Microelectronic Devices and Circuits- EECS105

First Midterm Exam

Wednesday, October 6, 1999

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Your Name: ____
(last) *(first)*

Your Signature: ____

1. *Print and sign your name on this page before you start.*
2. *You are allowed a single, handwritten sheet with formulas. No books or notes!*
3. *Do everything on this exam, and make your methods as clear as possible.*

Problem 1 ________ / 35
Problem 2 ________ / 40
Problem 3 ________ / 25

TOTAL _______ / 100

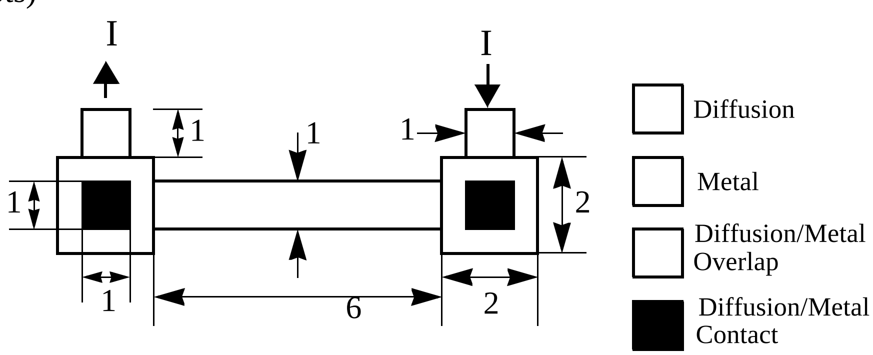
Problem 1 of 3. Answer each question briefly and clearly. (35 points)

What happens to n_i if the temperature increases? Give a brief qualitative explanation (5pts)

What is the concentration of holes, electrons and positive/gnegative ions if Si is doped with 10^{17} Boron atoms/cm^3, and 10^{19} As atoms/cm^3 at room temperature? ($n_i = 10^{10}$)(5pts)

What are the three types of charges in an MOS capacitor under inversion? Mention carrier type (holes or electrons), ion polarity (positive or negative), charge nature (depletion, accumulation or inversion) and location (gate, substrate surface or bulk). (Gate is n+, bulk is p)/(6pts)

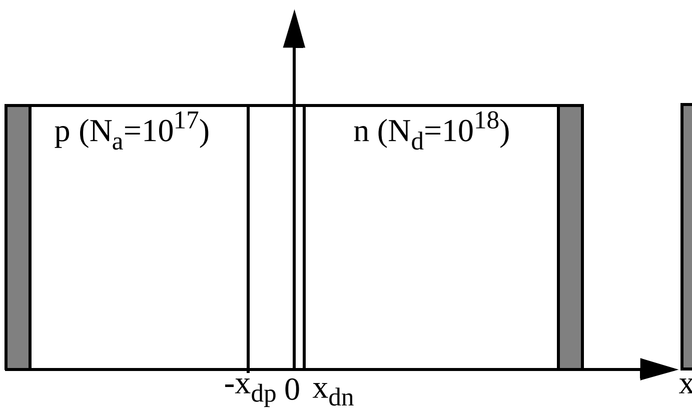
Find the resistance of the following structure (drawn to scale), if the Rs_1 (diffusion) is 20 Ω/square, Rs_2 (metal) is 1 Ω/square and contact hole conductivity (i.e. the area where the two layers touch) is 1Siemens/µm^2. (1Siemens = 1/Ω) Assume that "dogbone" contact areas amount to 0.65 squares. (6pts)



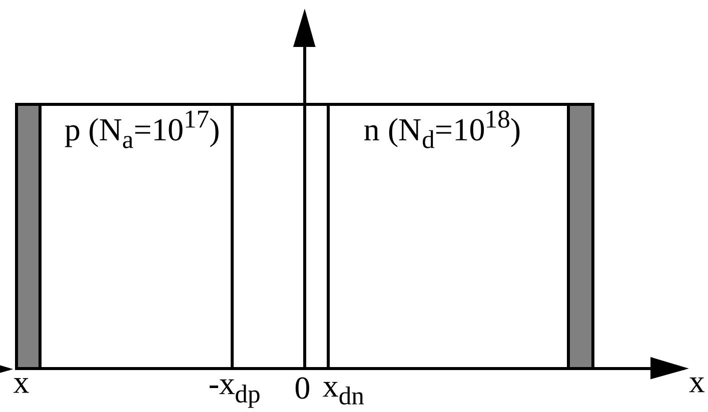
What is the “law” of the junction? (5pts)

