Internship Report

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Preface

This report documents the work done during the summer internship at Indian Institute of Technology Kanpur (IIT K), India under the supervision of Dr.Yogesh Singh Chauhan. The report first shall give an overview of the tasks completed during the period of internship with technical details. Then the results obtained shall be discussed and analysed.

I have tried my best to keep report simple yet technically correct. I hope that I succeed in my attempt.

Amratansh Gupta

Acknowledgements

Simply put, I could not have done this work without the lots of help I received cheerfully from NanoLab, IIT Kanpur. The work culture in IIT Kanpur really motivates. Everybody is such a friendly and cheerful companion here that work stress is never comes in way.

I would specially like to thank ***Dr.Yogesh Singh Chauhan*** and ***Dr. Sudip Ghosh*** for providing me the opportunity to work upon the nice ideas. Not only did they advised about my project but listening to their discussions in meetings have evoked a good interest in semiconductor devices and compact modelling.

I am also highly indebted to Ph.D. students, working in NanoLab, for helping me over various challenges and their time for numerous discussions with me.

Amratansh Gupta

Abstract

The report presents the tasks completed during summer internship at NanoLab, IIT Kanpur which are listed below:

- **Extensive study of MOS physics and short channel effects in MOSFET and fabrication of MOSFET using Silvaco – TCAD.**
- **Study of Berkeley Short-Channel IGFET Model (BSIM) 3v3 and the MOSFET modelling equations.**
- **Parameter extraction of BSIM3v3 using measured TCAD data of fabricated MOSFET (using Silvaco - TCAD) on IC-CAP software.**

All these tasks have been completed successfully and results were according to expectations. Fabrication of MOSFET with channel length 0.6µm was successful using Silvaco-TCAD. I extensively studied and investigated the literature based on MOS physics and short channel effects. Later on, I studied the MOS physics involved in BSIM 3v3 and executed the gained knowledge for parameter extraction process using measured TCAD data. The modelled I-V characteristics fit quite well the measured I-V characteristics with acceptable accuracy.

Amratansh Gupta

BSIM : INTRODUCTION

BSIM (*Berkeley Short-channel IGFET Model*) refers to a family of MOSFET transistor models for integrated circuit design. Accurate transistor models are needed for electronic circuit simulation, which in turn is needed for integrated circuit design. As the devices become smaller each process generation, new models are needed to accurately reflect the transistor's behaviour. To attempt standardization of these models so that a set of model parameters may be used in different simulators, an industry working group was formed, the Compact Model Coalition to choose, maintain and promote the use of standard models. BSIM models, developed at UC Berkeley are one of these standards. They include BSIM3, BSIM4, BSIM-BULK, BSIM-SOI, BSIM-CMG, and BSIM-IMG. I was assigned the task to extensively study the MOS physics and BSIM3 modelling equations and later to develop a BSIM 3 model card to model fabricated MOSFET using measured TCAD data.

The GOALS:

Following goals were set as I proceeded in my work:

- Fabrication of short channel MOSFET using Silvaco-TCAD and extensively study the MOS physics.
- Study of BSIM3 modelling equations and the MOS physics involved.
- Extraction of the model parameter of BSIM3v3 in order to fit simulated characteristics with the measured characteristics.

Fabrication of MOSFET using Silvaco-TCAD and study of MOS Physics:

In the initial days of internship, I got familiar with the features of SILVACO TCAD in order to understand the fabrication steps in a better way. I solved a few SILVACO based assignments involving various steps of fabrication of semiconductor devices and observed the results. Later on, I fabricated an n-channel enhancement type MOSFET with channel implant and arsenic (As) doped source/drain. Along with learning about the SILVACO, I also studied the MOS physics using following texts:

- **The MOS Transistor** by *Yannis Tsividis* & *Colin McAndew*

- **Modern Semiconductor Devices for Integrated Circuits**- *Chemming Hu*
- **Solid State Electronic Devices** - *Ben G. Streetman* & *Sanjay Kumar Banerjee*

I improved my understanding with the MOS physics and specially with small channel effects like Drain induced Barrier Lowering(DIBL), Gate Induced Drain Leakage(GIDL), Channel Modulation effect, hot carrier effect, velocity overshoot etc. I studied the fabrication steps involved in MOSFET fabrication and their details in order to understand the importance of various fabrication steps in detail and various models present in SILVACO for mobility, generation and recombination processes, oxidation process etc. Following is a MOSFET devices fabricated using SILVACO-TCAD (channel length 0.6µm).

