ECSE 2210 Microelectronics Technology
Quiz II
March 21, 2008

This quiz is from 10 – 11:50 AM. This is open book. Put proper units in your answers to get full credit. Show your work.

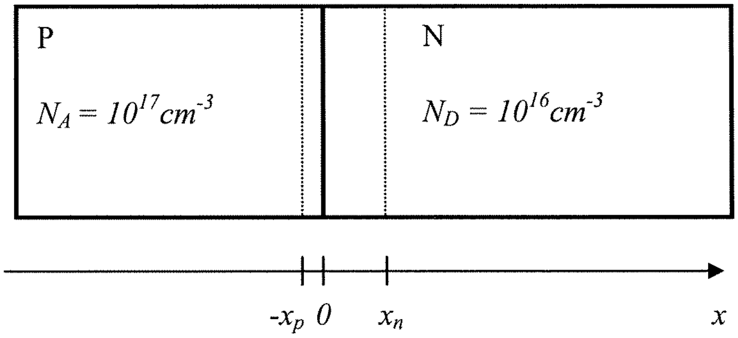
YOUR NAME ....Solutions....

1. pg. 1-3 ___30___ (30)
2. pg. 3-4 ___20___ (20)
3. pg 5-6 ___25___ (25)
4. pg 7-8 ___25___ (25)

Problem 1 (30 points)

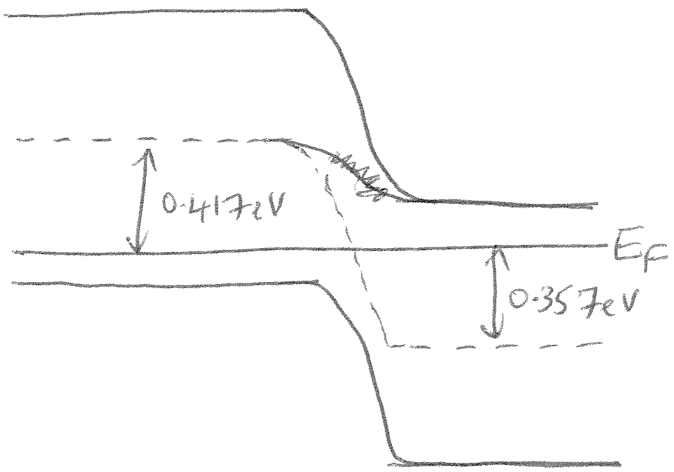
The figure below shows a Si pn diode maintained at room temperature. The doping concentrations are shown in the figure. Assume that the junction has a cross sectional area of 1 cm^2.

Diode A



$\varepsilon = 10^{-12}$ C/(Vcm)
$q = 1.6\times10^{-19}$C

(a) Draw the thermal equilibrium band diagram for this junction. Mark the energy levels E_C, E_F, E_i, and E_V in the diagram.



P-side

$$E_i - E_F = kT \ln \frac{10^{17}}{10^{10}}$$

$$= 0.417 eV$$

n-side

$$E_F - E_i = kT \ln \frac{10^{16}}{10^{10}}$$

$$= 0.357 eV$$

(b) Determine the position of the depletion layer edges on both sides (x_p= ?, x_n= ?).

$$W = \left[\frac{2\epsilon_{Si}}{q}\frac{N_A+N_D}{N_AN_D}\left(V_{bi}-V_A\right)\right]^{1/2}$$

$$= \left(\frac{2\times10^{-12}}{1.6\times10^{-19}}\times\frac{10^{17}+10^{16}}{10^{17}\times10^{16}}\times0.775\right)^{1/2} = 3.26\times10^{-5}\,\text{cm}$$

