Fall 2008

EE 612: Nanoscale Transistors

HW6: DUE THURSDAY, OCTOBER 21

MOSFET Mobility

A long channel MOSFET is often used to "measure" the effective mobility of carriers in the inversion layer. A long channel device minimizes the influence of the parasitic series resistance and short channel effects. It may also provide a gate capacitance big enough to do a CV curve on. For this exercise, you will use the MOSFET simulation tool on nanoHUB.org (also available in the ABACUS suite of tools). You will treat the simulator like a "black box" and just use the IV characteristics it computes as you would use measured IV characteristics. For the last problem, you will also need the CV characteristics.

Important note: You will need to write some Matlab scripts for this assignment. Be sure to turn them in as part of the solution.

For this problem, you should specify a MOSFET as follow (approximately the 45 nm technology node).

$N_A = 2.7 \times 10^{18}\ cm^{-3}$ for the bulk doping
$EOT = 1.1$ nm
$Q_F = 0.0$
$T = 300K$
$V_{DD} = 1.0V$
Assume an n^+ polysilicon gate
Select "Gaussian S/D doping density"
Specify a channel length of 1 micron.
(Note that the "45nm technology node" is designed for MOSFETs with channel lengths as short as about 45nm, but longer test devices are frequently better for characterization. That is why we use a 1 micron long channel length.)

1) Determine the effective mobility by plotting the transfer characteristic, I_D vs. V_{GS} at $V_{DS} = 0.05V$ and finding the mobility from the expression:

$$I_D = \mu_{eff} C_{ox} \left(\frac{W}{L} \right) (V_{GS} - V_T) V_{DS} .$$

To do this, you will have to download the file of the I_D vs. V_G data and write a Matlab script to extract μ_{eff} . Plot the resulting μ_{eff} vs. V_G .

Hint: you can download the comma separated IV data from the IV plot window.

To do this problem successfully, you will need to get an accurate value for the threshold voltage. Determine the threshold voltage as the gate voltage that is obtained by extrapolating the linear portion of the I_{DS} vs. V_{GS} characteristic, from the point of maximum slope, to zero drain current, I_{DS}. The point of maximum slope is the gate voltage where the transconductance is maximum.

2) There is another way to determine the mobility. Determine the "field-effect" mobility from

$$\mu_{FE} = \frac{L}{WC_{ox}V_{DS}}\left(\left. \frac{\partial I_D}{\partial V_{GS}} \right|_{V_{DS}} \right)$$

and plot it vs. V_G. Compare the field-effect to the effective mobility. Why are they different?

3) As discussed in your text book, when plotted vs. effective normal electric field (not vs. gate voltage or electric field at the oxide-silicon interface), plots of mobility vs. effective normal field display a "universal" characteristic. Plot the effective mobility, μ_{eff}, from part 1) vs. effective normal electric field and compare the results to those in Fig. 3.13 on p. 133 of the textbook by Taur and Ning.

4) One of the errors in measuring effective mobility is the assumption that $Q_I = C_{ox}(V_{GS} - V_T)$, which is not accurate near threshold and well above threshold where polysilicon depletion and the inversion layer capacitance reduce the gate capacitance. Careful experimentalists measure the gate capacitance and then compute the gate charge from $Q_I(V_G) = \int_0^{V_G} C_G(V)dV$. It's even easier for you, because the MOSFET simulation tool produces an output file of $Q_G(V_G)$. Note: This is the total charge on the gate, not just the inversion charge. You will need to use "Surface charge vs. Vg" data to re-extract effective mobility.

Remove the assumption that $Q_I = C_{ox}(V_{GS} - V_T)$, re-measure μ_{eff} and plot the new μ_{eff} vs. effective normal field. Compare the results to those obtained in part 3).

Note:

1. Make sure that MOSFET tool version is 1.21
2. In order to determine the inversion, you will need to see “Surface charge vs. Vg” plot, as shown below. The surface charge is the total charge, not just the inversion charge. You have to subtract charge at V_{gs}=0 out of the total charge.
3. Before running the simulation, make sure that distance from source-end is set as 525nm, as shown below.

Structural Properties | Model | Voltage Sweep

Simulate

I-Vg Plot

Plot Transfer Characteristic: yes
Vg Minimum: 0V
Vg Maximum: 1V
Number of Points: 11
Vd Bias Minimum: 0.05V
Vd Bias Maximum: 0.05V
Number of Curves: 1
Vb Bias Point: 0V

I-Vd Plot

Plot I-Vd Characteristic: no
Vd Minimum: 0V
Vd Maximum: 1.5V
Number of Points: 15
Vg Bias Minimum: 0.5V
Vg Bias Maximum: 1.5V
Number of Curves: 3
Vb Bias Point: 0V

1-D Plot

Where to Plot 1-D Plots Along Length?: 10nm
Where to Plot 1-D Plots Along Depth?: 525nm

3.

Result: Surface charge vs Vg

Id-Vg Characteristics
-----2D Plots-----
Doping
Potential enegry at Equilibrium
Potential energy at Final Bias
Electron density at Equilibrium
Electron density at Final Bias
Hole density at Equilibrium
Hole density at Final Bias
Electric field at Equilibrium
Electric field at Final Bias
-----1-D Plots Along Channel Length (x)-----
Doping (1D)
Potential at Equilibrium (1D)
Potential at Final Bias (1D)
Electric Field at Equilibrium (1D)
Electric Field at Final Bias (1D)
Electron quasi-fermi level at Equilibrium (1D)
Electron quasi-fermi level at Final Bias (1D)
Electron density at Equilibrium (1D)
Surface charge vs Vg
Electron density at Final Bias (1D)
-----1-D Plots Along the Depth (y)-----
Doping (1Dy)
Potential at Equilibrium (1Dy)
Potential at Final Bias (1Dy)
Electric Field at Equilibrium (1Dy)
Electric Field at Final Bias (1Dy)
Electron quasi-fermi level at Equilibrium (1Dy)
Electron quasi-fermi level at Final Bias (1Dy)
Electron density at Equilibrium (1Dy)
Electron density at Final Bias (1Dy)
Output Log

Download

2.

Exposed Dopants+Carriers ((C/cm2))

Appendix: Universal mobility data for electrons in silicon

```
% mobility data from Takagi 1994, [ MV/cm cm2/Vsec]
% mobility @ 300K, Nsub = 2.4e18

mu1=[1.3588 171.8619
1.3096 180.7714
1.2699 186.0684
1.209 194.3064
1.158 200
1.1092 207.3522
1.056 207.3522
1.0115 204.3794
0.96887 197.1326
0.93377 188.7749
0.91108 165.7681];
% mobility @ 300K, Nsub = 7.7e17

mu2=[
0.48062 243.0495
0.50176 301.8329
0.52383 333.9387
0.55706 341.251
0.58876 348.7234
0.6261 351.2504
0.66173 351.2504
0.69084 346.2146
0.71241 341.251
0.73919 333.9387
0.7717 322.0981
0.82065 304.0201
0.85149 295.3652
0.89995 282.8427
        0.93377 268.9025];
```