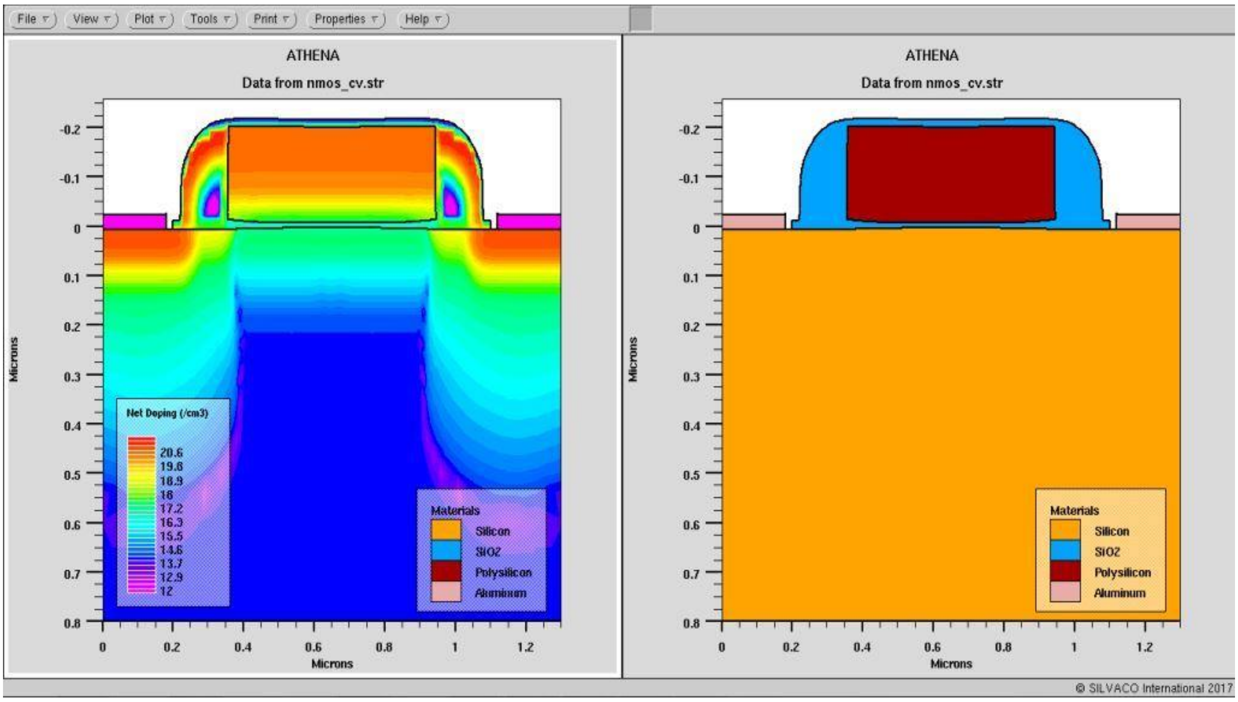

Fig1: SILVACO based **A).** MOSFET Showing Net doping **B).** MOSFET with various material

I observed the effects of variation in fabrication steps on the MOSFET working and plotted the various characteristics like C-V characteristics, I_d–V_{ds} characteristics and generated the data (referred as 'measured TCAD data') for parameter extraction in BSIM3.

Study of BSIM3 Modelling Equations & Involved MOS Physics:

In this task, I primarily focussed upon the literature based on BSIM3 and MOSFET physics which is relevant for modelling using BSIM3. I developed understanding with the BSIM3 model equations and relate them with the primary level MOSFET physics. I exclusively worked upon understanding the effects of various model parameters and their effects on various characteristics including the region of application. During this task, Ph.D. students, working in NanoLab IIT Kanpur, helped me a lot and cleared many doubts of mine regarding the BSIM3 equations and their relation with MOSFET physics. Dr.Sudip Ghosh provided me the adequate literature based on BSIM3, which was quite helpful in understanding the parameter extraction process in BSIM3v3. I spent nearly 25 days on studying the literature based on BSIM3 and MOS physics.

Extraction of the model parameter of BSIM3v3 for measured characteristics:

In last task of the internship, I worked on **Integrated Circuit Characterization and Analysis Program** (IC-CAP). I used IC-CAP for extraction of model parameters of BSIM3. During this task, it was very clear to me that parameters are specifically divided and they have their effects on characteristics in particular regions.

