COMPARISON OF THE MOBILITY MODELS IN MOSFET

ROSMAN BIN LALETE

THIS DISSERTATION IS SUBMITTED TO FULFILL THE PREREQUISITE OF

DEGREE IN ELECTRICAL AND ELECTRONIC ENGINEERING

WITH HONOR

SCHOOL OF ENGINEERING AND INFORMATION TECHNOLOGY

UNIVERSITY MALAYSIA SABAH

KOTA KINABALU

2006

UNIVERSITI MALAYSIA SABAH

JUDUL: COMPARISON OF THE MOBILITY MODEL IN MOSFET

IJAZAH: SARJANA MUDA KEJURUTERAAN ELEKTRIK & ELEKTRONIK

SESI PENGAJIAN: 2002/2003

Saya ROSMAN BIN LALETG
(HURUF BESAR)

Mengaku membenarkan tesis (LPS/Sarjana/Doktor Falsafah) ini di simpan di Perpusatakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hakmilik Universiti Malaysia Sabah.
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tingg
4. ** Sila tandakan (/).

[ ]	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972).
[ ]	TERHAD	
[✓]	TIDAK TERHAD	

Disahkan oleh

(TANDATANGAN PENULIS)

(TANDATANGAN PUSTAKAWAN)

Alamat Tetap: TMN. SEMPELANG, SLNG B, LOT 246, NO.H 7, 88100 K.K, SABAH.

Nama Penyelia

Tarikh: 29.05.2006

Tarikh:

CATATAN: * Potong yang tidak berkenaan.
* Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada berkuasa/organasasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT dan TERHAD.
* Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara penyelidikan atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (LPSM)

DECLARATION

I declare that this thesis writing is the sole work of mine except for quotation, summaries and the references which have been duly acknowledge.

2 May 2006

ROSMAN BIN LALETE
HK2002 – 3364

CERTIFIED BY

Mr.KHAIRUL ANUAR MOHAMMAD
(SUPERVISOR)

Mr.ISMAIL SAAD
(EXAMINER)

Mr. LIAU CHUNG FAN
(CHAIRMAN)

ACKNOWLEDGEMENT

First of all, I would like to thanks God for everything that He had give to me in my whole life. A special thanks to my project supervisor, Mr. Khairul Anuar Mohammad for the technical knowledge, the valuable advises and knowledge.

I would like also to express my gratitude to both my lovely parents Mr. Lalete B. Amat and Mrs. Noripah Bte Azis .Not forgotten to my sibling for their valuable support, feedback, and encouragement.

To my course mates Mr.Shahlan Rusian, Mr.Asmirul Yandi to my senior Mr.Saharudin Jair, Mr. Khairul Mohd Arshad and who are not mentioned here for their support and cooperation through out this project.

ABSTRAK

Low Field Mobility dan *Inversion Layer Mobility Model* adalah antara jenis-jenis *mobility model* yang terdapat dalam perisian *Technology Computer Aided Design* ataupun dikenali sebagai TCAD. Di dalam tesis ini, perbandingan dan pengkajian telah dilakukan terhadap kedua-dua jenis *mobility model* ini. Program ATLAS digunakan untuk melakukan proses simulasi untuk memperolehi keputusan bagi setiap perbandingan parameter yang dibuat. Perbandingan yang dibuat adalah tertumpu kepada parameter *Drain Characteristic, Electron Mobility dan Electron Velocity*. Bagi perbandingan Drain Characteristic, *Model Low Field Mobility* punyai I_D yang lebih tinggi iaitu sebanyak 0.00186A berbanding dengan yang lain. Keputusan ini kurang realistik tetapi apabila ia digabungkan dengan FLDMOB, keputusan yang diperolehi lebih realistic berbanding sebelumnya. Bagi perbandingan *Electron Velocity, Model Inversion Layer* lebih baik kerana ia memberikan nilai tetap berbanding *Model Low Field Mobility* kerna ia mengambil kira *Transverse Field Effect* dan juga *Velocity Saturation* dalam mereka model MOSFET. Semua perbandingan simulasi yang dibuat hanya menggunakan peranti NMOS sebagai bahan kajian.

