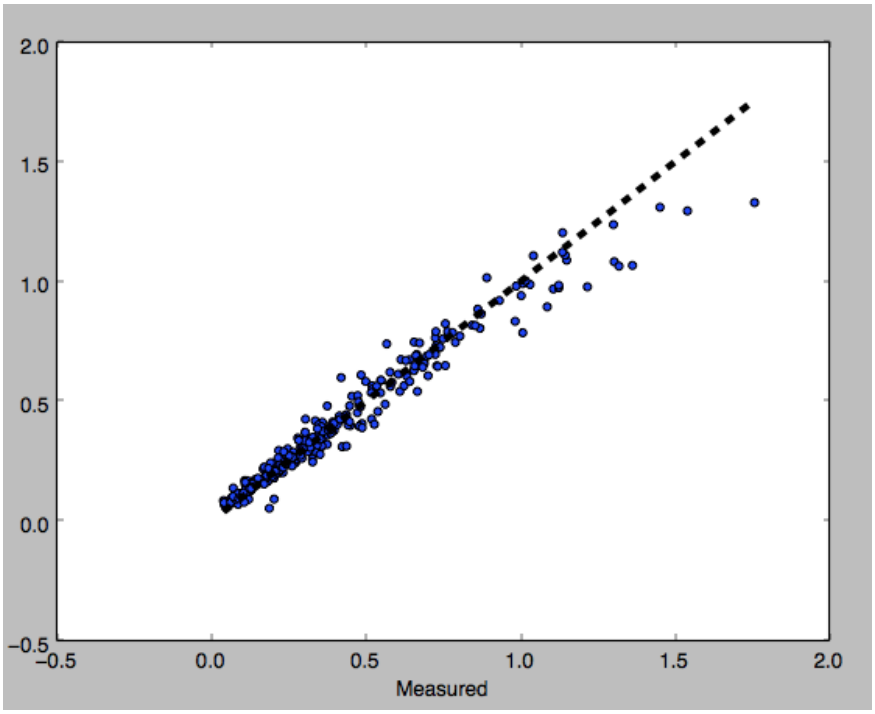
RANDOM FORESTS

Another machine learning technique used was Random forests, this lead to an accuracy of 97.1% and a mean square error of 0.0026 or Root mean percentage error of 5.0% which is very better then linear regression and also shows us that this is better then linear regression and leads to a very stable mode







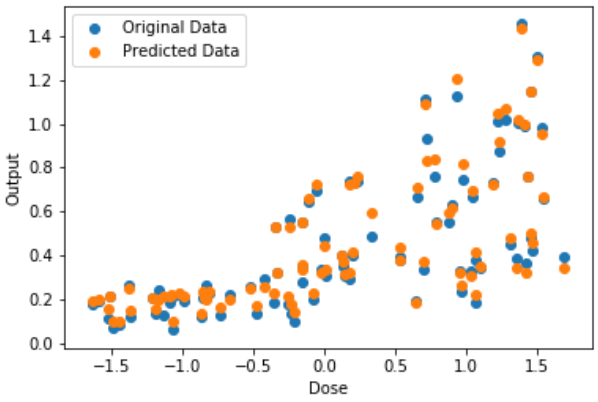


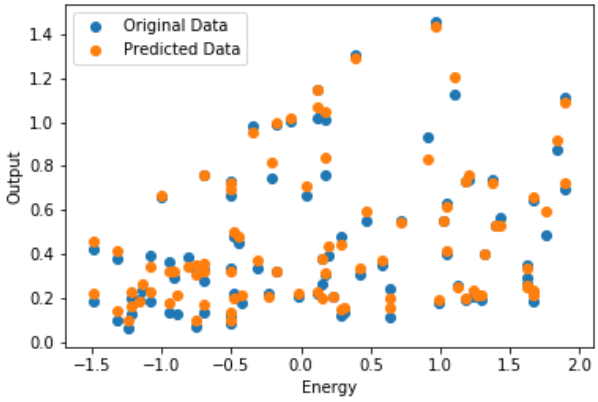
The cross validation plot is also very well, showing that the points are near to the line.

