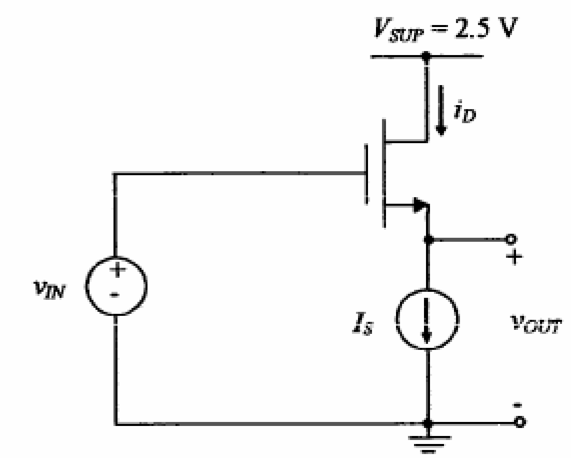
EE105, Spring, 2005, Midterm 1, Howe

1. MOSFET circuit [17 points]



Given:
$L = 0.5\ \mu m$
$W = 5\ \mu m$
$\mu_n C_{ox} = 100\ \mu A/V^2$
$V_{Tn} = 0.5$ V
$\lambda_n = 0\ V^{-1}$
$\gamma = 0$

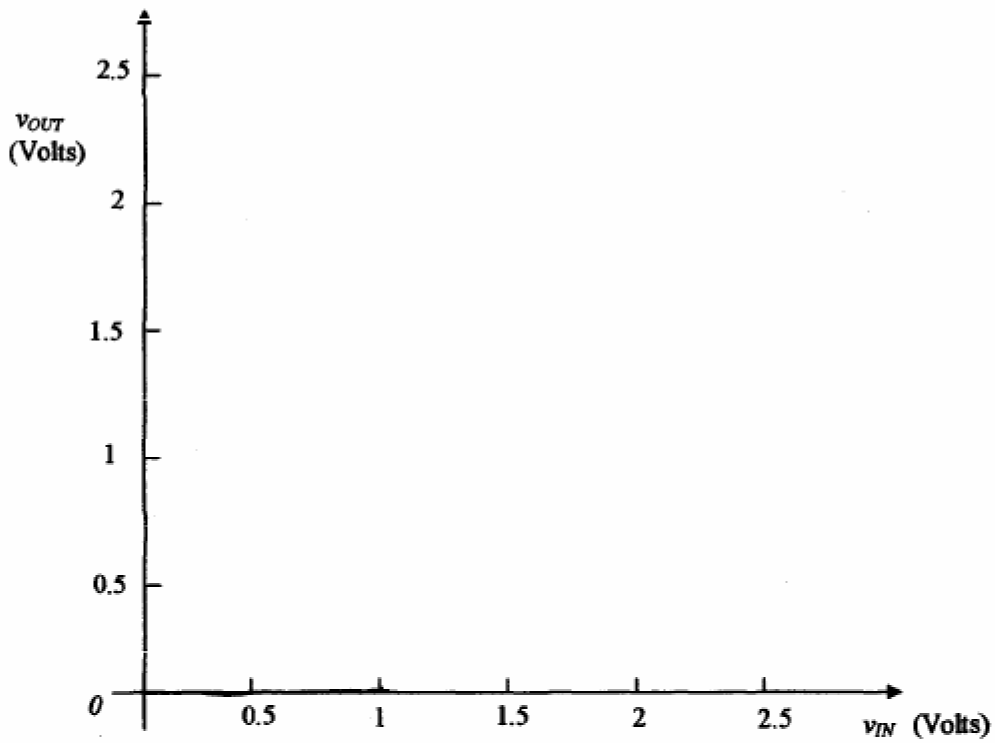
$I_S = 125\ \mu A$

(a) [3 pts.] Assuming that the transistor is operating in saturation, find an equation for the drain current i_D in terms of the input voltage v_{IN}, the output voltage v_{OUT}, and the device parameters. It is *not* necessary to substitute numerical values.

(b) [4 pts.] For $v_{IN} = 1.5$ V, (i) find the numerical value of the output voltage in Volts and (ii) verify that the transistor is saturated for this case.

