Nanosimulator for Analysis of Mosfet at Nanoscale

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***Abstract* - At nanoscale dimensions (below 100nm) the behavioral characteristics of MOSFET change due to quantum mechanical effect and deviate from the normal equations. In this paper we have proposed a simple Graphical user interface model-NANO SIMULATOR . This simulator is based upon modified equations to predict the curves of nanoscale MOSFETs. It has been developed to study the Current-Voltage characteristics and the model parameters i.e. threshold voltage,flat band voltage, mobility of nanoscale MOSFETs specifically at 90nm, 65nm, 45nm,32nm technology nodes(or CMOS Process). This GUI based NANO SIMULATOR also helps in studying various types of leakage currents at 90nm, 65nm, 45nm, 32nm technology nodes.**

Keywords - I-V Curve, Leakage Current Curve, Pushbutton, popup menu, MatLab GUI

I. NOMENCLATURE

Vgs- Gate to Source voltage
Vds- Drain to Source voltage
Vth- Threshold voltage
Vfb- Flat band voltage
Jtn- Direct gate tunneling in n-channel MOSFET current density
Jsdn- Source Drain Extension tunneling current density
Jtpoly-Leakage current density due to poly gate
Jfn- Fowler Nordheim Tunneling
Eox- Dielectric constant of gate oxide
EOT- Equivalent Oxide Thickness
Cox - Oxide capacitance
µ - Mobility

II. INTRODUCTION

As the transistor gate length drops to 45 nm and below and the gate oxide thickness drops to 1 nm physical limitations, such as off-state leakage current and reduction in drive currents, make geometric scaling an increasingly challenging task. Moreover, a combined study of I-V Curves on the basis of channel length scaling along with the leakage currents on the basis of gate oxide thickness scaling at various technology nodes by a GUI-SIMULATOR has not been reported yet in the existing literature. In this paper ,we present our GUI-SIMULATOR to study MOSFET at 90nm,65nm and 45nm technology nodes. This simulator is built upon MATLAB-*Graphical user interface* and the curves which this simulator will provide are also calculated by MATLAB Tool.

MatLab software environment with its own Graphical User Interface (GUI). The GUI is used to analyze the I-V characteristics of MOSFET at nanoscale and displays the curves and parameters such that a user can visualize the voltage and current variations as well as different type of leakage currents. The user interface also plays a vital role in controlling the application’s performance to suit the user’s requirements. The objective of this work is to make a easy understanding of MOSFET at nanoscale using a simple simulator with simple MOSFET equations. This simulator has the ability to take the input from user, and generates the characteristic curve and corresponding parameters. This paper is organized as follows. In section III, NANOSIMULATOR’s structure is shown by flow diagram in fig.1. Section IV describes nanoscale MOSFET modeling quations. Section V, explains how we can install the simulator. Section VI, explains modeling results for leakage currents. Section VII, describes modeling results for input-ouput characterstics. A summary and future work is presented in section VIII.

III. SOFTWARE STRUCTURE

The proposed simulator is built in MatLab software environment with its own GUI. MatLab code here used is in ‘m-file’ at backend because it is more flexible and have fewer limitations. User end code is in “.pfile”, so that our original file can be saved from unwanted disturbances. The GUI is a user friendly interface that can provide a user with the access to perform I-V analysis of MOSFET. This simulator can perform the following processing:

- Id-Vds Curve
- Id-Vgs Curve
- Jtn-Vgs Curve
- Jsdn-Vgs Curve
- Jtpoly-Vgs Curve
- Jfn-Vgs Curve
- Jfn-Eox Curve
- Jtn-EOT Curve
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Fig. 1 shows the flowchart of the simulator , where the code has been written using MatLab code to obtain the results on the GUI.

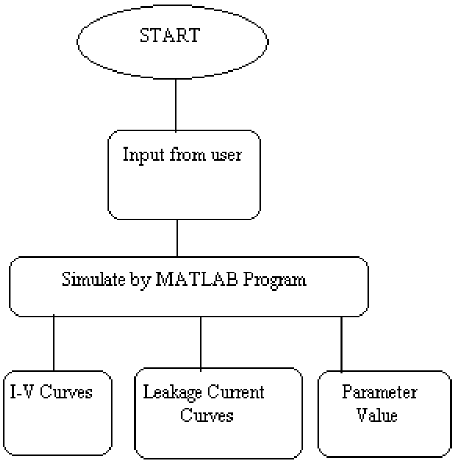


Fig. 1 Flowchart of the proposed simulator

IV. NANOSCALE MOSFET MODEL

Here we are giving analytical MOSFET’s I-V model for circuit simulator. This approach is necessary for circuit design. Analytical model is of two types[4],one is physically based,the other is continuity between different operation regions.Since Quantam Mechanical Effects have significant influences on the threshold voltages[2],on gate capacitance attenuation[3] due to finite inversion layer thickness.