ABSTRACT

Low Field Mobility and Inversion Layer Mobility Model a two type mobility model that's included in the *Technology Computer Aided Design* or knowing as TCAD. In this thesis, the comparison and examines done to both mobility model. The ATLAS Program has being used to do a simulation and getting the result for every comparison depends on the parameter given. The comparison parameter only looks for the Drain Characteristic, Electron Mobility and Electron Velocity. For parameter Drain Characteristic, Low Field Mobility Model has the higher I_D that equal to 0.00186 when comparing to the other models. This result is not realistic but when it has combine with the FLDMOB model, the result a more realistic than before. For parameter Electron Velocity, the Inversion Layer Mobility Model is more accurate compare to the Low Field Mobility Model because it takes to account the Transverse Field Effect and Velocity Saturation. Only NMOS device is being used for compare all the simulation result.

CONTENT OF PAGE

LIST OF FIGURE

LIST OF TABLE

CHAPTER 1

INTRODUCTION

1.1 PROLOGUE

Metal Oxide Semiconductor Field Effect Transistor or MOSFET has been one of the important classes of FET and it is also dominant technology in the semiconductor industries. In our everyday lives, most of the electronic devices that we used today have a MOSFET component. The concept of Metal Oxide Semiconductor FET was actually developed well before the invention of the Bipolar Transistor.

In the early 1930's patents were issued for device that resemble the modern silicon MOSFET but which were made from combination of material not including silicon (Jasprit Singh, 2001). Silicon is only semiconductor on which a high-quality insulator (SiO_2) can be grown with ease. The quality of its interface is good enough to allow electrons and holes moving near the interface to have reasonable mobilities.

Hence, it is very important to know as much as possible about the Mosfet device. But to have an in-depth understanding and the ability to this electronic component characteristic device, the effective ways is to simulate and to modeling a device that have a same physical properties like the real component.

Modeling electronic devices has been an important aspect in the area of development and understanding the semiconductor devices. Therefore by availability of the TCAD tools modeling and simulate out the MOSFETs devices under various carriers mobility can be done.

The NMOS is been analyzed using the ATLAS software to obtain the electrical characteristics. This characteristic will interpret into the Tonyplot and comparison will make base on the result given.

1.2 OBJECTIVE

The main objective of this thesis can be simplified as follows;

- To make a comparison of drain characteristics of the models
- To make a comparison layout of the Low field Mobility and Inversion Layer Model in 2-Dimension.
- To make a comparison of Low field mobility models with Parallel Field Electrical Dependency

1.3 AIM OF THESIS

The aim of this thesis is to do comparison and evaluation of the different mobility models used in TCAD software that is available. With different mobility model that been published and used in TCAD, studying various model will present a clear understanding behind the rational of how each individual model is being proposed by different researcher. The reader also will able to understand the factors affecting each of the models and the reliability.

1.4 THESIS OVERVIEW

This thesis report will give detail information on the project which has been done.

CHAPTER 2 will give a brief introduction about the MOSFET basic operation. It is also included a theory of how mobility model in the channel of a MOSFET devices.

CHAPTER 3 will give some information and background about the various carrier mobility models which is being used by the TCAD software.

CHAPTER 4 will discuss about the methodology used for the simulation that is ATLAS. It also gives a briefing based on comparison for the various mobility within the ATLAS software as discuss at chapter 3.

CHAPTER 5 will give the presentation and investigation of the simulation result for the various mobility models in n-MOSFET under different biasing. The parameters compared in this chapter are electron velocity, electron mobility and drain-voltage characteristic curve.

CHAPTER 6 will conclude all the comparison made at Chapter 5. It also included recommendation for the further work for pursued in the further.

CHAPTER 2

THEORITICAL

2.1 INTRODUCTION.

The field-effect transistor (FET) controls the current between two points but does so differently than the bipolar transistor. The FET operates by the effects of an electric field on the flow of electrons through a single type of semiconductor material. This is why the FET is sometimes called a unipolar transistor.

Placing an insulating layer between the gate and the channel allows for a wider range of control (*gate*) voltages and further decreases the gate current (*and thus increases the device input resistance*). The insulator is typically made of an oxide (*such as silicon dioxide, SiO_2*), this type of device is called a **Metal-Oxide-Semiconductor FET** (*MOSFET*) as show in figure 1 below.