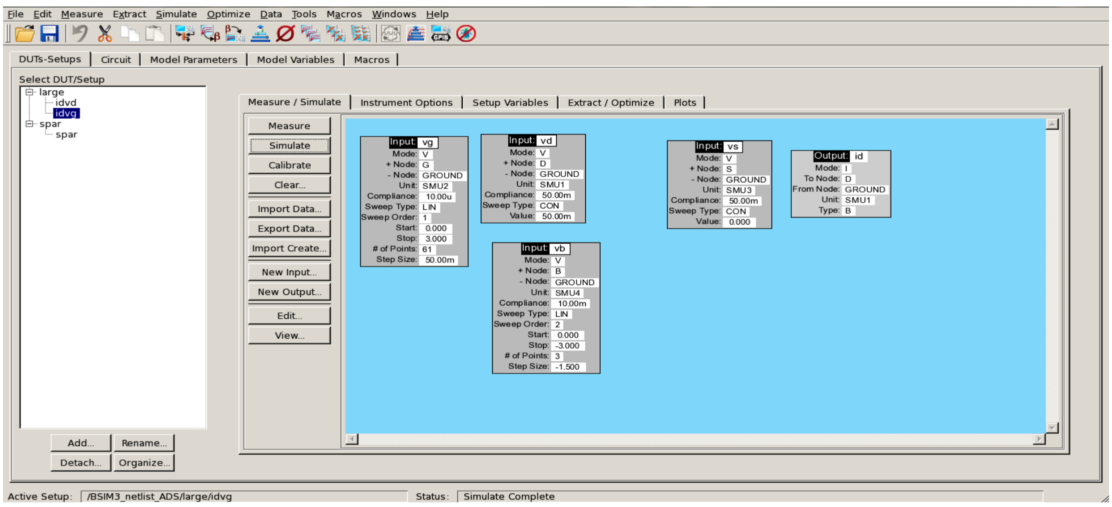

Fig 2: IC-CAP Interface

I started the extraction process from the threshold voltage region where I extracted BSIM3 model parameters like ***Vth0, K1, K2, Dvt0, Dvt1, Dvt2, Nlx**** etc. using **I_d - V_g** measured TCAD characteristics at **V_{ds}=0.05V.** In fig 3, smooth curve simulated curve is coinciding with the measured data curve (at the bending of curves) is proving the parameters for threshold voltage have been extracted. The plot is linear on X-axis and logarithmic on Y-axis.