Modified equation for Threshold voltage:

Initially the threshold voltage will be equation 1

V_th=V_fb+phi_s_qm+sqrt(2*q*epsilon_si*N_a*phi_s_qm)/C_ox; (1)

Threshold voltage in linear region due to QME is given by equation 2

V_th_qm$_{linear}$=V_fb+phi_s_qm+phi_c$_{linear}$+sqrt(2*q*epsilon_si*N_a*(phi_c$_{linear}$+phi_s_qm))/C_ox; (2)

Threshold voltage in saturation region due to QME is given by equation3

V_th_qm_sat= V_fb+phi_s_qm+phi_c_sat+sqrt(2*q*epsilon_si*N_a*(phi_c_sat+phi_s_qm))/C_ox; (3)

Where

alpha_t= ((3*m_e*q^2*N_a*d_cl)/(2*epsilon_si*h_^2))^(1/3);

phi_s = (q*N_a*(d_cl)^2)/(2*epsilon_si);

phi_s_qm = (q*N_a*((d_cl+9/(4*alpha_t))^2))/(2*epsilon_si);

V_fb = -0.56-phi_b; Flat Band Voltage

phi_c$_{linear}$ = (V_dsat)/2;

phi_c_sat = V_dsat/2;

Modified equation for mobility:

Due to QME and Short Channel Effects mobility equations are different from classical mobility.

Mobility in linear region is given by equation 4

u_eff = u_o./(1+theta*(V_gs-V_th_qm$_{linear}$)); (4)

Mobility in saturation region is given by equation 5

u_eff_sat = u_o./(1+theta*(V_gs-V_th_qm_sat)); (5)

where

u_o = 0.06; low field surface electron mobility

E_cro$_{linear}$ = v_sat./u_o; Vertical electric field component in linear region

E_cro_sat = v_sat./u_eff_sat; Vertical electric field component in saturation region

theta = u_o/(2*t_ox*v_norm); %constant

v_norm = 2.2e7 ;v_sat = 1e5; %unit: m/s

v_sat is saturation velocity

Modified equation for Bulk Deplition region charge:

Without QME and SCE the value of Q_{BO} is given by equation6
Q_dep = q*N_a*d_cl (6)

Without QME and SCE the value of Q_{BO} is given by equation7
Q_bo_qm = q*N_a*(d_cl+(9/(4*alpha_t))) (7)

Where
d_cl = sqrt((2*epsilon_si*2*phi_b)/(q*N_a))
alpha_t=((3*m_e*q^2*N_a*d_cl)/(2*epsilon_si*h_^2))^(1/3)
h = 6.626e-34; %unit: J.s
h_ = h/(2*pi);
epsilon_o = 8.854e-12; %unit: F/m
epsilon_si = 11.80*epsilon_o;
epsilon_sio2 = 3.90*epsilon_o;

Modified equation for I_{DS} and V_{dssat}:

V_dsat = (L*E_cro$_{linear}$*((sqrt(1+(2*(V_gs-V_th))/((L*E_cro$_{linear}$)*eta)))-1));

I_dst = (W*u_eff*C_t/L).*(1./I_2).*I_6;
I_dsat = ((W*u_eff2*C_t/L).*(1./Iss_1))*Is_6;

Where
eta = 1-((Q_bo_qm)/(2*phi_s_qm*C_ox))

C_t = (1/C_ox+1/C_inv)^(-1)
C_inv is capacitance of inversion layer

Modified equation for Jtn and V_{GS}:

A = exp(-gamma*sqrt(q*E_b));
B = exp(q*(phi_s-phi_b-E_g/2)/(k*T));
C = 1-exp(-q*V_gs/(k*T));
E = 1.+(gamma*k*T)./(2.*sqrt(q*E_b));
F = 4*pi*q*m_e*((k*T)^2)/(h^3);
J_t = (F.*E.*C.*B.*A)*1e-4;