In a n-MOSFET device, the channel is made of n-type semiconductor so the charges free to move along the channel are negative charged (*hence n*) - they are electrons. The n-channel MOSFET consist drains and source gate where is conducting with highly n-type semiconductor which is isolate from p-type substrate. The region between the drain and source gate covered by polycrystalline or metal. The gate channel is between the drain and source and it is separated by the oxide gate.

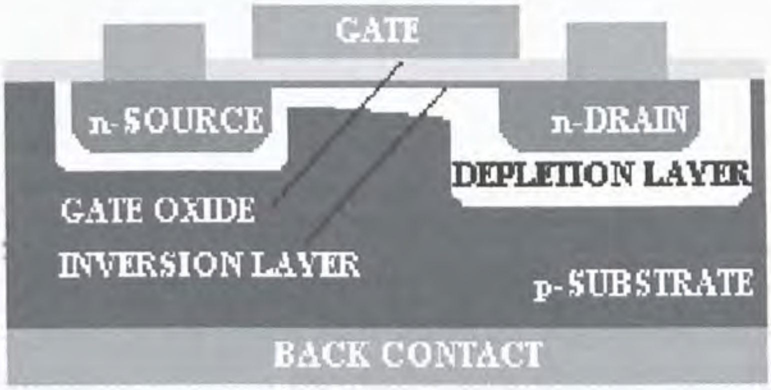

Figure 1: 2 :1: Cross-section of n-type Metal-Oxide-Semiconductor-Field-Effect-Transistor (MOSFET)

The source and drain channel are electrically disconnected unless there is an n-type inversion layer at the surface to provide a conducting the channel. When the surface is inverted and voltage is applied between the source and drain junctions carries can enter the channel at the sources and leave at the drain. This will allowed current flow from drain to source for n-type MOSFET. Changing the gate to source (V_{GS}) voltage can reduce the drain current in this type of MOSFET and hence it is call a *depletion mode*. If the channel region is not inverted at $V_{GS} = 0$, it is call *enhancement mode*. This mode is far more frequently used in the circuits than a depletion mode device (Jasprit Singh,2001).

2.2 Basic MOSFET Operation.

In circuit application, MOSFET typically function either as voltage controlled resistor in analog circuit but as a switches in digital circuit. For n-type MOSFET, it can separate into three different modes and it is depends on the input voltage given at the terminal that is:

Mode 1 : Equilibrium Condition ($V_{GS} < V_T \Rightarrow I_D = 0$)

Under this mode, there is no biasing effect on the p⁺ substrate and no current flowing from the drain gate to the source. This will not happened in real situation because the voltage that supply to the gate is very small and it can reach the p⁺ substrate and this is why the channel will not produced. Figure2 show the n-type MOSFET in equilibrium mode.

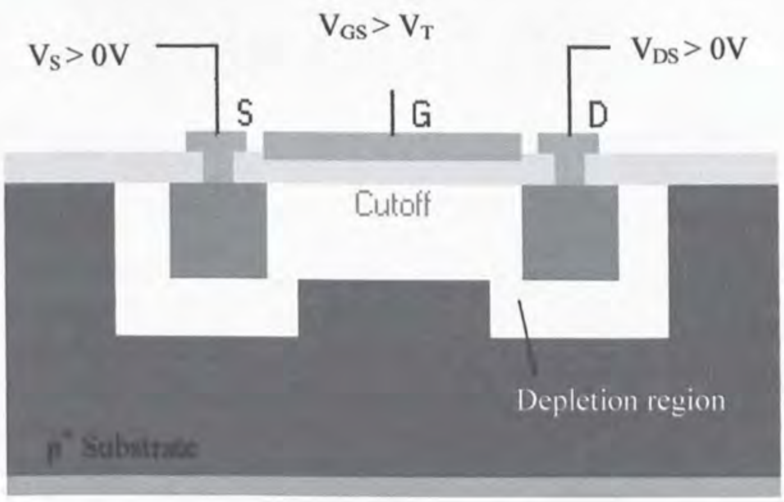

Figure 2:2:2 :MOSFET under equilibrium condition

Mode 2 : $V_{GS} > V_T$ and $V_{DS} = 0 \Rightarrow I_D = 0$

In this mode, positive voltage is being applied to gate voltage V_{GS} thus will increase above the threshold voltage V_T. It will induce negative charge below the gate metal to form a thin region near the surface. This region is known as a ***depletion***

region as shown in figure3. The threshold voltage will reach the p^+ substrate and electron motion in it will be pulled by the holes in the depletion region and channel will form between the drain and source gate. This channel will allow the current to flowing between it. The V_{DS} still zero and its only can increase up to 0.5V.

