Department of Electrical and Computer Engineering, Cornell University

ECE 3150: Microelectronics

Spring 2016

Exam 1 ` **March 24, 2016**

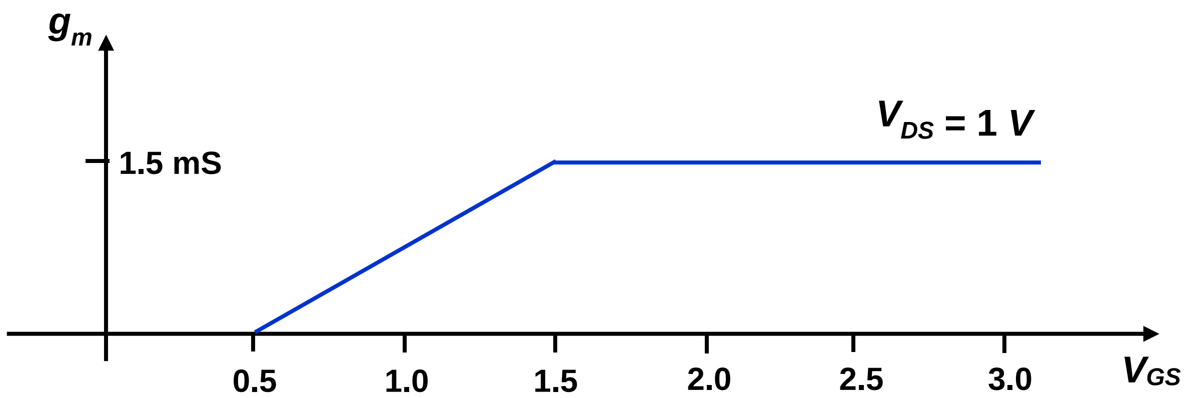
INSTRUCTIONS:

- **Every problem must be done in the <u>separate</u> booklet**
- **Only work done on the exam booklets will be graded – do not attach your own sheets to the exam booklets under any circumstances**
- **To get partial credit you must show all the relevant work**
- **Correct answers with wrong reasoning will not get points**
- **All questions do not carry equal points**
- **All questions do not have the same level of difficulty**
- **<u>Assume room temperature if the temperature is not specified</u>**
- **TOTAL POINTS: 100**

DO NOT WRITE IN THIS SPACE

Problem 1 (FET Warm Up) – 10 points

The transconductance g_m of a NFET is measured as a function of V_{GS} for $V_{DS} = 1V$, $V_{BS} = 0V$, and is plotted below. $W = 10\ \mu m$. $L = 1\mu m$. $\lambda_n \approx 0$. $\varepsilon_{ox} = 3.9\varepsilon_o$.



In addition, the gate-to-source capacitance C_{gs} is measured with $V_{DS} \approx 0\ V$, $V_{GS} = 3\ V$, and $V_{BS} = 0\ V$ and is found to be 172.5 femto-Farads.

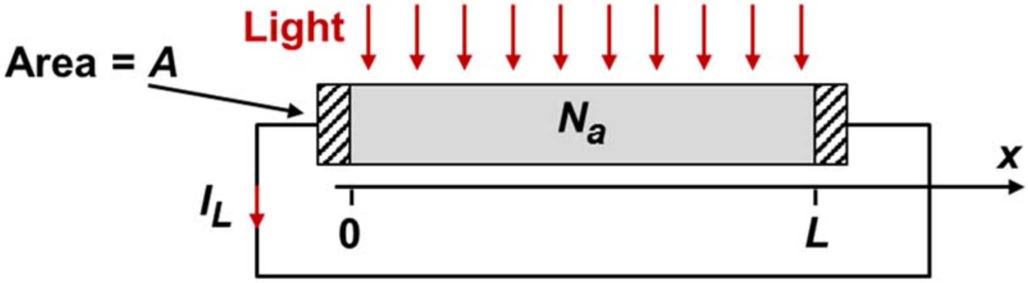
a) Plot carefully the transconductance g_m of the NFET as a function of V_{GS} for $V_{DS} = 2\ V$, $V_{BS} = 0\ V$ and indicate various regions of NFET operation, and V_{GS} values corresponding to break-points on the plot, and also indicate the g_m values. (5 points)

b) What is the oxide thickness t_{ox} ? Need a numerical value. (2.5 points)

c) What is the electron mobility μ_n ? Need a numerical value. (2.5 points)

Problem 2 (Light and Current) – 35 points

Consider a P-doped semiconductor, with two metal contacts, that is illuminated with light resulting in the generation of electron-hole pairs at the uniform rate G_L (units: 1/(cm^3-s)).