Where
m_o =9.11e-31 %unit: Kg
m_ox = 0.32*m_o;
m_e = 0.19*m_o;
h = 6.63e-34 ; %unit: J-s
q = 1.6e-19 ; %unit: C
phi_b = ((k*T)/q)*log(N_a/n_i); %eV
gamma = (4*pi*t_ox*1e-9*sqrt(2*m_ox))/h;
N_a=4e24 ; %unit: m-3
n_i= 1.45e16 ; %unit: m-3
k = 1.38e-23 ; %unit: J/K
T = 300 ; %unit: K

Modified equation for Jtpoly and V_{GS}:

A = exp(-gamma.*sqrt(q.*E_b));
B = exp((phi_s-phi_b-(E_g*q)/2)/(k*T));
C = 1-exp(-V_gs./(k*T));
E = 1+(gamma*k*T)./(2.*sqrt(q.*E_b));
G = (k*T)^2;
F = 4*pi*m_e*q^2/(h^3);
J_tpoly = F*G.*E.*C.*B.*A;

Modified equation for Jfn and V_{GS}:

A = (q^3.*m_n.*El_ox.^2)
B = 16*pi^2*m_o*h_*phi_ox
C = 4.*sqrt(2*m_e).*(phi_ox^(3/2))
D = 3.*h_.*q.*El_ox
J_fn = ((A./B).*exp(-C./D)).*10^-4;

Where
phi_ox= q*3.1-del_phi;
m_o =9.11e-31; %unit: Kg
m_e = 0.4*m_o;
m_n= 0.19*m_o;
V_ox =(V_gs-V_fb)-phi_s;
El_ox= V_ox/(T_ox*1e-9);
Eg = 1.12; %unit: eV

V. HOW TO INSTAL NANOSIMULATOR

The display results are obtained using the proposed MatLab GUI. Fig. 3 is the MatLab GUI window that shows the input from the user, analysis of characteristic curves, parameter analysis. Copy two files from the given CD namely NanoSim.p and NanoSim.fig .Paste these files in a particular directory and set the path of the MatLabDirectory. Type "run NanoSim" on Command Window of MATLAB Press 'Enter' and the simulator will be displayed as shown.

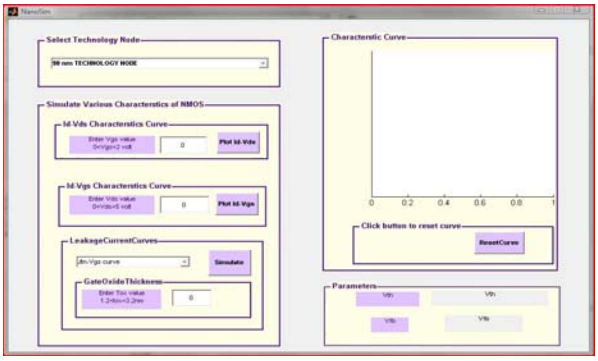
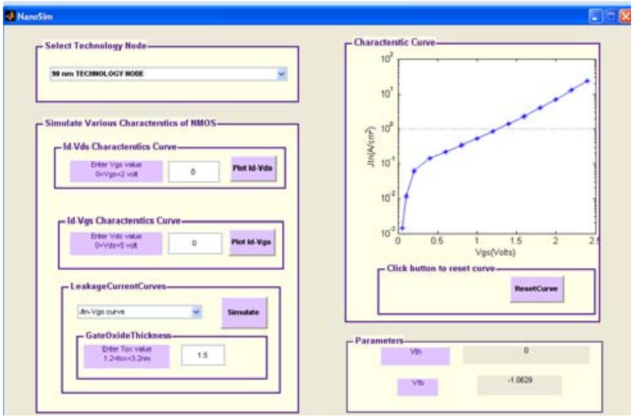


Fig. 2 Nano Simulator

VI .MODELING RESULTS FOR LEAKAGE CURRENTS

An analytical model for gate direct tunneling current density is modeled using MATLAB codes, the results drawn are being presented here.