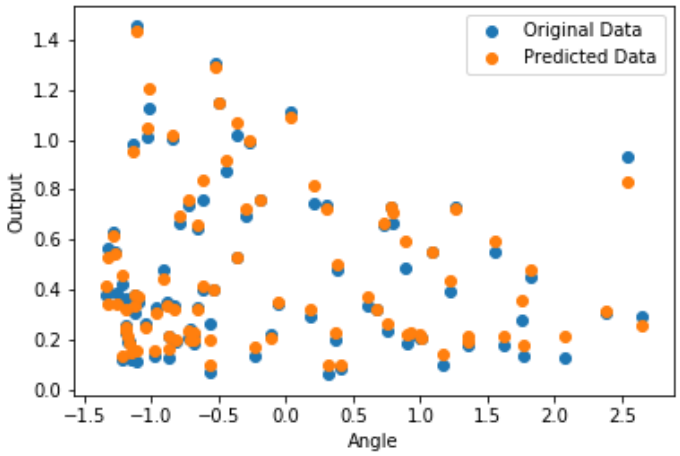
This shows that random forests works well for behavioural modelling.

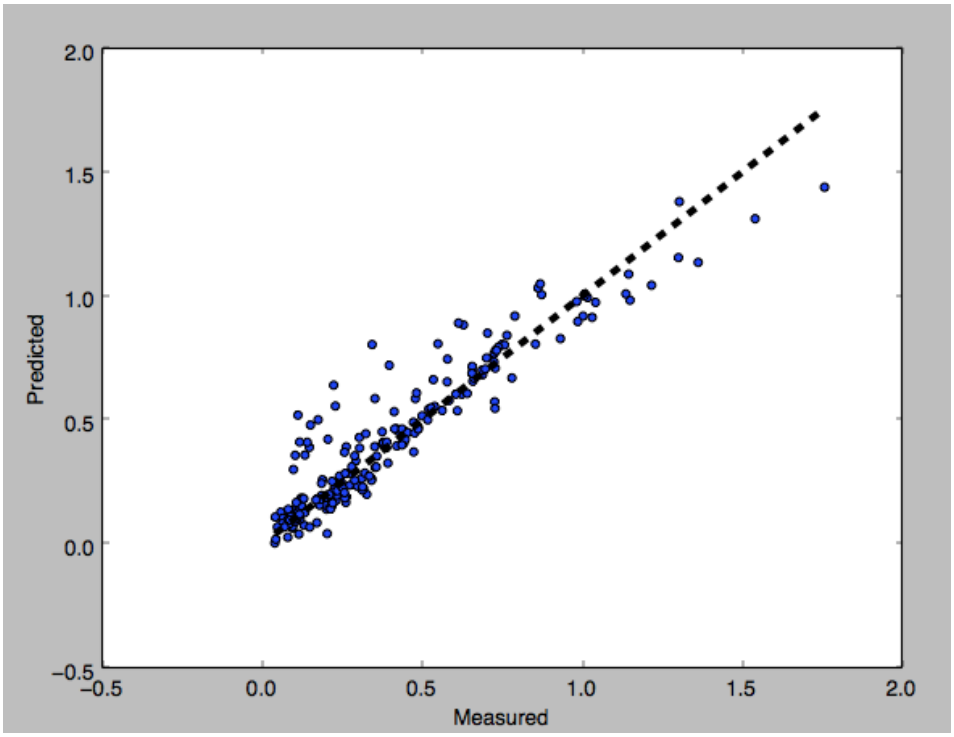
Artificial Neural Network

Finally, the data was analysed by a neural network model. The model has 5 hidden layers with nodes 100,30,30,30,30.The Model is the most precise.It lead to an R2 Score of 98.6 % and mean square error of 0.013 ie Root mean square error of 3.6% .









This shows that ANN also works well for behavioural modelling.

Conclusion

In this project the various prospects of machine learning techniques in semiconductor process modelling.Three behavioural models were developed out of which two were highly efficient for predicting the depth of the p-n junction formed in GaAs MESFET.Both Random Forest and Artificial Neural Network has good predictive strength.In future other models will be investigated while the present models will be tested for real life data.

Acknowledgment

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