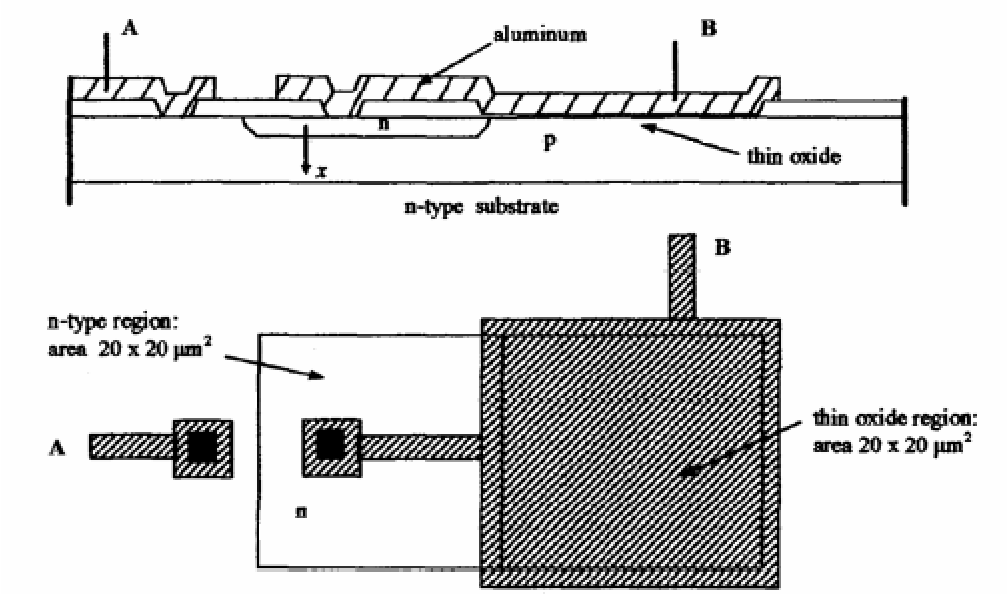
(c) [3 pts.] For $v_{IN} = 0.5$ V, (i) find the numerical value of the output voltage in Volts and (ii) identify the transistor's operating region.

(d) [4 pts.] Sketch the output voltage v_{OUT} as a function of the input voltage v_{IN} over the range $0 \text{ V} \leq v_{IN} \leq 2.5$ V on the graph below. *Note:* the current source I_S only works for $v_{OUT} > 0$ V and is a short-circuit for $v_{OUT} = 0$V.



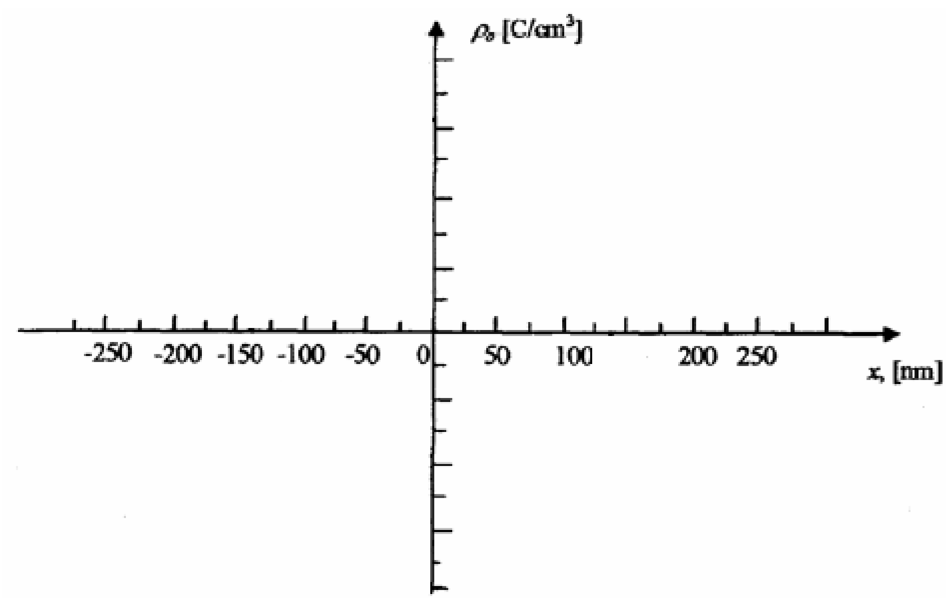
(e) [3 pts.] For a DC input voltage $V_{IN} = 1.5$ V, find the numerical value of the transconductance g_m. If you couldn't solve part (b), you can assume that $V_{OUT} = 0.25$ V for this part (not the correct answer to (b), of course).