A)Gate Direct Tunneling Current Density in n-MOSFET



90 nm TECHNOLOGY NODE

Enter Vgs value 0<Vgs<2 volt: 0

Enter Vds value 0<Vds<5 volt: 0

Jtn-Vgs curve

Enter Tox value 1.2<tox<3.2nm: 1.5

Vth: 0

Vfb: -1.0629

Fig 3.Tunneling Current Density Jt(A/cm2) versus Vgs (Volts) in n-MOSFET at Various Oxide Thicknesses(i.e. tox=1.5nm)[6]

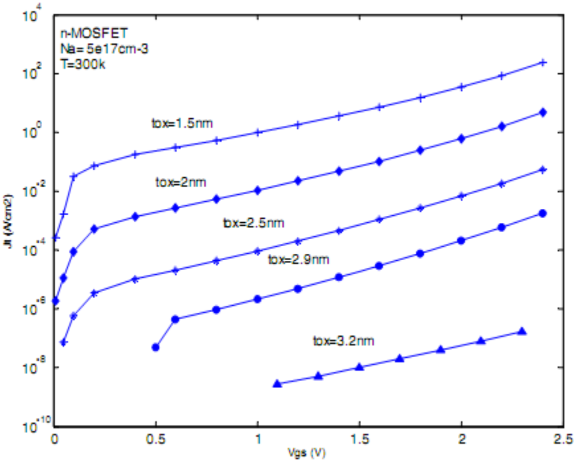
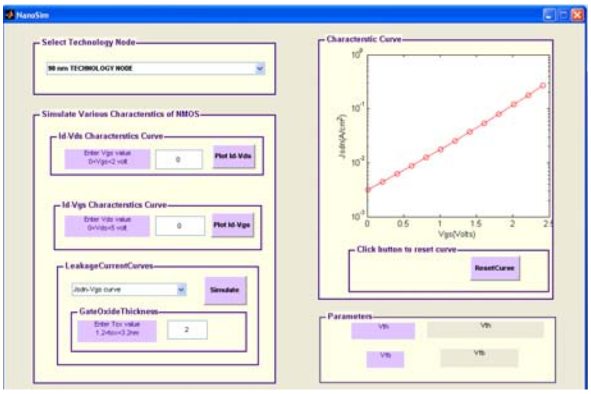


Fig 4: Plot of fig3 is matching with ref[6]

B)Edge Direct Tunneling Current Density



90 nm TECHNOLOGY NODE

Enter Vgs value 0<Vgs<2 volt: 0

Enter Vds value 0<Vds<5 volt: 0

Jsdn-Vgs curve

Enter Tox value 1.2<tox<3.2nm: 2

Vth: Vth

Vfb: Vfb

Fig 5.SDE Tunneling Currents in n-MOSFET at 2nm Oxide Thickness[6]

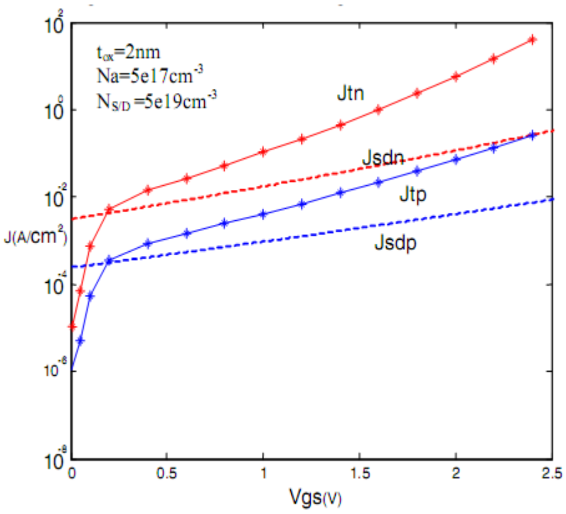


Fig 6: Plot of fig5 is matching with ref[6]

VII .MODELING RESULTS FOR I/O CHARACTERSTICS

Vth, Cox, µ are the parameters which undergo a change due to Short Channel Effects and so the conventional equations are invalid at Nanoscale and we include Quantum Mechanical effects[1]. And by the addition of QME effects we got such input-output characterstic curves as shown in Fig7&Fig8 at 90nm technology node.