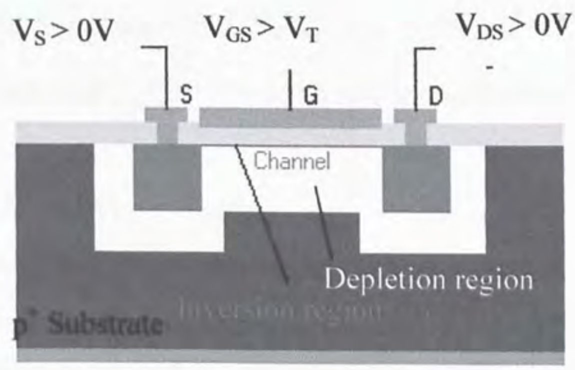

Figure 3:2:2 : Small signal applied at gate voltage

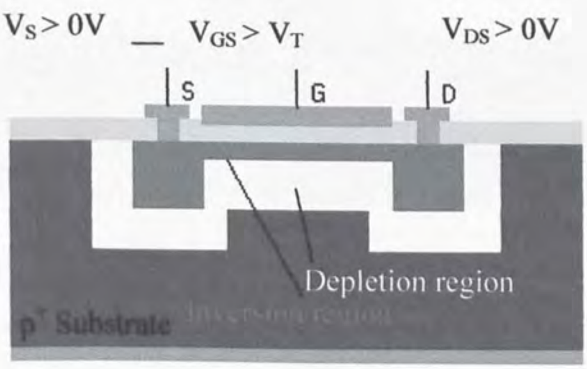

Figure 4:2:2 : Inversion region start to occur

Mode 3 : Linear region $V_{GS} > V_T$ and $V_{DS} = 0 \Rightarrow I_D = 0$

The channel region that form between drain and source gate is acting like a voltage controlled resistor where resistance increases when the V_{DS} increase. When the V_{DS} increase above zero, drain current starts to flow. In this region of operation the Id current is quadratic function of source and drain voltage. This means, the increases of the drain current is slowly when the V_{DS} voltage is increases. The channel depth at drain will decreases followed by the increasing of the source-drain voltage.

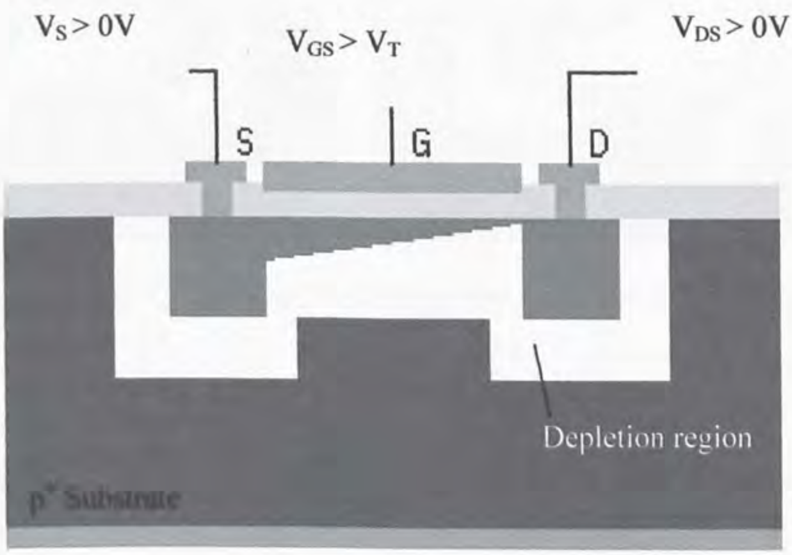

Figure 5:2:2 :MOSFET under linear region

Mode 4 : Pinch Off Region $V_{GS} > V_T = V_{SAT} \Rightarrow I_D > I_{SAT}$

When the V_{DS} reaches the V_{SAT} where V_{DS} = Vsat, the depth at the drain gate decrease up to zero. When this happened, the forming region is known as a pinch-off region. In this mode, any increasing of the source-drain voltage does not effecting increasing of source-drain current.