2. Integrated charge-storage element [17 points]



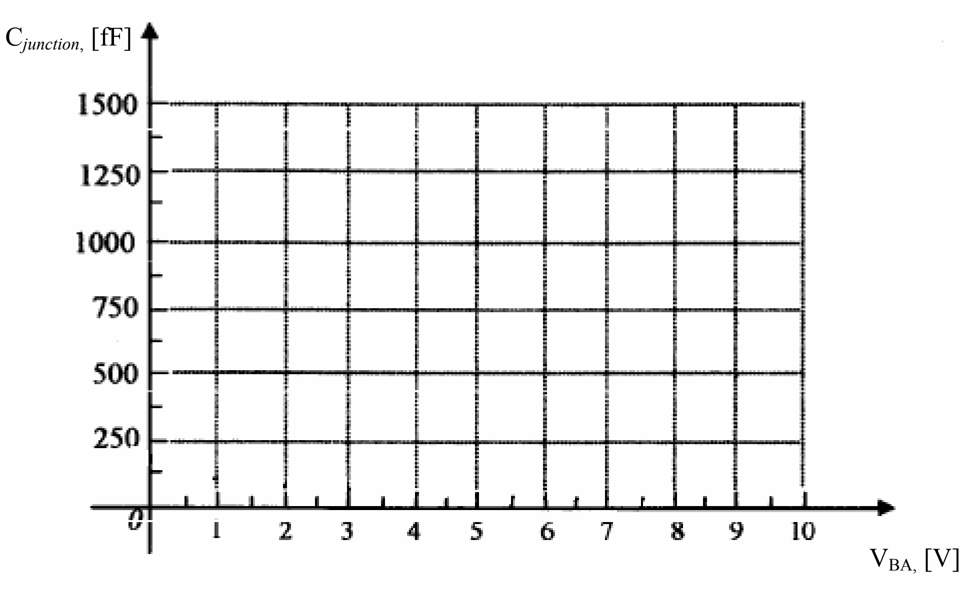
Given: The n region connected to electrode B is doped with phosphorus with $N_d = 2 \times 10^{16}$ cm^{-3} and with boron ($N_a = 1 \times 10^{-16}$ cm^{-3}). The p region connected to electrode A is doped with only boron ($N_a = 1 \times 10^{-16}$ cm^{-3}). The permittivity of silicon is $\varepsilon_s = 1.035 \times 10^{-12}$ F/cm and the permittivity of oxide is $\varepsilon_{ox} = 3.45 \times 10^{-13}$ F/cm. The thin oxide has a thickness $t_{ox} = 10$ nm. The built-in potential of aluminum is $\varphi_{Al} = -360$mV

(a) [4 pts.] Sketch the charge density in thermal equilibrium along the x axis (see location in the cross section above. *Given*: the width of the depletion region on the p-side of the junction is $x_{po} = 140$nm = 0.14 μm. Unit charge: $q = 1.6 \times 10^{-19}$ C.