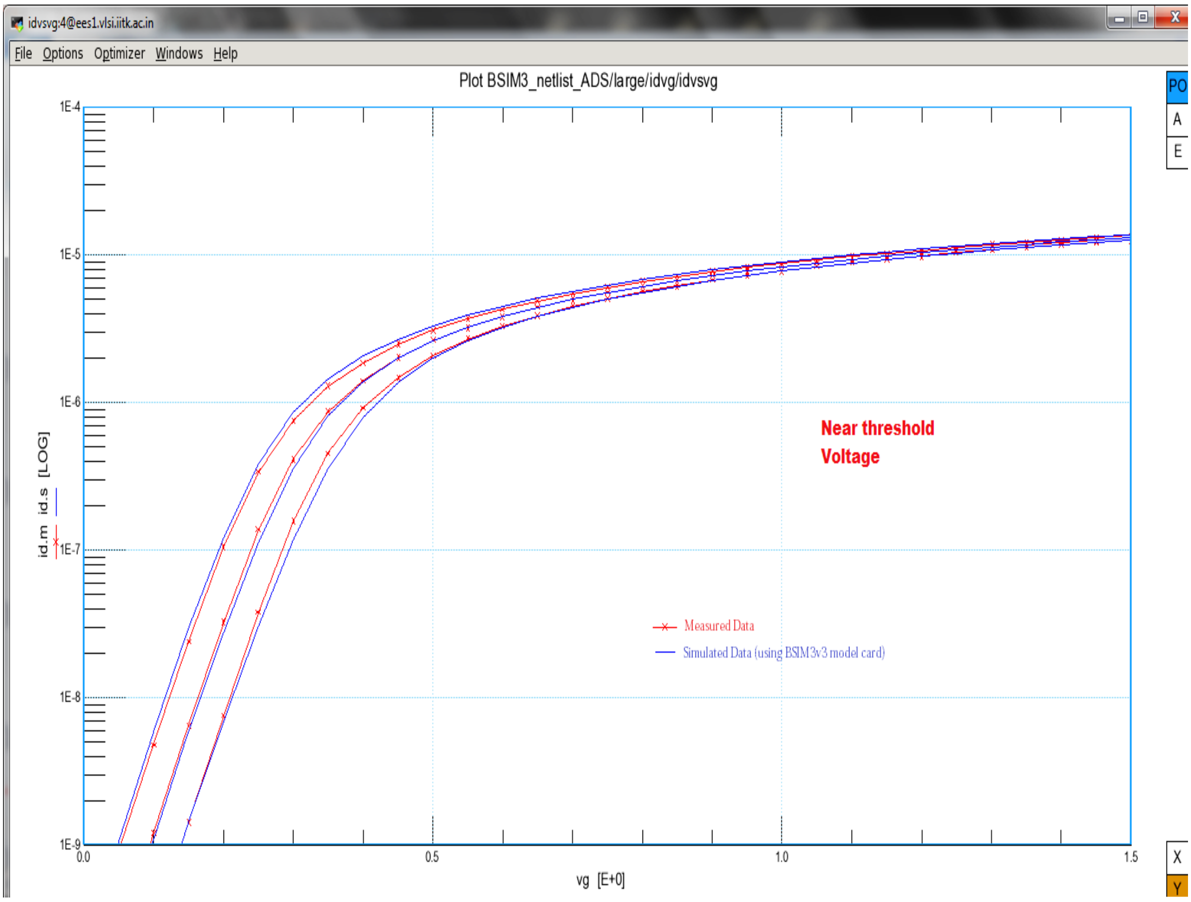

Fig 3: $I_d - V_g$ near threshold voltage with measured and simulated data

In the next step, I focussed on strong inversion region where I extracted the BSIM3 model parameters corresponding to strong inversion region e.g. ***U0, Ua, Ub, Uc*** etc. Employing the knowledge gained through the study of MOS physics and BSIM3, I was able to generate following characteristics in which simulated characteristics is precisely following the measured characteristics.

*Letters in **bold** and ***Italics*** are BSIM3v3 **Model Parameters** in this report

