6.012 Microelectronic Devices and Circuits
Spring 2005

April 20, 2005
Quiz #2

Problem #points

NAME________________________________ 1__________

RECITATION TIME______________________ 2__________

3__________

Total____________

General guidelines (please read carefully before starting):

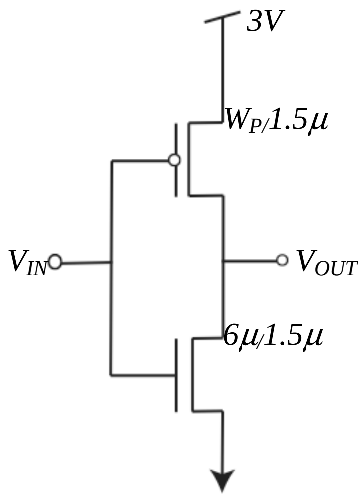
- Make sure to write your name on the space provided above.
- Open book: you can use any material you wish. But no computers.
- All answers should be given in the space provided. Please do not turn in any extra material.
- You have 120 minutes to complete the quiz.
- Make reasonable approximations and *state them*, i.e. low-level injection, extrinsic semiconductor, quasi-neutrality, etc.
- Partial credit will be given for setting up problems without calculations. NO credit will be given for answers without reasons.
- Use the symbols utilized in class for the various physical parameters, i.e. N_a, τ, ε, etc.
- Pay attention to problems in which *numerical answers* are expected. An algebraic answer will not accrue full points. Every numerical answer must have the proper *units* next to it. Points will be subtracted for answers without units or with wrong units. In situations with a defined axis, the *sign* of the result is also part of the answer.

Unless otherwise stated, use:

$q = 1.6 \times 10^{-19}$ C
$kT/q = 25$ mV at room temperature
$n_i = 10^{10}$ cm^{-3} for silicon at room temperature
$\varepsilon_{Si} = 10^{-12}$ F/cm $\varepsilon_{ox} = 3.45 \times 10^{-13}$ F/cm

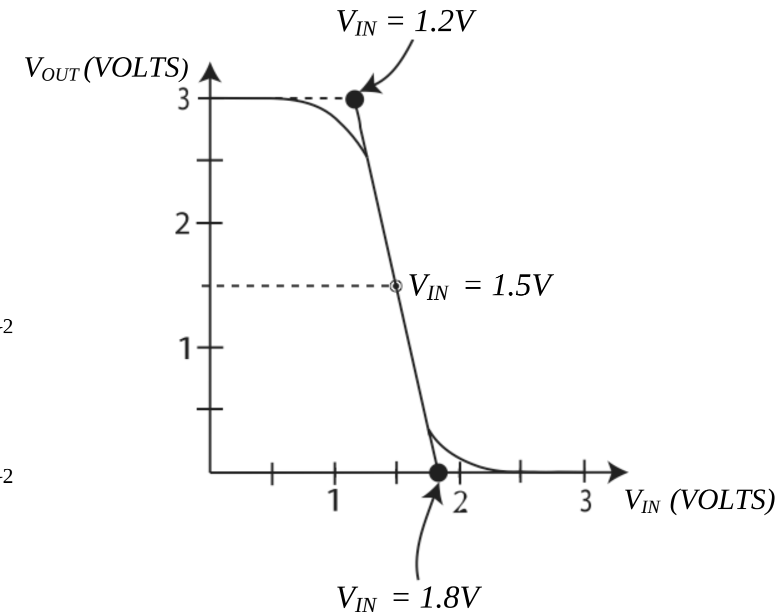
1. (30 points)

A CMOS inverter has the following voltage transfer characteristics and transistor data.



NMOS Data
$\mu_n C_{ox} = 50\ \mu A/V^2$
$V_{Tn} = 0.5V$

PMOS Data
$\mu_p C_{ox} = 25\ \mu A/V^2$
$V_{Tp} = -0.5V$

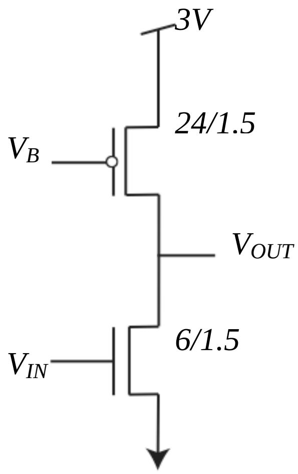


a) Calculate W_p such that $-I_{Dp} = I_{Dn} = 100\mu A$ at $V_{IN} = V_M$.

b) Calculate the NMOS transconductance, g_{mn}, at $V_{IN} = V_M$.

c) Calculate $(\lambda_n+\lambda_p)$.