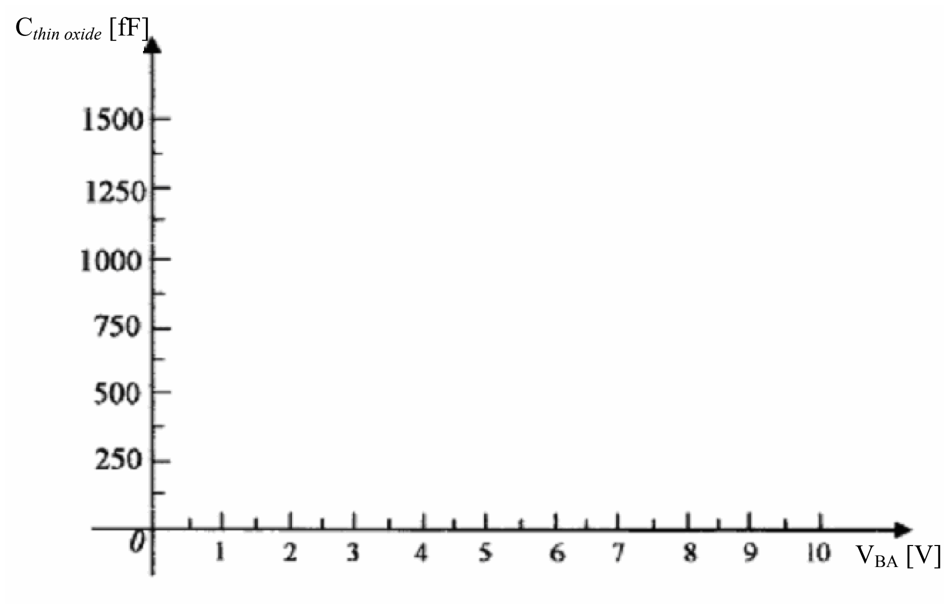


(b) [3 pts.] Find the numerical value of the junction capacitance $C_{junction}(0)$ between the 20 x 20 μm^2 n-type region and the underlying p layer in the thermal equilibrium (v_{BA} = 0 V) in fF. *Given*: 1 fF = 10^{-15} F. *Hint*: the information given in part (a) should be very useful.

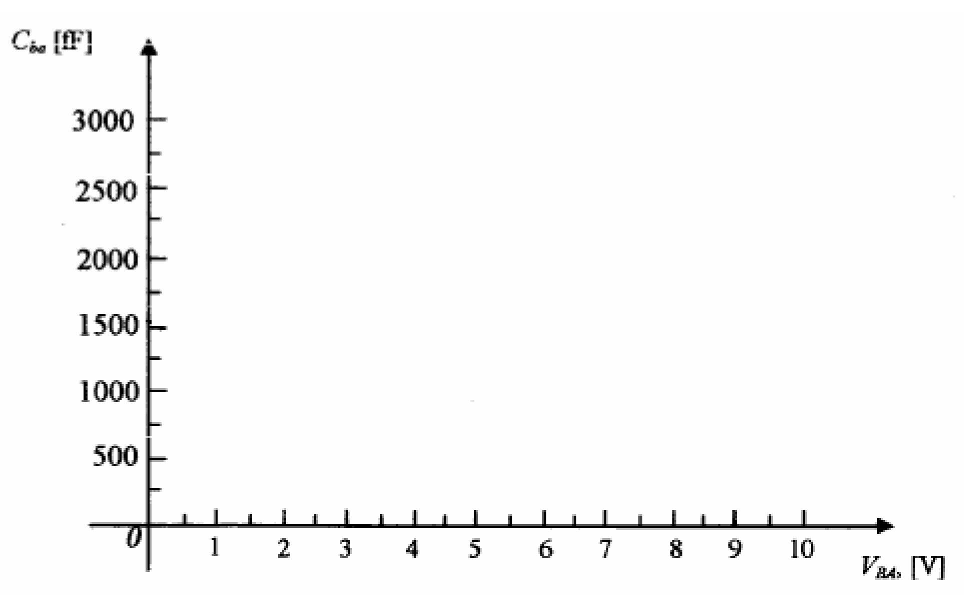
(c) [4 pts.] Plot the junction capacitance versus v_{BA} on the graph below. If you couldn't solve part (b), you can assume that the thermal equilibrium capacitance is 1000 fF in order to do this part.



