# EECS 105  Practice Midterm II

Fall 2001                                    Prof. Roger T. Howe

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### Guidelines

Closed book and notes; one 8.5" x 11" page (both sides) of *your own notes* is allowed.
You may use a calculator.
Do not unstaple the exam.
Show all your work and reasoning on the exam in order to receive full or partial credit.

The exam will have 50 points and last 80 minutes, so you should time the sample problems at 1.6 minutes per point.

## Exam Coverage

Lectures 14-29, Problem Sets 6-10, and related material in the textbook.

## Midterm Review Session

**Tuesday, Nov. 13, 2001, 6:00 – 7:30 pm, 277 Cory Hall**

Solutions to sample midterm problems will be distributed and discussed at the review session; they will also be available in 497 Cory Hall on Wednesday morning, Nov. 14.

## Midterm Exam

**Wednesday, Nov. 14, 2001, 6:00 – 7:30 pm, Sibley Auditorium**

## Midterm Office Hours

*RTH*                                    *Teaching Assistants:  TBA*
Thursday, November 8, 4-5:30
Monday, Tuesday OH cancelled due to Japan trip.

**MOSFET Small-Signal Model in Sub-Threshold Region [16 points]**

An n-channel MOSFET with $v_{GS} < V_T$ is considered to be cutoff. However, careful measurements show that the drain current is not zero. For $v_{DS} > 0.1V$, the drain current $i_D$ can be modeled by the following equation:

$$i_D = \mu_n V_{th} \left( \frac{W}{L(v_{DS})} \right) |q_N(v_{GS})|,$$

where $|q_N(v_{GS})| = V_{th} \sqrt{\frac{q \varepsilon_s N_a}{-\phi_p}} e^{(v_{GS}-V_T)/V_a}$

and $L(v_{DS}) = L_o(1 - \kappa v_{DS})$

*Given:*

$\mu_n = 500 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$, $N_a = 10^{17} \text{ cm}^{-3}$, $V_{th} = 0.025$ V, $V_T = 1.0$ V, $W = 45\mu\text{m}$, $L_o = 1.5 \, \mu\text{m}$, $\kappa = 0.01$ V$^{-1}$. $\varepsilon_s = 11.7 \, \varepsilon_o = 1.03 \times 10^{-12}$F/cm, $q = 1.6 \times 10^{-19}$C

(a) [3 pts.] Find the numerical value of the DC drain current $I_D$ for the operating point $V_{GS} = 0.90$ V, $V_{DS} = 1$ V.

Given: $|Q_N(V_{GS})| = (4.95 \times 10^{-9} \text{ C/cm}^2) e^{(V_{GS}-V_T)/V_a}$

(b) [5 pts.] What is the numerical value of the small-signal transconductance $g_m$ at this operating point? If you couldn't solve part (a), you may use $I_D = 0.1 \, \mu$A for this part -- of course, this is *not* the correct answer to part (a). *Hint:* your answer to part (a) can help you answer this part without plugging in all the constants ....

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(c) [5 pts.] What is the numerical value of the small-signal output resistance $r_o$ at this operating point? If you couldn't solve part (a), you may use $I_D = 0.1$ μA for this part -- of course, this is *not* the correct answer to part (a). *Hint:* your answer to part (a) can help you answer this part without plugging in all the constants ....

(d) [3 pts.] Find an expression for the product of the transconductance and the output resistance $g_m \times r_o$ for this operating point. If $V_{GS}$ is changed so that $I_D$ is increased by 5 times, does this product increase or decrease? Assume that $V_{DS}$ remains constant.