Mode 5 : Saturation Mode $V_G > V_T$,$V_D > V_{DSat}$ => $I_D = I_{DSat}$

In the saturation mode, there are no free electric carriers. The drain current I_D now independent of the source-drain voltage V_{DS}. Electrons in the channel are pulled into pinch-off region and flow at the saturated drift velocity due to the high longitudinal electric field along the channel.

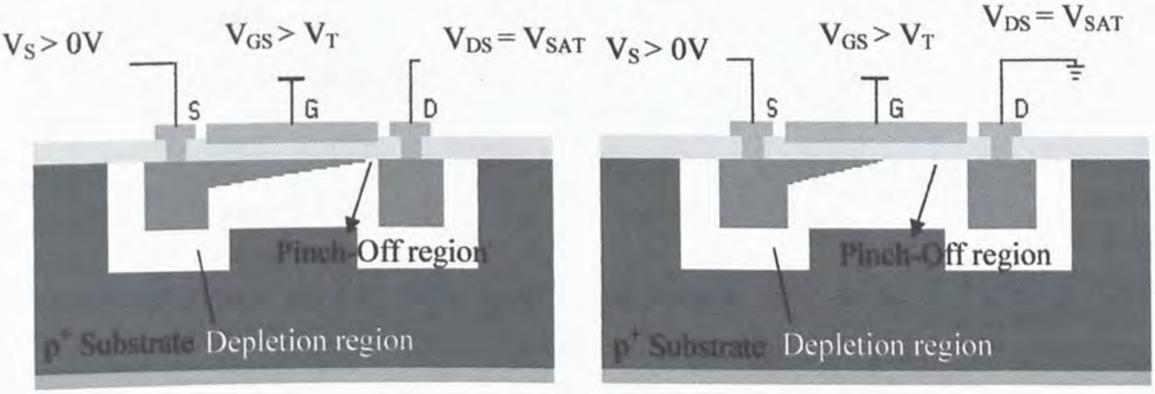

Figure 6:2:2 : MOSFET start to Pinch-off and then become saturate mode

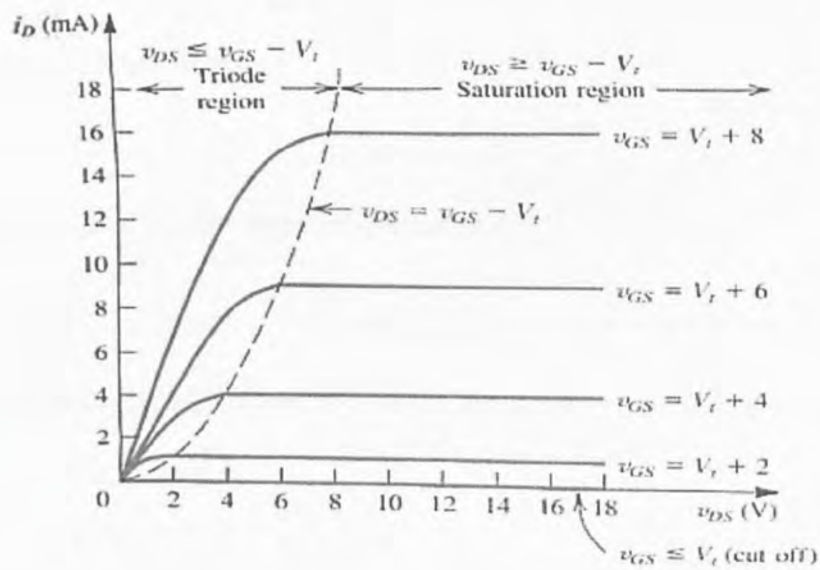

Figure 7:2:2 : Current- voltage characteristic of n-channel MOSFET with current saturation caused by pinch-off.