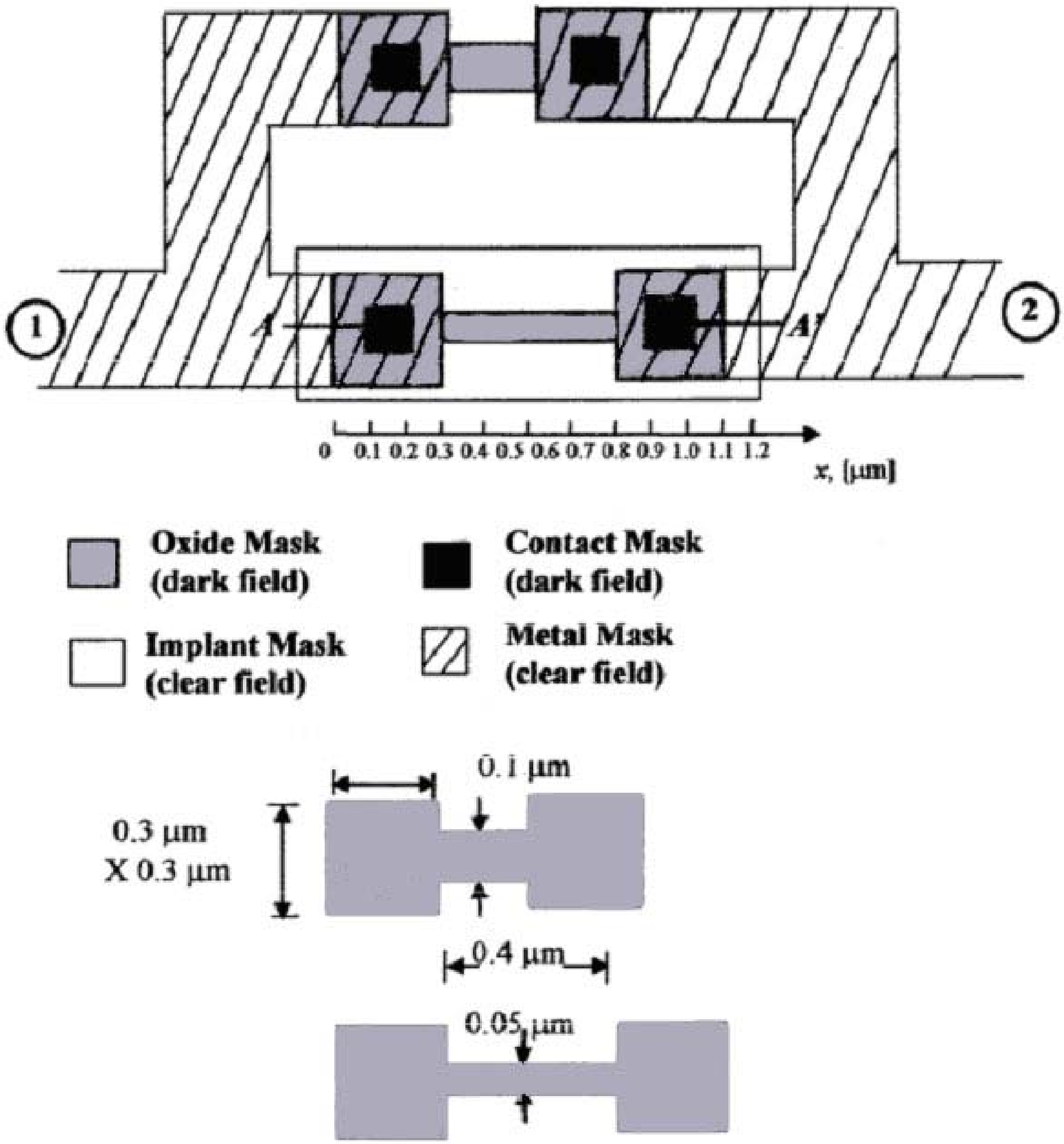
(d) [3 pts.] Sketch the capacitance of the 20 x 20 μm^2 thin-oxide area as a function of the voltage V_{AB} on the graph below. *Given*: due to oxide charges, the threshold voltage is V_{Tn} = 4 V, the minimum capacitance of the structure is one-half the maximum capacitance, ~~and the thermal equilibrium capacitance is three-quarters of the maximum.~~



(e) [3 pts.] Sketch the capacitance C_{ba} as a function of the voltage V_{AB} on the graph below. Ignore the contribution of the overlap of the metal onto the thick-oxide regions.