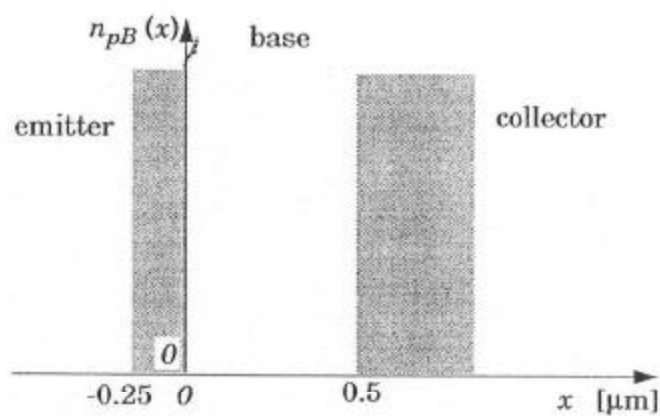**2** Oxide-Isolated npn Bipolar Transistor Structure [10 points]
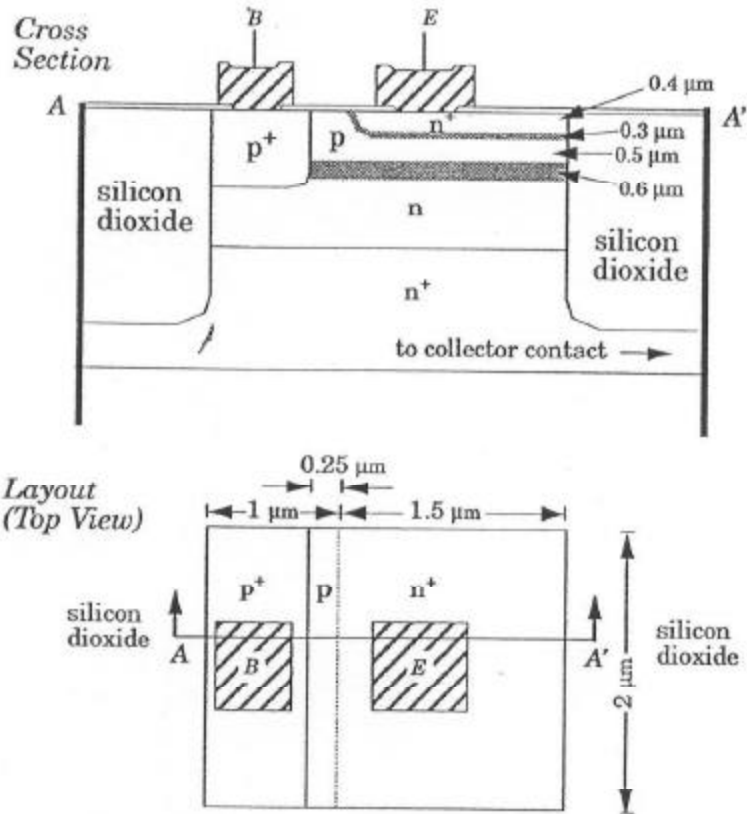


Note that the thicknesses of the emitter and the base regions $W_E$ and $W_B$ are given in the cross section, along with the thicknesses of the depletion regions between the emitter and base, $x_{BE}$ and between the base and collector $x_{BC}$. The base doping is $N_{aB} = 10^{16} \text{cm}^{-3}$.
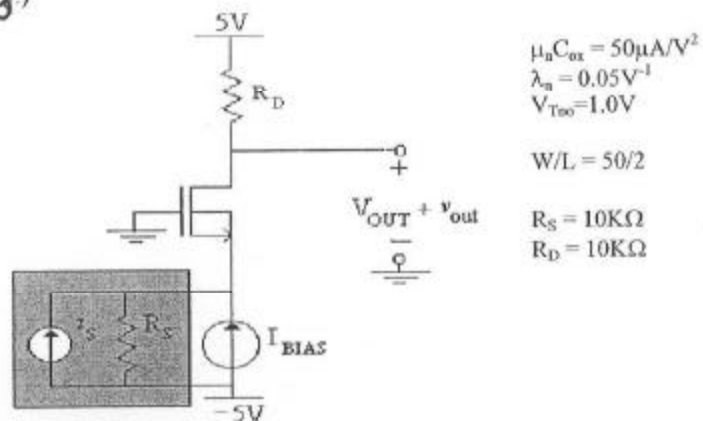
Given: $\varepsilon_s = 1.03 \times 10^{-12}\text{F/cm}$.

(a) [5 pts.] What is the numerical value of the small-signal capacitor $C_\mu$ between the base and the collector?

(b) [5 points] Given that the transistor is under forward-active bias with $V_{BE} = 650$ mV and $V_{CE} = 1.0$ V. Sketch the electron concentration in the base, $n_{pB}(x)$ on the graph below. The numerical values for the electron concentration should be accurate at $x = 0$ (edge of the emitter-base junction) and at $x = 0.5$ μm (edge of the base-collector junction).

3)



$\mu_n C_{ox} = 50\mu A/V^2$
$\lambda_n = 0.05 V^{-1}$
$V_{Tno} = 1.0V$

W/L = 50/2

$R_S = 10K\Omega$
$R_D = 10K\Omega$

a) We would like $V_{OUT}$=0V. What is $I_{BIAS}$?
b) What is the minimum $v_{OUT}$ such that the MOSFET remains in its constant current region?
c) What is $R_{in}$ in $K\Omega$?
d) What is the transresistance $R_m$?
e) What is $v_{out}/i_s$ ?