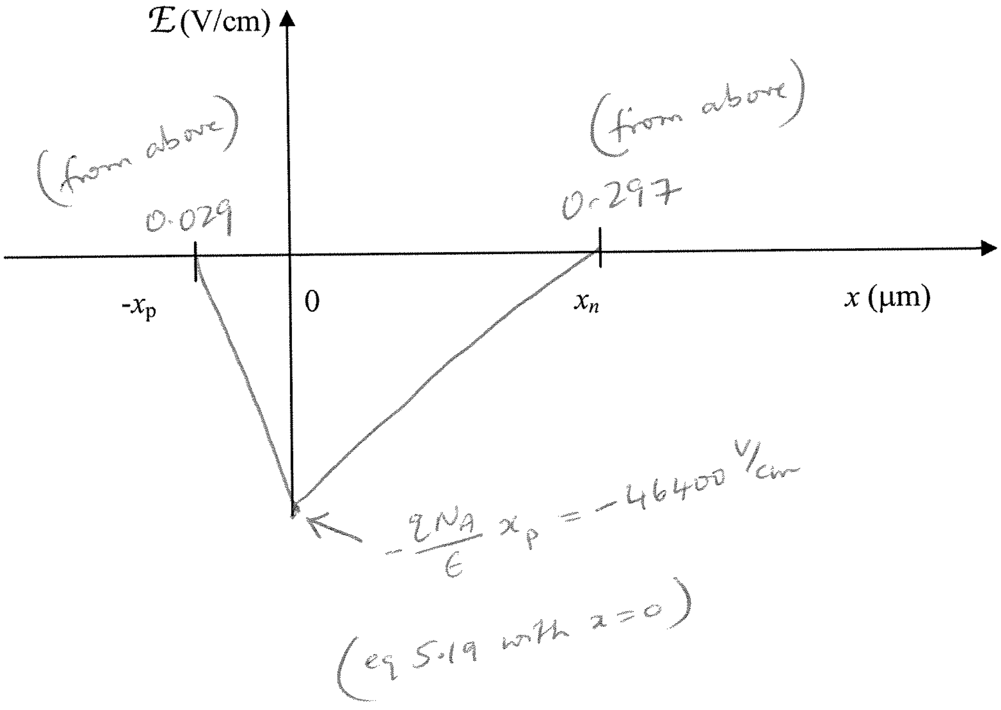
$$x_p = 0.326\times\frac{10^{16}}{10^{16}+10^{17}} = 0.029\,\mu m$$

$$x_n = 0.326-0.029 = 0.297\,\mu m.$$

(c) Determine the built-in voltage V_{bi}.

$$V_{bi} = \frac{kT}{q}\ln\frac{N_AN_D}{n_i^2} = 0.775\,V$$

(d) Sketch the electric field as a function of x. Mark all the important numerical values in the graph.



e. The diode below is identical to the one above, except that an intrinsic region is placed at the metallurgical junction as shown below. Circle True or False for the following questions:

Diode B

P	Intrinsic	N
$N_A = 10^{17} cm^{-3}$		$N_A = 10^{16} cm^{-3}$

If the diodes were ideal, then both diodes will have the same reverse saturation current.

[✓ True] False

If the diodes were ideal, for a given forward bias, diode A will have higher forward current than diode B.

True [✓ False]

For a given reverse bias, diode A will have higher junction capacitance than diode B.

[✓ True] False

The diode A will have higher breakdown voltage than diode B.

True [✓ False.]

If the diodes were not ideal, diode A will have higher reverse current than diode B for a given reverse voltage.

True [✓ False]

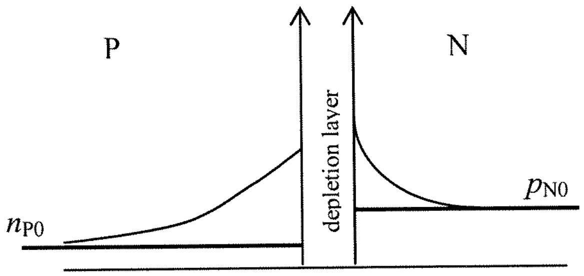
Problem 2 (20 points)

(a) The minority carrier concentration in a Si p-n junction with applied bias is shown below on a linear scale. This diode is **(choose one: [✓ forward biased], reverse biased, in thermal equilibrium)**? The majority electron concentration n_N in the n-side is **(choose one: larger than, [✓ smaller than], same as)** the majority hole concentration p_P in the p-side. Justify both answers with a brief explanation.

$n_{po} < p_{no}$

$\frac{n_i^2}{n_n} < \frac{n_i^2}{p_p}$

$n_n < p_p$



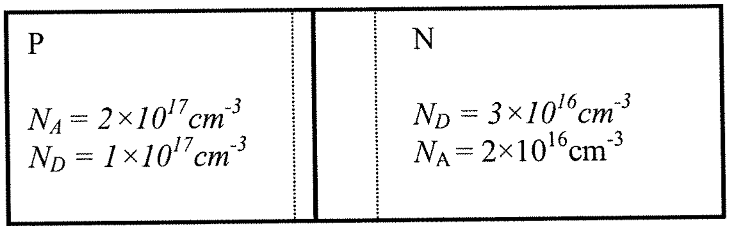
(b) The question is about the application of PN junction diodes. Give an example when a PN junction diode is **forward** biased under normal operation. Give an example when a PN junction diode is **reverse** biased under normal operation.

LED : Diode is forward biased

Detectors : Diodes are generally reverse biased

: varactors : reverse biased Capacitance

(c) Consider the diode below. Calculate the built-in voltage.