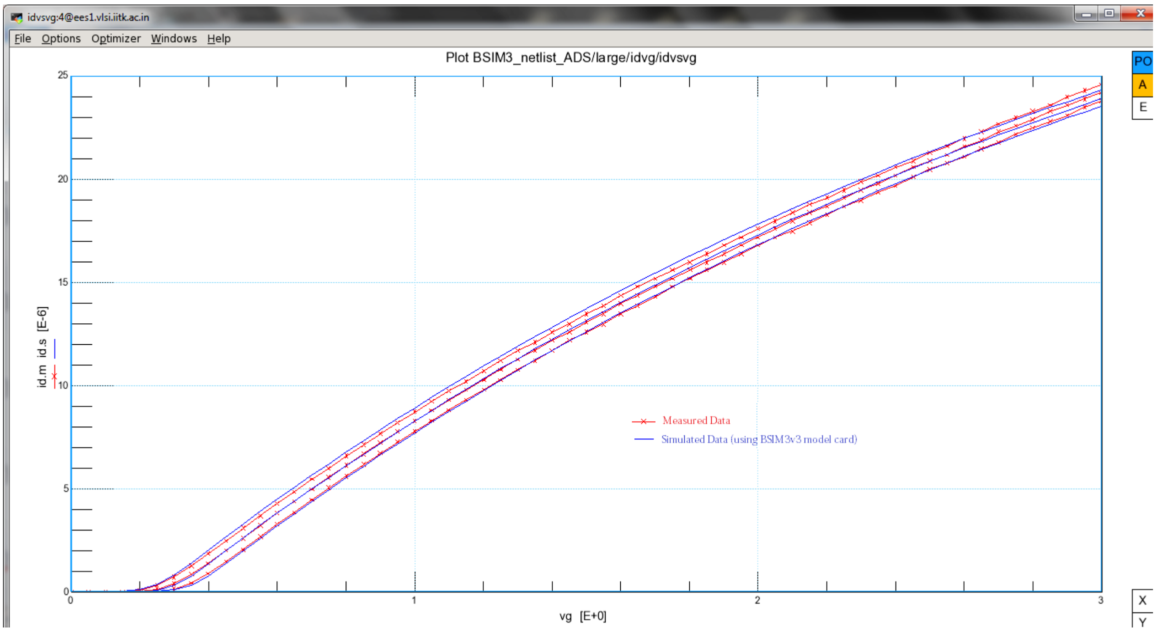

Fig 4: $I_d - V_g$ in strong inversion region with measured and simulated data

In the next step, I worked on subthreshold region on $I_d - V_g$ characteristics and extracted BSIM3 parameters e.g. ***Voff, Nfactor, Cdsc, Cdscd*** etc**.** The complete $I_d - V_g$ characteristics is shown in fig 5 (**X-axis**: Linear; **Y-axis**: Logarithmic):