The P-doping in the semiconductor is N_a . The minority carrier lifetime is **infinite**. The electron and hole mobilities are μ_n and μ_p , respectively, and the diffusivities are D_n and D_p , respectively. The intrinsic carrier concentration is n_i . For the following questions, assume steady state. *Note that half the points will be for the sketches wherever asked. So don't forget the sketches.*

a) What is the excess electron concentration $n'(x)$ at $x = 0$? (2.5 points)

b) What is the excess hole concentration $p'(x)$ at $x = L$? (2.5 points)

c) Set up an equation whose solution will give you the excess electron concentration $n'(x)$ in steady state everywhere in the device (i.e. for $0 \le x \le L$). (5 points)

d) Solve the equation obtained in part (c) above and find an expression for the excess electron concentration $n'(x)$ in steady state in the entire device (i.e. for $0 \le x \le L$) and **sketch it**. (5 points)

e) Find an expression for the excess hole concentration $p'(x)$ in steady state in the entire device (i.e. for $0 \le x \le L$) and **sketch it**. (2.5 pints)

f) Find and **sketch** the electron diffusion current everywhere in the device (i.e. for $0 \le x \le L$). (5 points)

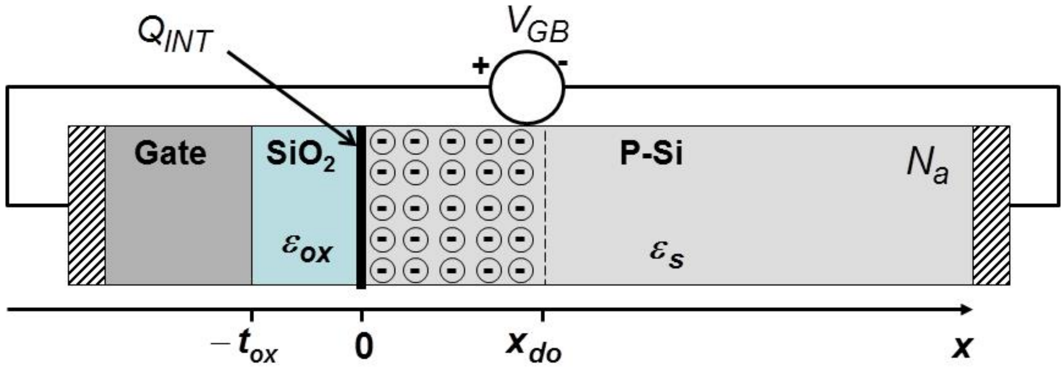
g) **Sketch** the hole diffusion current everywhere in the device (i.e. for $0 \le x \le L$). (2.5 points)

h) If $D_n = 2D_p$, find an expression for the electric field $E_x(x)$ everywhere in the device (i.e. for $0 \le x \le L$) and **sketch it**. (5 points)

i) Find an expression (with proper sign) for the current I_L that flows in the external circuit. (5 points)

Problem 3 (NMOS Structure) – 15 points

Consider the following MOS structure:



Right at the interface between the semiconductor and the oxide (i.e. at $x = 0$) there is fixed interface charge (due to trapped positively charged ions) represented by a sheet charge density Q_{INT} (units: Coulombs/m^2). You will need to figure out the characteristics of the MOS structure in the presence of this sheet charge density.