$\varepsilon = 10^{-12}$ C/(Vcm)
$q = 1.6\times10^{-19}$C

$$V_{bi} = \frac{kT}{q} \ln \frac{N_A N_D}{n_i^2}$$

$$= 0.0259 \ln \frac{(2-1)10^{17} \times (3-2)10^{16}}{10^{20}}$$

$$= \underline{0.775V}$$

(d) Consider two pn junction diodes. Diode A is made from Si and diode B is made from SiC. Bandgap of SiC is 3.26eV. Write Diode A or Diode B for the following questions:

Which diode will have higher breakdown voltage? B

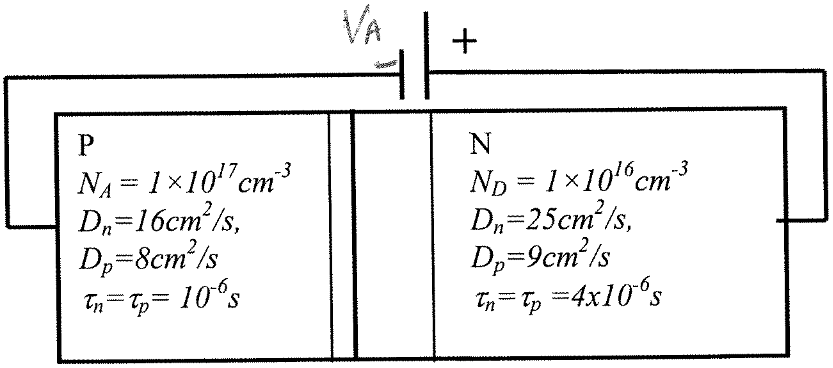
Which diode will have higher reverse saturation current? A

Which diode will have higher built-in voltage? B

Which diode will absorb more of the sunlight? A

Problem 3 (25 points)

Consider an ideal diode shown below. Assume cross sectional area = 1cm^2



(a) The diode is biased as shown. Is it forward biased or [✓ reverse biased?] Circle the correct answer.

(b) Calculate the current through the diode for the above biasing condition.

$$I_0 = \underbrace{qA \frac{D_n}{L_n} n_{po}}_{p\text{-side}} + \underbrace{qA \frac{D_p}{L_p} \cdot p_{no}}_{n\text{-side}}$$

$$L_n = \sqrt{D_n \tau_n} = \sqrt{16 \times 10^{-6}} = 4 \times 10^{-3} cm$$

$$L_p = \sqrt{D_p \tau_p} = \sqrt{9 \times 4 \times 10^{-6}} = 6 \times 10^{-3} cm$$

$$I_0 = qA \left[\frac{16}{4 \times 10^{-3}} \times \frac{n_i^2}{10^{17}} + \frac{9}{6 \times 10^{-3}} \times \frac{n_i^2}{10^{16}} \right]$$

$$= 2.4 \times 10^{-12} A$$

(c) Suppose the diode is biased such that a current of 2A flows through the diode. What will be the magnitude of applied voltage?

$$I = I_0 \left(e^{\frac{qV_A}{kT}} - 1 \right)$$

$$2A = 2.4 \times 10^{-12} \left(e^{\frac{qV_A}{kT}} - 1 \right)$$

$$\underline{V_A = 0.71V}$$

(d) Under a certain reverse biased condition, the capacitance of the diode is measured to be 10nF. What should be the depletion layer thickness?

$$C_J = \frac{\epsilon A}{W}$$

$$W = \frac{\epsilon A}{C_J} = \frac{10^{-12} \times 1}{10\times 10^{-9}} = 1\times 10^{-4}\,\text{cm}$$

$$W = 1\,\mu\text{m}$$

(e) In part d, what should be the applied reverse bias voltage?

$$W = \left[\frac{2\epsilon_{Si}}{q}\,\frac{N_A+N_D}{N_A N_D}\cdot\left(V_{bi}-V_A\right)\right]^{1/2}$$

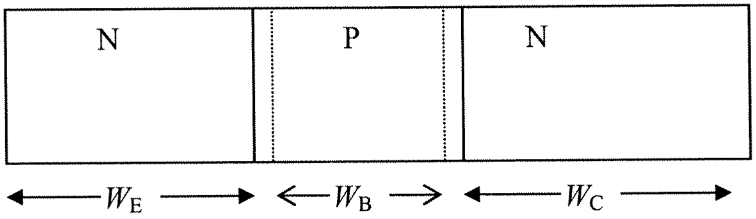
$$1\times 10^{-4}\,\text{cm} = \left[\frac{2\times 10^{-12}}{1.6\times 10^{-19}}\cdot\frac{10^{17}+10^{16}}{10^{17}\cdot 10^{16}}\cdot\left(0.775-V_A\right)\right]^{1/2}$$

$$\underline{\underline{V_A = 6.5\,\text{V}}}$$

If you neglect V_{bi}, you will get 7.3V.
(OK if you mention that you neglected)

Problem 4 (25 points)

Consider an npn transistor with doping concentration and dimensions shown below.