Sketch the minority charge concentration in the bulk of a pn junction under forward bias, and also under reverse bias (no need to calculate the width of the depletion regions - assume that the diode is “short”). (8pts):

Vd = 0.7V

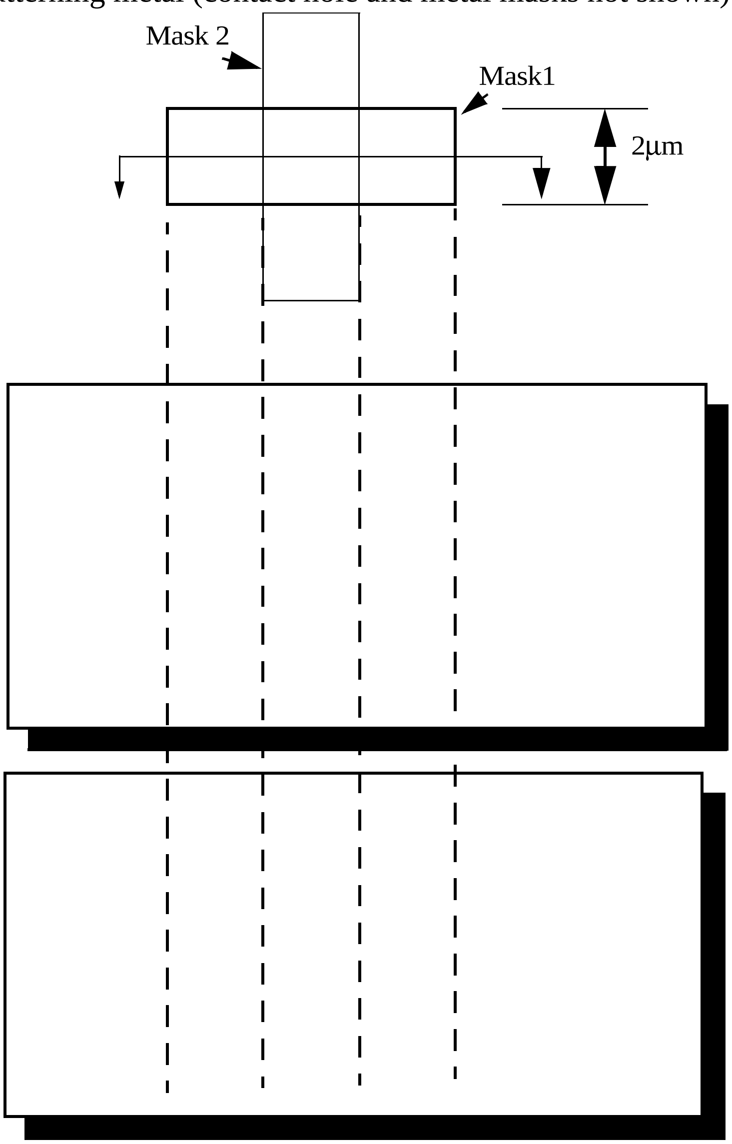


Vd = -0.7V



Problem 2 of 3 (40 points)