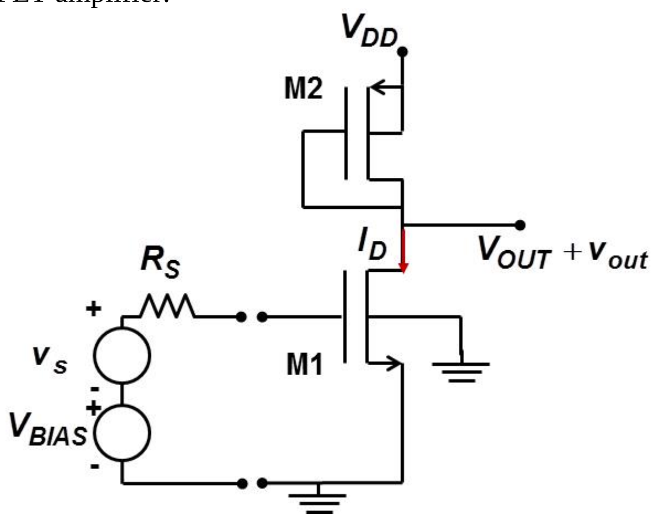
a) Assuming a depletion region thickness of x_{do}, **find** and **sketch** the E-field in the range $-t_{ox} \le x \le x_{do}$ (5 points)

b) Assuming a depletion region thickness of x_{do}, **find** and **sketch** the potential in the range $-t_{ox} \le x \le x_{do}$ (5 points)

c) Find an expression for the flatband voltage V_{FB}. (5 points)

Problem 4 (FET Circuits and Amplifiers) – 40 points

Consider the following FET amplifier:



Assume that for the NFET:

$W = 10\ \mu m$

$L = 1\ \mu m$

$\mu_n C_{ox} = 200\ \mu A/V^2$

$\lambda_n = 0.1\ 1/V$

$V_{TN} = 0.5\ V$

$N_a = 10^{17}\ cm^{-3}$

And assume that for the PFET:

$W = 20\ \mu m$

$L = 1\ \mu m$

$\mu_p C_{ox} = 100\ \mu A/V^2$

$\lambda_p = 0.1\ 1/V$

$V_{TP} = -0.5\ V$

$N_d = 10^{17}\ cm^{-3}$

And:

$V_{DD} = 2.5\ V$

a) If $V_{OUT} = 1.5$ V, what is V_{BIAS}? (5 points)

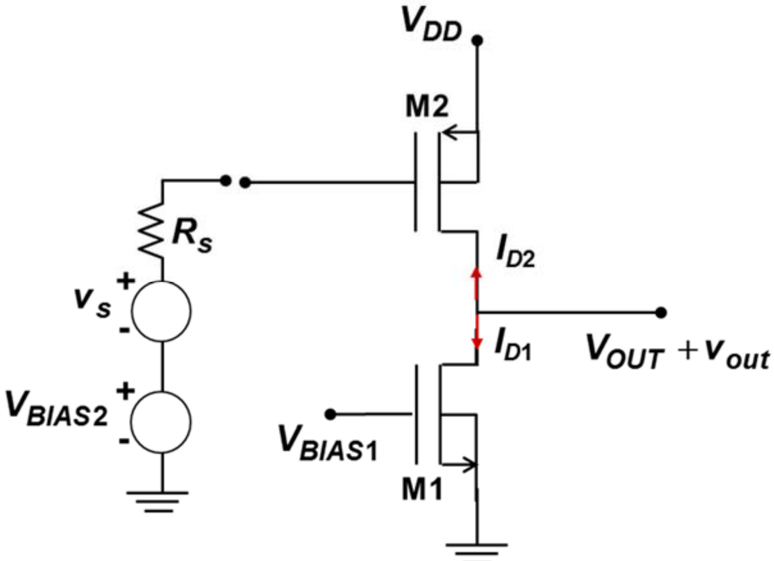
b) What is the highest voltage V_{OUT} can take if both the FETs are to remain in the saturation region? (5 points)

c) What is the lowest voltage V_{OUT} can take if both the FETs are to remain in the saturation region? (10 points)

d) Draw a small signal circuit for the amplifier and find an expression for the open circuit voltage gain, $A_V = v_{out}/v_s$. Do you think the gain of this amplifier is going to be relatively large or small? (5 points)

e) Find an expression for the output resistance R_{out} . (5 points)

For the following parts, suppose the circuit is now modified as follows:



f) Draw a small signal circuit for the amplifier and find an expression for the open circuit voltage gain, $A_V = v_{out}/v_s$. Do you think the gain of this amplifier is going to be relatively large or small? (5 points)

g) Find an expression for the output resistance R_{out} . (5 points)