2.3 CARRIER MOBILITY AND MODEL

Carrier mobility is an important quantity which is used to characterize a semiconductor material and in device development. The equation V=IR in the Ohm's law can being replace (T.Ytterdal, 2003) by some other equivalent forms;

$$R = \rho \frac{L}{W} = \frac{1}{\sigma} \frac{L}{A} \quad \text{(Equation 1)}$$

L = Length.

W = Width of the sample.

J = Current density

A = Area of the sample.

ρ = Resistively of the material

σ = Conductivity of the material

We can written current as a;

$$I = jA \quad \text{(Equation 2)}$$

The Ohm's law now becomes,

$$j = \sigma F \quad \text{(Equation 3)}$$

By derive it to *E* where *E* = electric field vector,

$$E = \frac{V}{L} \quad \text{(Equation 4)}$$

Using both equation above, we can solve the to find the current density from formula below;

$$j = E\sigma \quad \text{(Equation 5)}$$

σ is equal to ;

$$\sigma = qn\mu_n + qn\mu_p \quad \text{.......................................} \quad \text{(Equation 6)}$$

n = Electron concentration

p = Holes concentration

q = Electric charge (1.6×10^{-19} C)

μ_n = Electron mobility

μ_p = Hole mobility

Since in this thesis is discussion with N-MOSFET, the minority will be conveniently disregarded. Therefore,

$$\sigma \approx qn\mu_n \quad \text{.......................................} \quad \text{(Equation 7)}$$

By substitute the equation 7 into equation 5, the current density express in Ohm's law equal to:

$$\begin{aligned} j &= E\sigma \\ &= E \times qn\mu_n \end{aligned} \quad \text{.......................................} \quad \text{(Equation 8)}$$

If the same current density for a given carrier concentration (n) and electric field (E), then the mobility can be linked to the drift velocity (V_d) as;

$$V_d = -\mu_n E \quad \text{.......................................} \quad \text{(Equation 9)}$$

From here, there is a linear relationship between the drift velocity and the electric field. However the equation can be used when the electric field in the MOSFET is very small. From here, the relationship of the carrier mobility is constant at low electric field but becomes a function of the electric field when high field involved. At the higher electric field it is not only the drift velocity deviates from being linear dependent. It will become saturated when or after reaching the saturated point.

The Electric Field also is an important element in the FET that causes the electron and holes to accelerate across the channel of a MOSFET device. It is also known as the mobility modeling in the MOSFET. However, the momentum from the flowing electrons and holes from one side to the other side could be affected by the scattering mechanisms. For example likes a phonon or lattice vibration, ions impurity, surface roughness near the oxide gate, material imperfection and carrier-carrier scattering.

2.3.1 CARRIER – CARRIER SCATTERING

This scattering is account for the high doping level for both majority carriers which the device is subjected to high level injection. The result of this effect is described by Fletcher (Ken Yamaguchi, 1983) where the mutual diffusion of the two groups of charge gaseous particles apply to the quasi-neutral electron hole plasma when the injection level is high.

2.3.2 PHONON or LATTICE SCATTERING

Phonon or Lattice Scattering is about the increasing of mobility (μ_o) depend on the increasing the of the lattice temperature. When the temperature increases the area for atom vibrate in will be large. The frequency of vibration will increase and this will cause higher probability of carrier collide with an atom thus causing the phonon scattering. Figure 8 show the example for the phonon scattering.

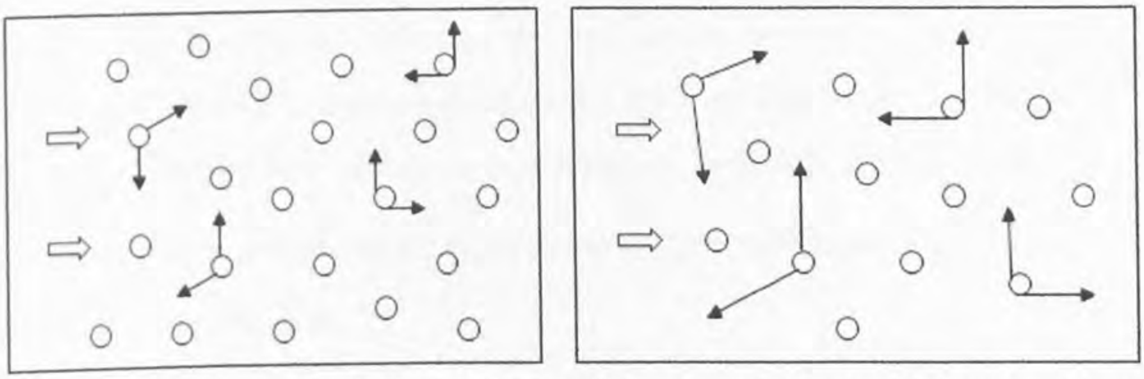

Figure 8:2:3: Phonon scattering where mobility can move wider than before depend on temperature increase