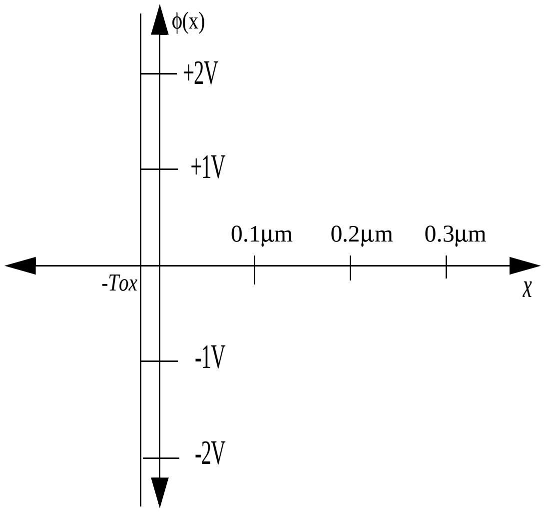
Follow these steps to create an MOS transistor:
0. Start with p-type $10^{17}/cm^3$ Boron susbstrate.
1. Grow 0.5µm of SiO_2 everywhere.
2. Use mask 1 to etch SiO_2 where mask 1 is dark.
3. Grow 15nm SiO_2 everywhere. (draw cross section after this step)
4. Deposit and pattern 0.5µm of n+ poly using mask 2 (poly remains where mask 2 is dark).
5. Implant n+ regions (to make source and drain) in areas *not* covered by poly or thick SiO_2. (draw cross section after this step).
6. The device is finished by cutting contact holes over source/drain, and by depositing oxide and patterning metal (contact hole and metal masks not shown) (*10 points*).



Cross section after step 3.

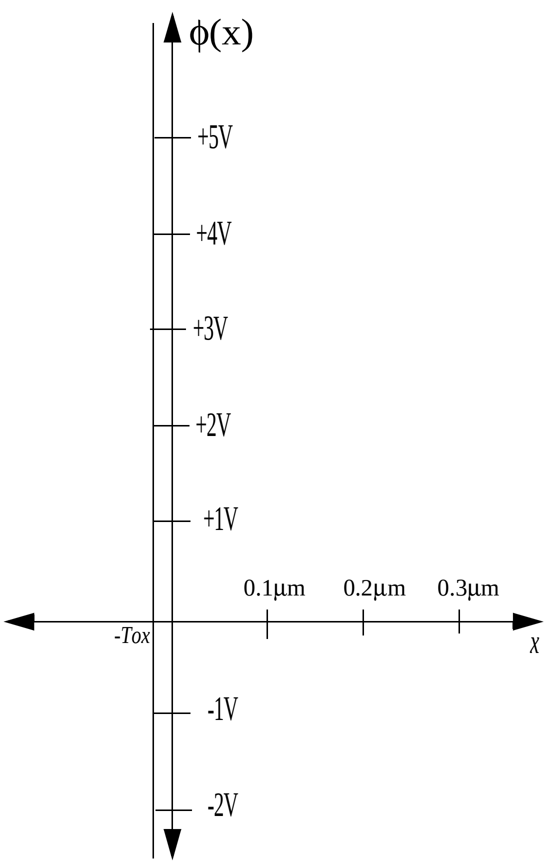
Cross section after step 5

After the transistor has been completed, apply V_{DS}=0V, V_{BS}=0V, and $V_{GS} = V_{tn0}$ to bring this device to the *onset of inversion*. Draw $\phi(x)$ (with reference to intrinsic silicon) and mark the values of V_{tn0}, X_{dmax}. ($\varepsilon_o=8.85\text{x}10^{-14}$F/cm, $\varepsilon_{ox}=3.9\varepsilon_o$, $\varepsilon_{si}=11.7\varepsilon_o$, electron charge is $-1.6\text{x}10^{-19}$Cb) (*10 points*).



(Tox not drawn to scale)

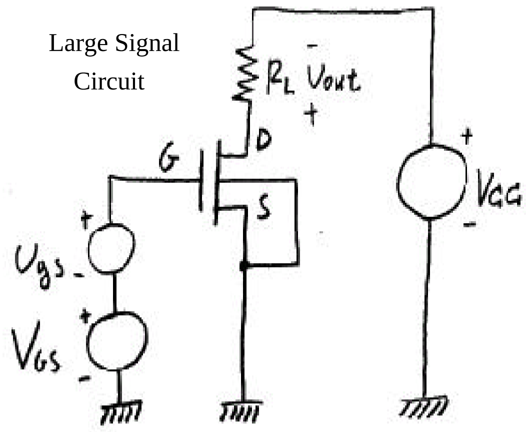
Apply V_{BS} = 0V, V_{DS} = 2V, V_{GS}=3V and draw $\phi(x)$ at a spot very close to the source, and also at a spot very close to the drain. Draw both plots on the same graph, but mark each plot carefully. (Hint: the bulk potential stays the same, at ϕ_p with reference to intrinsic silicon in both cases)(*15 points*).