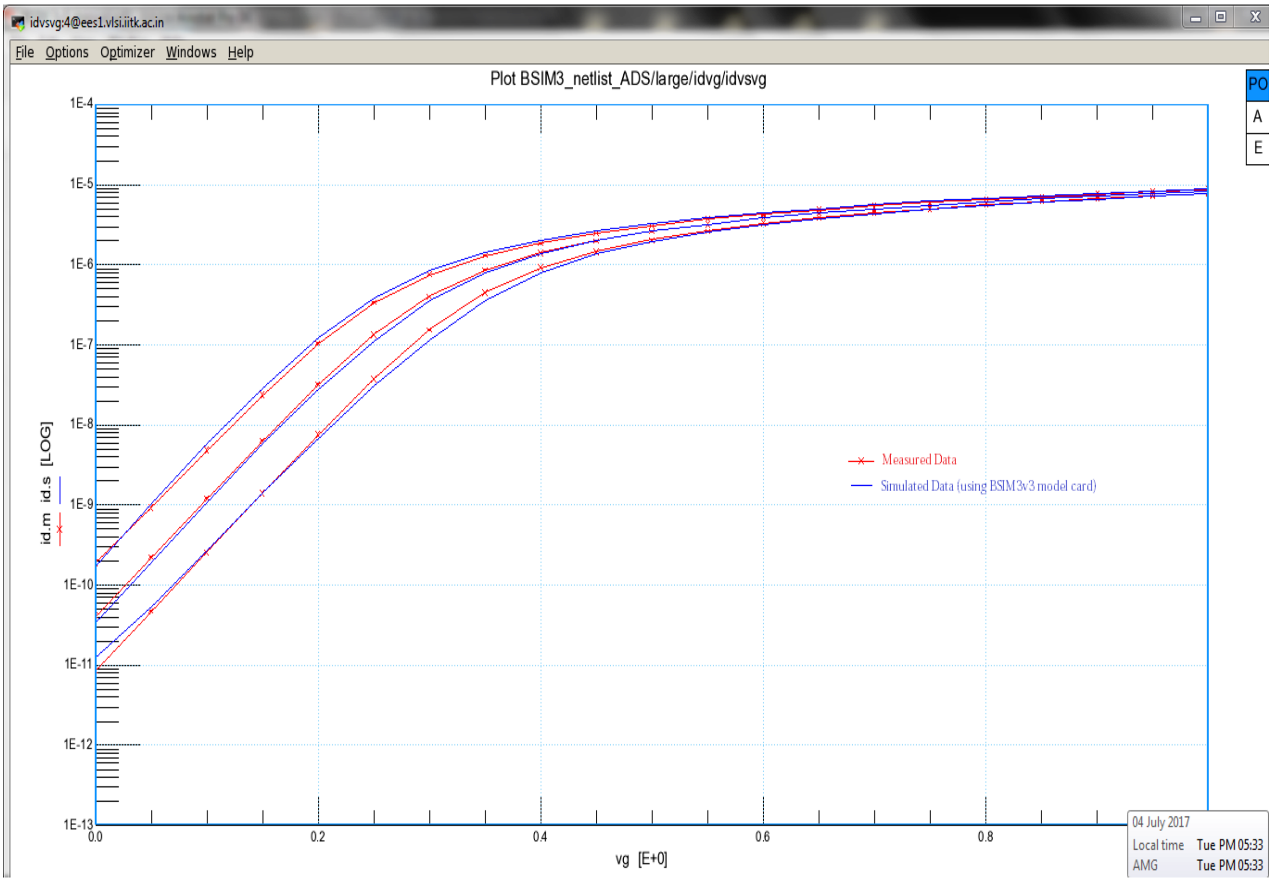

Fig 5: $I_d - V_g$ measured and simulated characteristics

After dealing with $I_d - V_g$ measured and simulated characteristics, now it is the turn to concentrate on $I_d - V_d$ measured and simulated characteristics along with keeping an eye on $I_d - V_g$ measured and simulated characteristics. Because $I_d - V_g$ simulated characteristics may have change during parameter extraction of $I_d - V_d$ simulated characteristics from measured $I_d - V_g$ measured characteristics. I focussed on $I_d - V_d$ measured and simulated characteristics where I extracted BSIM3 model parameters like ***Vsat, A0, Ags, Pscbe1, Pscbe2, Pclm, Pavg, Pdiblc1, Pdiblc2, Drout*** etc at different V_{gs} values. The $I_d - V_d$ measured and simulated characteristics are shown in fig 6(**X-axis**: Linear; **Y-axis**: Linear).

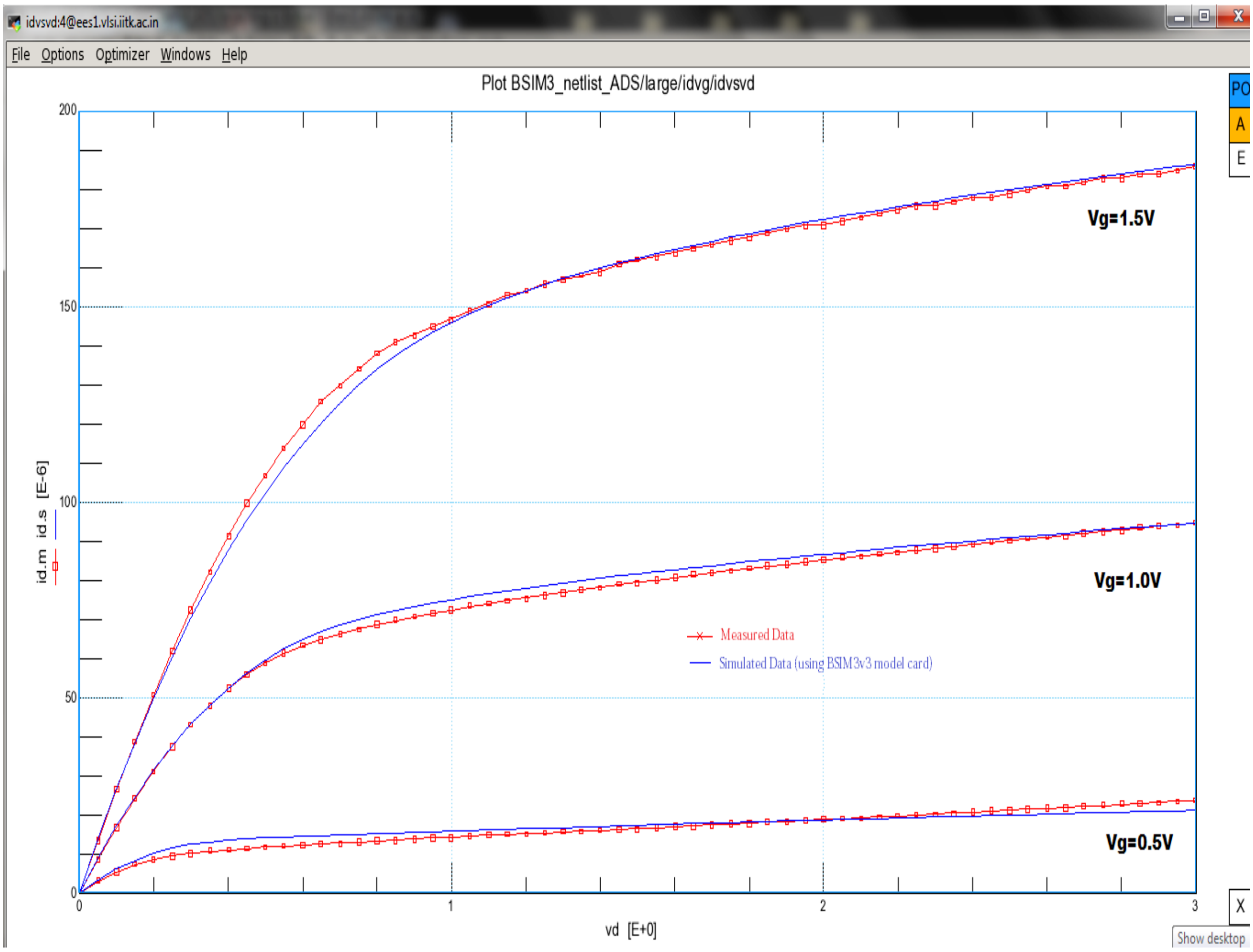

Fig 6: $I_d - V_d$ measured and simulated characteristics

One can observe the complete $I_d - V_d$ measured and simulated characteristics including subthreshold currents, which is shown in fig 7.