2.3.3 SURFACE ROUGHNESS

When the carriers travel across from gate to source through the inversion layer, they undergo mobility degradation due to the microscopic roughness between the oxide-silicon and the bulk material. Figure 9 below show the example of the surface roughness.

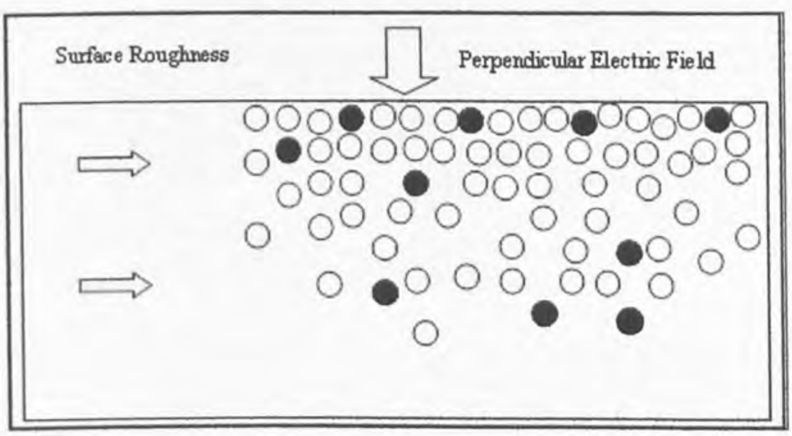

Figure 9:2:3: Surface roughness scattering

2.3.4 TRANSVERSE AND LOGITUDINAL FIELD EFFECT

The basic operation of the FET is by applying a bias voltage at the gate. It will introduce a transverse field effect on the bulk material causing the inversion layer. However, there also a strong dependence on the drain bias which also known as longitudinal electric field. As shown mathematically in section 2.3, the carrier drift velocity is directly proportional in a linear fashion until the electric field reach ε_{sat} .In simple mathematical terms;

When $\mathrm{E} < \varepsilon_{sat}$;

$$V_d = -\mu_n \mathrm{E} \quad \text{(Equation 10)}$$

When $\mathrm{E} > \varepsilon_{sat}$;

$$V_d = V_{sat} \quad \text{(Equation 11)}$$

When maximum longitudinal electric field near the drain end of the channel will be ;

$$\mathrm{E}_{sat} = \frac{V_d - V_{sat}}{\Delta L} \quad \text{(Equation 12)}$$

REFERENCES

[1] ATLAS User's Manual Device Simulation Software Volume 1.

[2] Narain D.Arora, John.R Hauser, David J.Roulston, "Electron and Hole Mobilities in Silicon as a function of Concentration and Temterature",IEEE Transaction Electron Devices, VOL 29, No.2, 1982.

[3] D.B.M Klaassen, "A Unified Mobility Model for Device Simulation – Equation Model & Concentration Dependends, VOL.35, No.7, 1992

[4] Ken Yamaguchi, "A Mobility Model of Carrier in the MOS Inversion Layer", IEEE Transaction on Electron Devices, VOL Ed-30, No.6, JUN 1983.

[5] Shirahata M, Kusano H, Kotani N, Kusanoki S and Akasaka Y, "A Mobility Model Including the Screening Effect in the MOS Inversion Layer", IEEE Transaction Computer Aided Design, VOL.11, No.9, SEPTEMBER 1992.

GENERAL READING

[6] Jasprit Singh, "Semiconductor for devices, Basic Prinsiples", United States of Amerika, John Wiley & Sons Inc, 2001.

[7] T.Ytterdal, Y.Cheng, T.A Fjeldly, "Device Modelling for Analog and RF CMOS Circuit design", John Wiley & Sons Inc, 2003.