3. IC resistors [16 points]

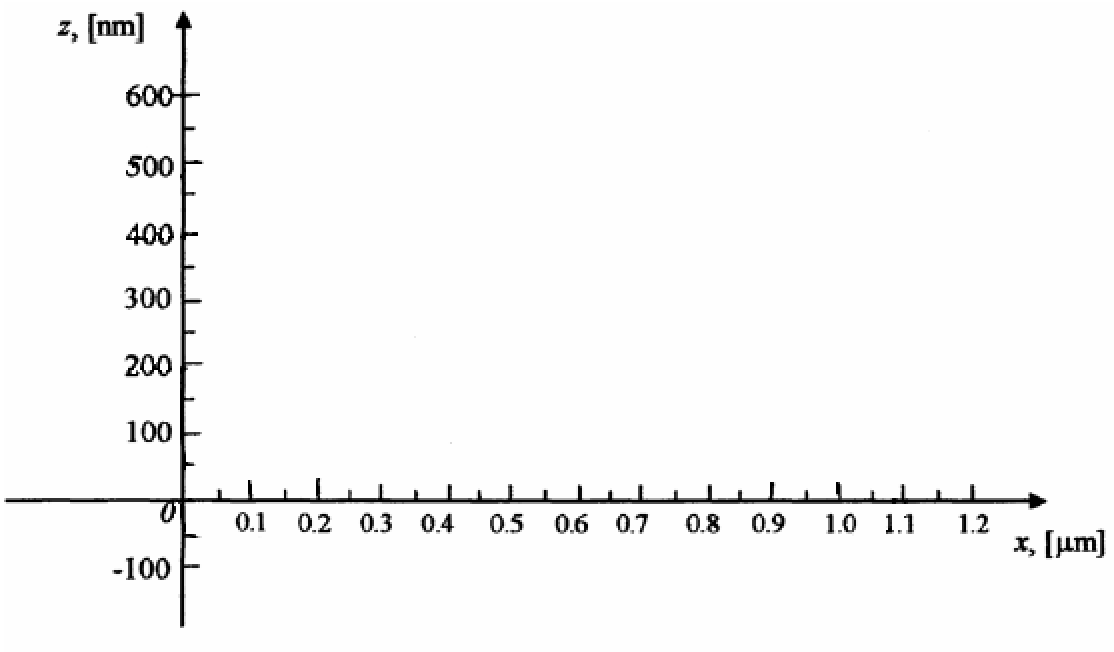


Process Sequence:

1. *Starting material*: boron-doped silicon wafer with a concentration of 2 x 10^{17} cm^{-3}
2. Deposit a 0.2 μm (=200 nm) thick SiO_2 layer
3. Pattern the oxide using the **Oxide Mask** (dark field) by etching it down to the silicon.
4. Implant the phosphorus with dose Q_d = 2 x 10^{12} cm^{-2} and anneal to form a 50 nm-thick phosphorus-doped regions where the silicon is exposed.
5. Spin on photoresist and pattern with the **Implant Mask** (clear field).
6. Implant phosphorus with dose Q_d = 2 x 10^{12} cm^{-2} and then etch off the photoresist.
7. Anneal to activate the second implant; the phosphorus regions remain 50 nm thick.
8. Deposit a 200 nm-thick SiO_2 layer and pattern using the **Contact Mask** (dark field).
9. Deposit 200 nm of aluminum and pattern using the **Metal Mask** (clear field).

Given: mobilities for this problem are $\mu_n = 800\ cm^2/(Vs)$ and $\mu_p = 200\ cm^2/(Vs)$. The saturation electric field for electrons is $E_{sat} = 1.25 \times 10^4$ V/cm and their saturation velocity is $v_{sat} = 10^7$ cm/s. Count the "dogbone" contact areas as 0.65 square for both resistors.

(a) [4 pts.] Sketch the cross section ***A-A'*** on the graph below **after step 9**. *Identify all layers clearly*.



(b) [4 pts.] What is the sheet resistance $R_\square$ of the 0.2 μm long, 0.1 μm wide resistor?

$R_\square =$

(c) [4 pts.] What is the maximum current I_{max} in μA through the 0.4 μm long, 0.05 μm wide resistor?

$I_{max} =$ μA

(d) [4 pts.] Plot the current-voltage curve between terminals 1 and 2 over the range indicated on the graph below