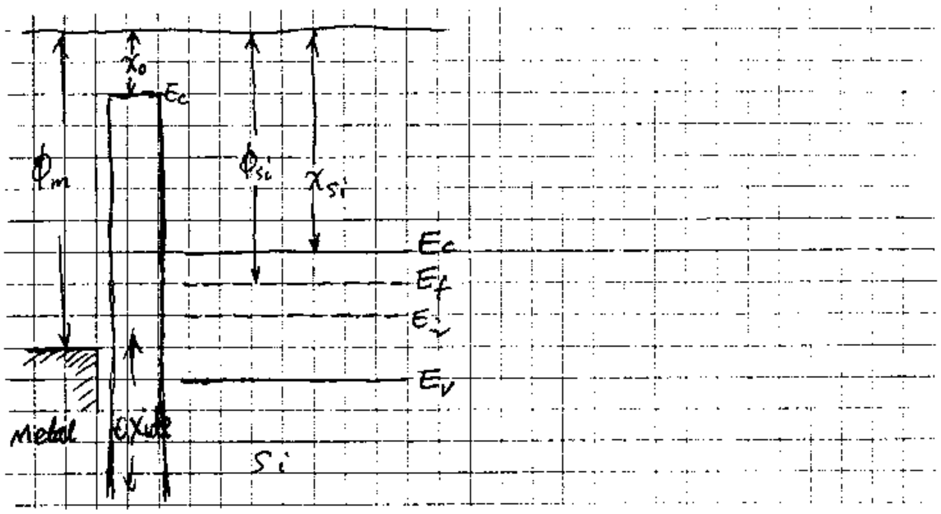
1998 Final Exam for ECE 350 (2.5 hour Dec.16, 1998; Instructor: Jimmy Xu)

Name____________________ Student Number____________________

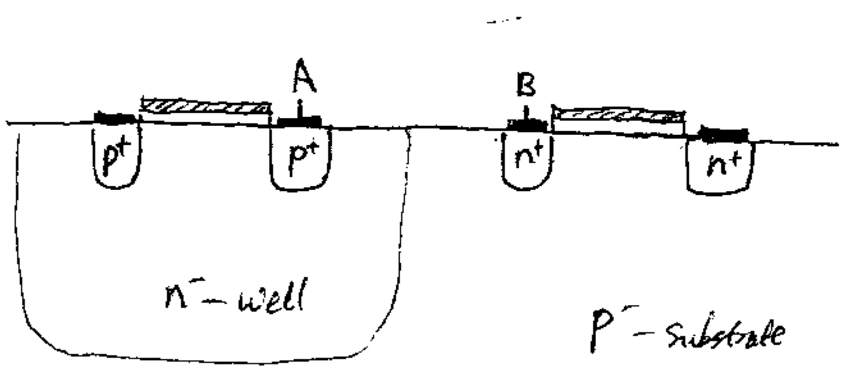
Useful constants:

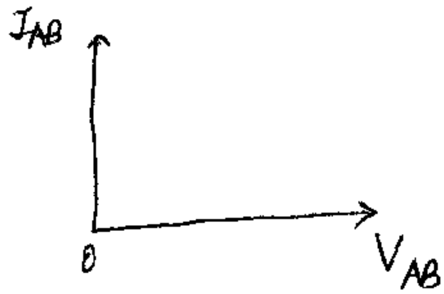
$n_i(Si)=1.5\times10^{10}\ cm^{-3}$, $kT(300K)=0.0259eV$; $\varepsilon(Si) = 11.8\times8.85\times10^{-14}\ F/cm$, $q=1.6\times10^{-19}\ C$

Q1 (8 points):
Sketch a qualitatively correct band diagram at equilibrium for a certain MOS structure shown below. What type of MOSFET (i.e. n-channel or p-channel) would this be? What might be its threshold voltage (if the oxide and interface are free of defects)?



Q2 (12 pts)
Shown below is a cross-section view of a basic CMOS structure. How would the current between A and B terminals depend on their voltage difference V_{AB} ? Explain your answer on the basis of BJT operations. Sketch the corresponding $I_{AB} - V_{AB}$ dependence.





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Q3 (30 points):

(A, 20 pts)For a long n-channel MOSFET, derive I_{DS} as function of μ, C_i, L_G, Z, V_T, V_{DS}, V_{GS}, etc., step by step from first principles, e.g., $J=\rho<V>$, where ρ is local charge density and $<V>$ is local average velocity (V_T can be assumed as a constant for the moment).

(B, 2pts) For a given V_{GS} ($>V_T$): Upto what value of V_{DS}would the above derivation be valid?

(C, 3pts) What should be the $I_{DS} - V_{DS}$ relation beyond this point of V_{DS}? Why?

(D, 5pts) If the device is short and the short-channel effect is significant, what happens ?(to the above I_{DS}–V_{DS} relation).

Q4 (15 pts)
(A, 10 pts) A normal npn BJT is operating in its normal mode, its base width W is much shorter than the diffusion length (recombination in the base can thus be neglected), and it has a certain current gain β_0. If everything else is kept the same, but the base width is halved, what would be the current gain now? Why?

(B, 5 pts) After shortening the base to half as above, if we double the emitter doping, would the current gain change? Why?

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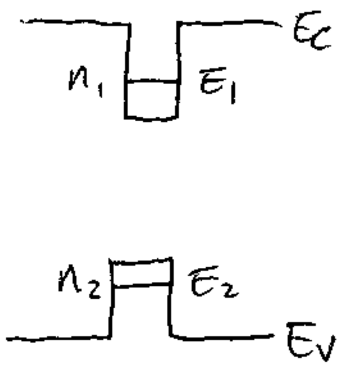
Q5 (15 pts)
(A, 5pts) Given a semiconductor quantum well structure, as shown below, one can make it into a semiconductor laser by incorporating the quantum well into a pn diode structure. Show how you would incorporate it by first sketching the band diagram of the resultant laser diode structure at equilibrium and then (b) the corresponding band diagram at a near (or above) lasing voltage.



(B, 5 pts) In order for it to lase between E_1 and E_2, what should be the relation between the number of electronics in the upper energy level and that in the lower energy level? Prove it step by step from the considerations of the radiation and absorption processes.

(C, 5 pts) If the effective mass of the hole in the quantum well is reduced, would it affect the lasing wavelength ? how and why?

Q 6
(A, 15 pts) Consider a p-type silicon substrate at T=300K doped to $N_a = 10^{14}$ cm^{-3}. Let the defects charge at the Si – SiO interface $Q_{fix} = 10^{10}$ cm^{-2}, $d_{ox} = 50$nm, assume the oxide is silicon dioxide (its dielectric constant is 3.9 x 8.85 x10^{-14} F/cm), and take $\Phi_{ms} = -0.83$V. Calculate the threshold voltage.

(B, 5 pts) If you increase the p doping, which way would the threshold voltage change? because of the change(s) of what component(s)?