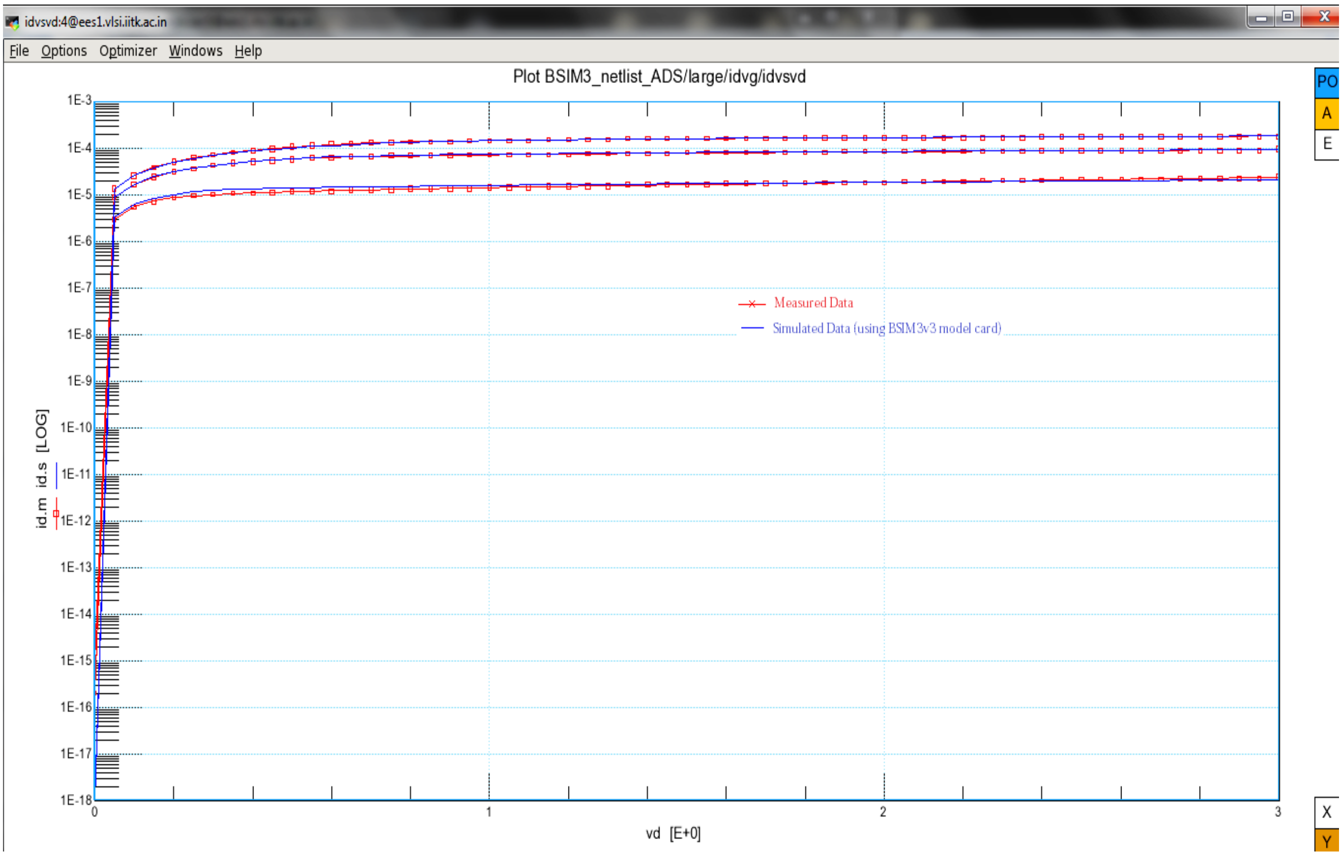

Fig 7: $I_d - V_d$ measured and simulated characteristics (**X-axis**: Linear; **Y-axis**: Log)

