ECE 340 Homework XV Spring 2003

Due: Wednesday, April 30, 2003

1. *For an n-channel Si MOSFET with an oxide thickness d=150 Å, a channel mobility μ_n = 1000 cm^2 /V-s, Z=100 μm, and L=5 μm, determine the threshold voltages for $N_a = 10^{15}$ and $10^{17}/cm^3$, respectively. Calculate and tabulate $I_D(V_D,V_G)$ in the linear region at 300 K. Allow V_D to take on values of 0.1, 0.3, 0.5, 0.7, 0.9 and 1.1 V for V_G =2, 3, 4, and 5 V. Assume that $Q_i = 5x10^{11}$ qC/cm^2 . Also, determine I_{Dsat} in the saturation region for each gate bias and doping.*

Solution:

Assume the gate material is n+. (At present, most practical gate is made from poly n+.)

$$f_F = 0.0259\ln\frac{N_a}{n_i}, \qquad C_i = \frac{e_i}{d} = \frac{3.9\times 8.85\times 10^{-14}}{150\times 10^{-8}} = 2.301\times 10^{-7} F/cm^2, \qquad Q_d = -2\sqrt{qe_s f_F N_a}$$

You can look up the Fig 6-17 to get Φ_{ms} , or by assuming n+ material havs E_F at E_C: $\Phi_{ms} = -0.55 - f_F$

$V_T = \Phi_{ms} - \frac{Q_i}{C_i} - \frac{Q_d}{C_i} + 2f_F$ (please notice that Q_d is negative here).

N_a (cm^{-3})	f_F (V)	Q_d (C/cm^2)	Φ_{ms} (V)	V_T (V)
10^{15}	0.288	-1.38×10^{-8}	–0.9	$-0.613V$
10^{17}	0.407	-1.65×10^{-7}	–1.05	0.133

We can use either equation 6-49 or 6-50. The solution offered below uses 6-49. If you use 6-50, the solution should be similar.

This problem is most easily solved using some computer programs such as MS-Excel or Matlab. There are three operation modes for MOSFET: cut-off, linear region, and saturation region. The condition and I_d equations for these three modes are:

Cutoff: happen when $V_G < V_T$, $I_d = 0$

Linear region: $V_G > V_T$, and $V_{DS} < V_G - V_T$, $I_{Linear} = \frac{m_n Z C_i}{L}\left[(V_G - V_T)V_D - \frac{1}{2}V_D^2\right]$

Saturation Region: $V_G > V_T$, and $V_{DS} > V_G - V_T$, $I_{sat} = \frac{1}{2}\frac{m_n Z C_i}{L}(V_G - V_T)^2$

Use your favorite computer program, you should be able to obtain following table.

For $N_a = 10^{15} cm^{-3}$, Table for I_d (mA)

V_D(V) / V_G(V)	0.1	0.3	0.5	0.7	0.9	1.1
2	1.18	3.4	5.43	7.29	8.95	10.4
3	1.64	4.78	7.74	10.5	13.1	15.5
4	2.01	6.16	10.0	13.7	17.2	20.6
5	2.56	7.54	12.3	17.0	21.4	25.6

For $N_a = 10^{17} cm^{-3}$, Table for I_d (mA)

V_D(V) / V_G(V)	0.1	0.3	0.5	0.7	0.9	1.1
2	0.836	2.37	3.72	4.89	5.87	6.67
3	1.30	3.75	6.02	8.11	10.1	11.7
4	1.76	5.13	8.32	11.3	14.2	16.8
5	2.22	6.51	10.6	14.6	18.3	21.9

Table for $I_{D,SAT}$ (mA) :

N_a(cm^{-3}) / V_G(V)	10^{15}	10^{17}
2	15.7	8.02
3	30.0	18.9
4	48.9	34.4
5	72.5	54.5

2. *Plot I_D vs. V_D for V_G = -2, -3, and -4V for a thin-oxide (100Å) p-channel transistor. The substrate doping and effective interface charge are $N_d=10^{16}$ cm^3 and $Q_i = 5x10^{10}q$ C/cm^2, respectively. Assume that I_{Dsat} remains constant beyond pinch-off and μ_p=200 cm^2/V-s and Z=10L.*

For pMOS:

$$f_F = -0.0259\ln\frac{N_d}{n_i} = -0.347V\ ,$$

$$C_i = \frac{e_i}{d} = \frac{3.9\times 8.85\times 10^{-14}}{100\times 10^{-8}} = 3.452\times 10^{-7}\,F/cm^2\,,$$

$$Q_d = 2\sqrt{qe_s f_F N_a} = 4.816\times 10^{-8}\,C/cm^2$$

You can look up the Fig 6-17 to get Φ_{ms}, or by assuming n+ material havs E_F at E_C: $\Phi_{ms} = -0.55 - f_F$