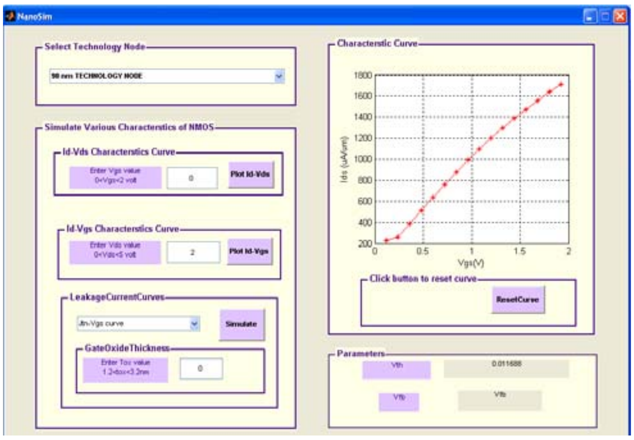


Fig7: Id-Vgs Curve

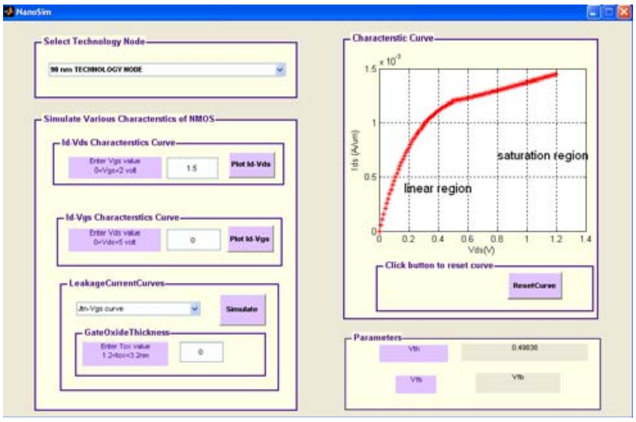


Fig8: Id-Vds Curve at Vgs=1.5v [5]

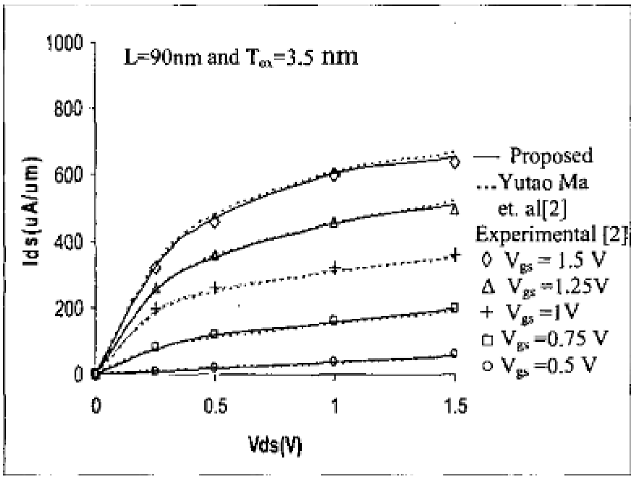


Fig9: : Plot of fig8 is matching with ref[5]

VIII. CONCLUSION

A simulator for Leakage Current detection and classification as well as I-V characterstics using MatLab program has been developed. At all technology nodes I-V Curves were successfully visualized. The Leakage Current detection, Input-Output characterstic results are displayed to a user via MatLab graphical user interface (GUI). The significant features of the developed GUI are the ability to graphically display the results by taking inputs from user side,hence this tool is user friendly. At backend we have done calculation by considering short channel effects and QME effects hence the developed simulator provides accurate, efficient and reliable curves and parameter values to study. In future this simulator will be available to our users online with some special functions like online help and also more curves can be studied by this (i.e.Doping and Temperature effects on nanoscale mosfet).

IX. REFERENCES

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BIOGRAPHIES

Er.Pragya Kushwaha was born in1988. She is a student of M.Tech Microelectronics U.I.E.T(P.U.) Chandigarh, India. She obtained her Bachelor Degree in Engineering (Electronics and Communication) from R.K.G.I.T. Ghaziabad, India, in 2009. Currently, her research interest includes low power and high speed memories at nanoscale.

Dr. Amit Chaudhry was born in India, in 1976. He completed his Ph.D (Microelectronics) in 2010 from Panjab University, Chandigarh, India. He joined Panjab University, University Centre for instrumentation and microelectronics October, 2002. He was responsible for teaching and research in VLSI and microelectronics to post graduate students. His research areas include device modeling for sub 100nm MOSFETS. He is a life member of various societies in the area of microelectronics. Currently he is a Senior Assistant Professor, University Institute of Engineering and Technology, Panjab University, Chandigarh. He has more than 18 publications in national and international Journals/Conference proceedings.

Garima Joshi was born in India, in 1981. She is M.E (Electronics and Communication Engineering) from UIET, Panjab University, Chandigarh, India. Her area of research includes modeling and simulation of Nanoscale MOSFETS. Currently she is working as Assistant Professor (Electronics and Communication Engineering) in UIET, Panjab University, Chandigarh, India. She has 5 publications in international Journals/Conference proceedings.