An inverter with a p-channel current source has the same current 100µA flowing through the p and n channel device at V_{IN}=V_M is shown below. This inverter has different p-channel sizing but the same transistor data.



NMOS Data
$\mu_n C_{ox} = 50\ \mu A/V^2$
$V_{Tn} = 0.5V$

PMOS Data
$\mu_p C_{ox} = 25\ \mu A/V^2$
$V_{Tp} = -0.5V$

d) What is the value of the V_B such that $-I_{Dp} = I_{Dn} = 100\mu A$ at $V_{IN} = V_M$?

e) Calculate the voltage gain at $V_{IN} = V_M$.

2. (35 points)

You are given a *pn* junction diode where you have microscopy and chemical staining techniques to determine the area of the diode is $10^{-4}cm^2$ and the n-type region is degenerately doped ($>>10^{19}cm^{-3}$).

You have access to a capacitance-voltage measurement system and have measured three data points and have been asked to determine some of the diode parameters.

V	C
-1.0V	0.68pF
0V	1pF
0.6V	3.2nF

Note: If you could not calculate some of the parameters, leave your answer in terms of those unknown parameters.

a) Calculate the depletion region width at thermal equilibrium, x_{po}.

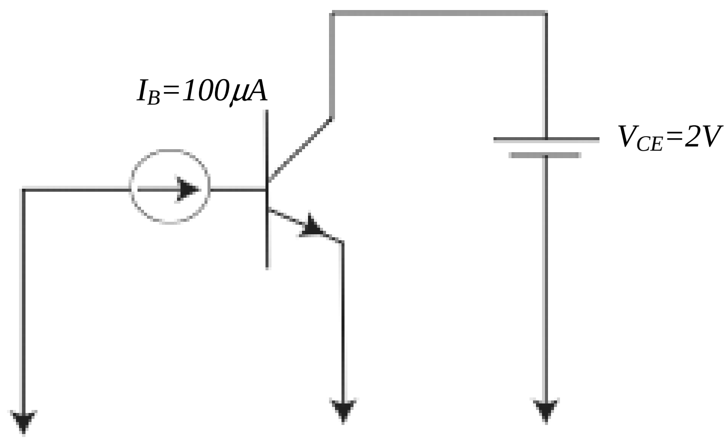
b) Calculate the built-in potential ϕ_B for this diode.

c) Calculate the doping concentration of the p-type region of the diode.

d) Calculate the physical width of the p-type region. Ignore the depletion region.

3. (35 Points)

A silicon *npn* bipolar transistor with Ebers-Moll parameters $I_s(Si) = 10^{-15}$A, and $\beta_F(Si)=100$ is biased as shown below.