Here we use results from Fig 6-17, $\Phi_{ms} = -0.25V$

$$V_T = \Phi_{ms} - \frac{Q_i}{C_i} - \frac{Q_d}{C_i} + 2f_F = -0.25 - \frac{5\times 10^{10}\times 1.6\times 10^{-19}}{3.542\times 10^{-7}} - \frac{4.816\times 10^{-8}}{3.542\times 10^{-7}} - 2\times 0.347 = -1.11 Volts$$

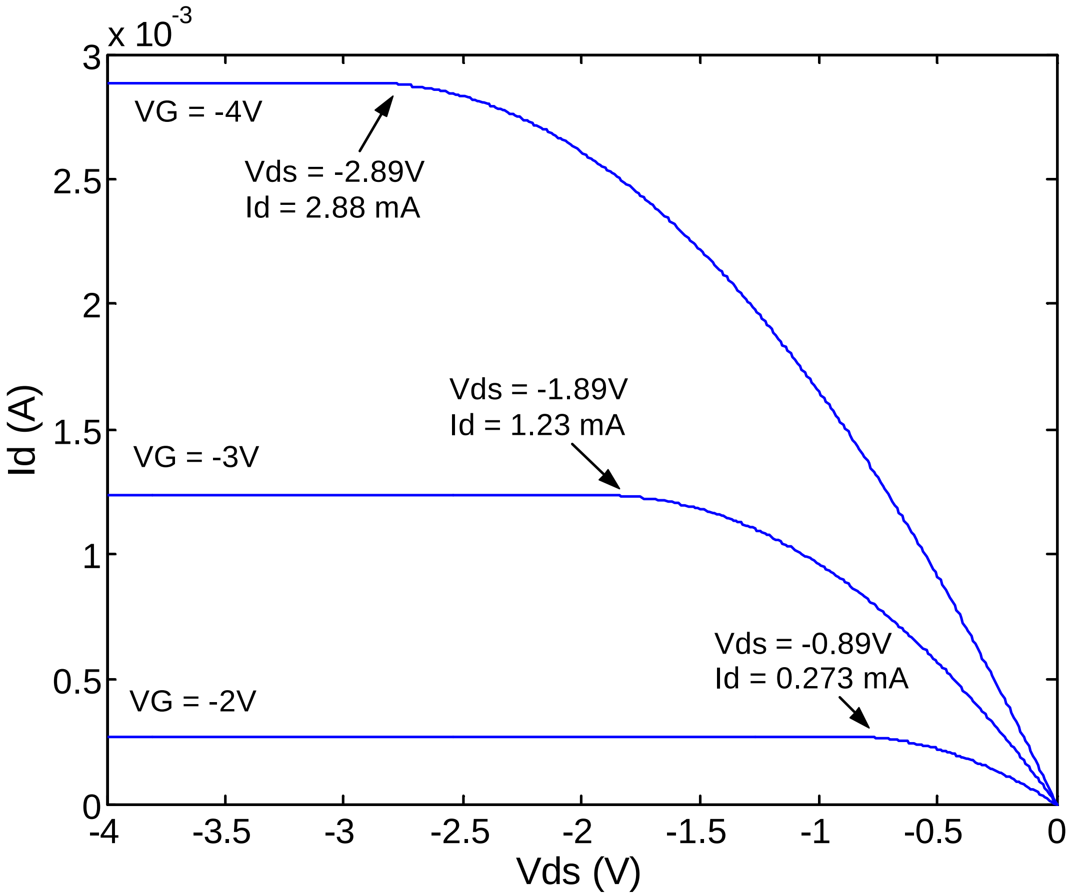
The condition and I_d equations for three operation modes of a pMOS are:

Cutoff: happen when $V_G > V_T$, $I_d = 0$

Linear region: $V_G < V_T$, and $V_{DS} > V_G - V_T$, $I_{Linear} = \frac{m_p Z C_i}{L}\left[(V_G - V_T)V_{DS} - \frac{1}{2}V_{DS}^2\right]$

Saturation Region: $V_G < V_T$, and $V_{DS} < V_G - V_T$, $I_{sat} = \frac{1}{2}\frac{m_p Z C_i}{L}(V_G - V_T)^2$

The plot is shown next page:



x 10^-3
3
2.5
2
1.5
1
0.5
0
Id (A)
-4
-3.5
-3
-2.5
-2
-1.5
-1
-0.5
0
Vds (V)
VG = -4V
Vds = -2.89V
Id = 2.88 mA
Vds = -1.89V
Id = 1.23 mA
VG = -3V
Vds = -0.89V
Id = 0.273 mA
VG = -2V