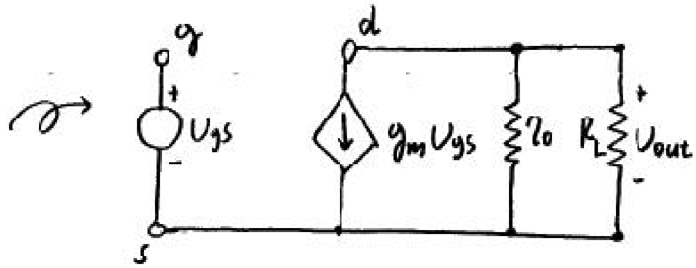
(Tox not drawn to scale)

Consider the small signal model for this transistor at V_{GS}=2V, V_{BS}=0V. The large signal source V_{CC} is such that the transistor is saturated. Calculate the values of g_m and r_o (assume μ_n=215cm^{2}V^{-1}s^{-1}, and that the channel-length modulation parameter λ_n is 0.1V^{-1}). If we connect a small-signal source v_{gs} = 1mV, what is the small signal voltage, v_{out}, across R_L = 100KΩ connected as shown? (Do not take λ_n into account when you calculate g_m). (*15 points*)

Large Signal Circuit

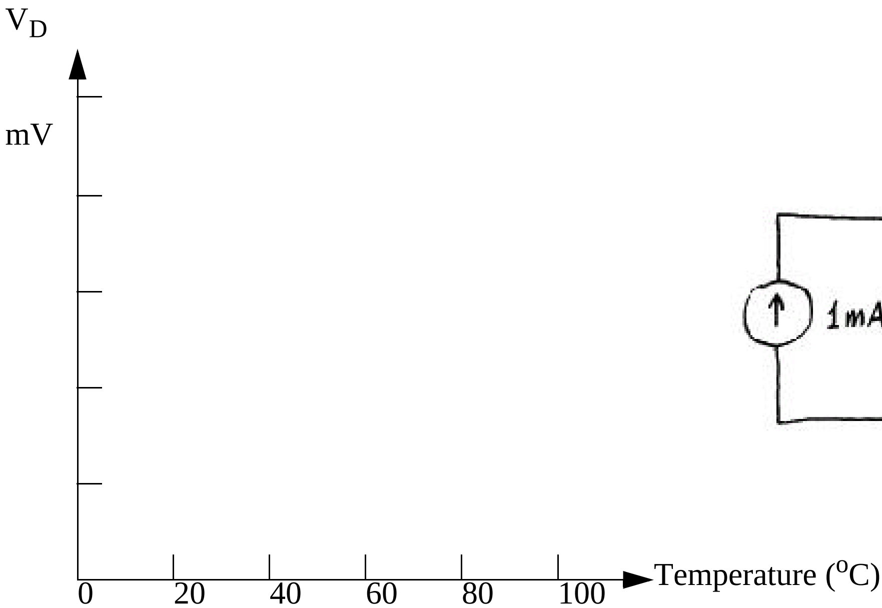


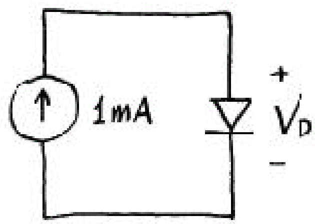
Small Signal equivalent Circuit



Problem 3 of 3 (25 points)

Consider a short pn junction with $I_o = 10^{-9}$A. You want to make a thermometer out of this diode, by feeding it with a constant forward current of 10^{-3}A, and by reading the bias voltage. What kind of function of temperature will be this voltage? (linear or some other kind?) Calculate the V_D values for 0^oC, 25^oC and 100^oC. Graph the relationship between temperature and V_D. (Boltzman's constant is 1.38 10^{-23} J/K. The absolute zero temperature is at 0^oK or at -273^oC.) (*15 points*)





How would a npn BJT be affected by the following parameters (draw up or down arrows to indicate that a parameter increases or decreases, respectively, given an increase of the respective design variable.) (*10 points*)

Design Variable	β_F	α_F
Emitter Doping		
Emitter Width		
Base Doping		
Base Width		