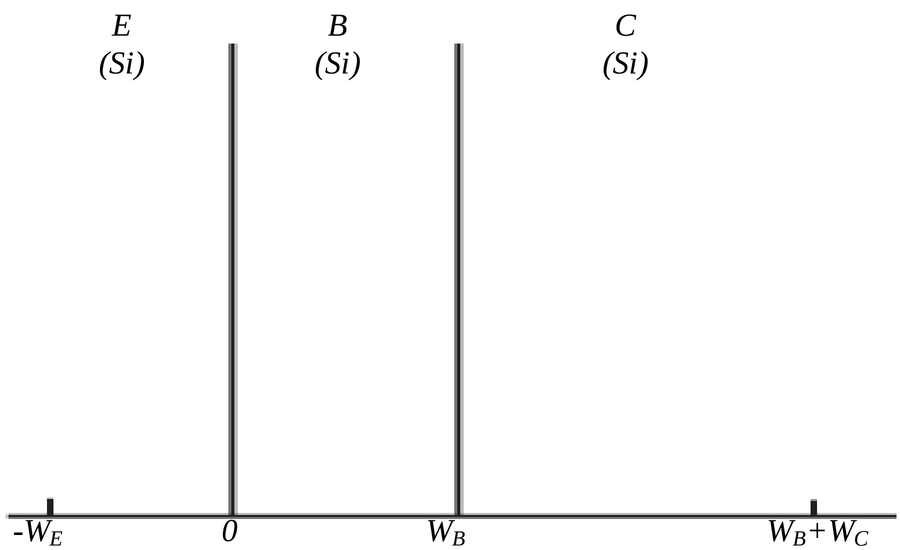


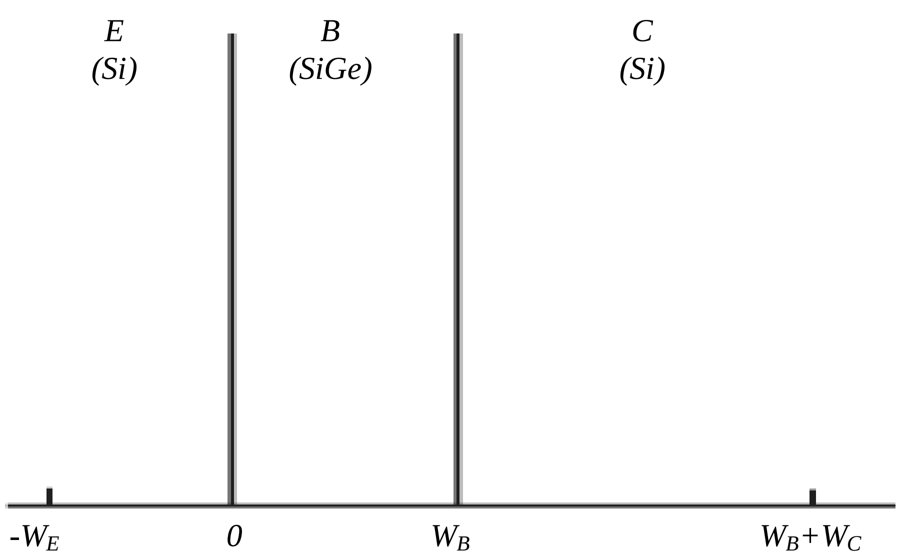
a) What is the region of operation? Explain your answer.

b) Calculate the collector current I_c.

c) Calculate the base-emitter voltage, V_{BE}.

d) A second *npn* bipolar transistor is fabricated with the emitter and collector regions consisting of Si, while the base region consists of another semiconductor, called SiGe, which has an intrinsic carrier concentration n_i(SiGe) = 1 x 10^{11} cm^{-3}. Assume that the diffusivities D_n and D_p in SiGe are identical to those for Si, and that the width of the emitter, base, and collector regions are the same in both devices, i.e. W_E(Si)=W_E(SiGe), W_B(Si)=W_B(SiGe), and W_C(Si)=W_C(SiGe). For both devices, $N_{dE}=10^{19}$ cm^{-3}, $N_{aB}=10^{17}$ cm^{-3}, and $N_{dC}=10^{16}$ cm^{-3}. Assume that recombination only takes place at the contacts. For V_{BE}=0.6V and V_{BC}=-1.4V, sketch the minority carrier densities in the emitter, base, and collector, for both the Si and SiGe transistors, on the axes below (note that the space-charge regions are omitted and only the quasi-neutral regions are shown). Label the sketches with the numerical values at the contacts and at the edges of the space-charge regions. (i.e. neglect the space-charge regions)





e) For the Si and SiGe bipolar transistors and bias conditions given in (d), calculate the ratio of the collector saturation currents, I_S(SiGe)/I_S(Si).

f) For the Si and SiGe bipolar transistors and bias conditions in (d), calculate the ratio of the forward active current gains, β_F(SiGe)/β_F(Si).

g) The Si and SiGe bipolar transistors in (d) are now biased in the forward active region with the same V_{BC}, and V_{BE} adjusted such that the collector currents of the two devices are equal, i.e. $I_c(Si)=I_c(SiGe)$. Under these bias conditions, calculate the ratio of the input resistances of the two devices, $r_\pi(SiGe)/r_\pi(Si)$.