The corresponding $I_d - V_g$ measured and simulated characteristics (after making changes to $I_d - V_d$ simulated characteristics) is shown in fig 8 which is given as follows:

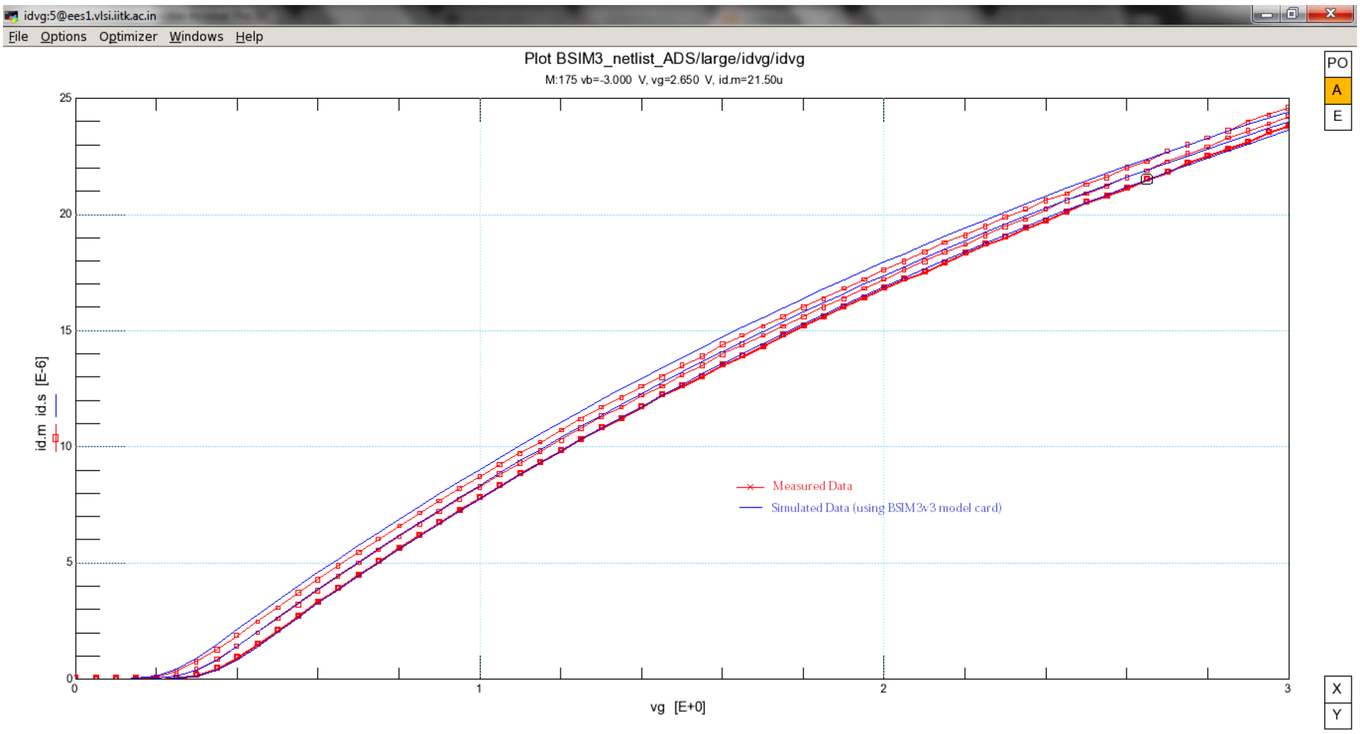

Fig 8: $I_d - V_g$ measured and simulated characteristics (after extracting model parameters for : $I_d - V_d$ simulated characteristics)

The above mentioned I_d – V_g measured & simulated characteristics and I_d – V_d measured and simulated characteristics were investigated by Dr. Sudip Ghosh. He found the work satisfactory and with acceptable accuracy. The BSIM3 model card with extracted parameters can be found here. BSIM3 Model Card

Conclusion:

The whole experience of working at Indian Institute of Technology Kanpur was great. This institute has an awesome work culture, great minds and high quality of work. I learned a lot of about MOS physics and modelling. The work I could complete here was very satisfactory. I hope my work on BSIM3 based parameter extraction and MOS Physics meet its goals.