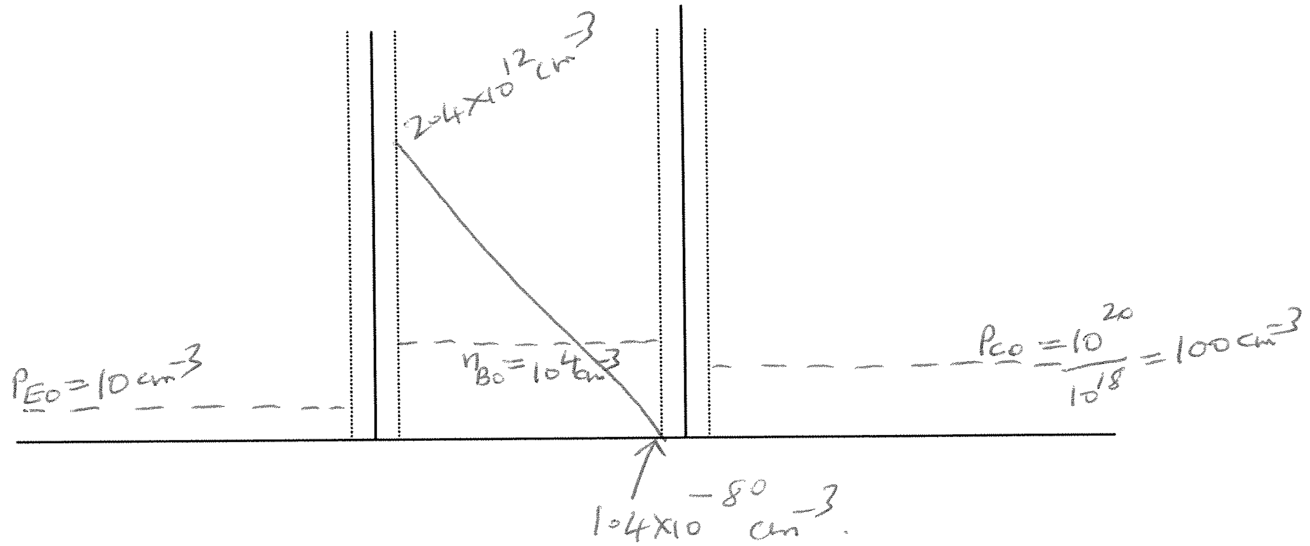


Area = 10^{-2} cm^2

	Emitter	Base	Collector
Doping conc. (cm^{-3})	10^{19}	10^{16}	10^{18}
W (μm)	100	1	100
Lifetimes (s)	10^{-9}	10^{-7}	10^{-9}
Elect. mobility (cm^2/Vs)	100	1000	150
Hole mobility (cm^2/Vs)	75	400	100

Answer the following questions.

a. Plot the minority carrier concentration profiles in the three regions under thermal equilibrium conditions.



b. If V_{BC} = -5V, and V_{BE} = 0.5V, plot the minority carrier concentration profiles in the base region. Plot the profile in the same graph above. Mark all important numerical values in the plot.

$$\frac{n_B(0)}{n_{B0}} = e^{0.5/.0259} \Rightarrow n_B(0) = 2.4\times10^{12}\ \text{cm}^{-3}$$

$$\frac{n_B(W)}{n_{B0}} = e^{-5/.0259} \Rightarrow n_B(W) = 1.4\times10^{-80}\ \text{cm}^{-3}$$

c. With the transistor biased as in (b), calculate the collector current, Ic.

$$I_c = qAD_B \cdot \frac{\left(2.4\times10^{12} - 1.4\times10^{-80}\right)}{1\times10^{-4}}$$

$$= 1.6\times10^{-19}\times10^{-2}\times\overset{25}{\cancel{10.4}}\times\frac{2.4\times10^{12}}{1.\times10^{-4}}$$

$$= \cancel{4\times10^{-4}}\,A$$

$$\underline{\underline{1\,mA}}$$

$$\frac{D_B}{\mu_B} = \frac{kT}{q}$$

$$D_B = \overset{1000}{\cancel{400}}\times0.0259$$

$$= \underset{25}{\cancel{10.4}}\,cm^2/s$$

d. If the emitter doping is reduced from $10^{19}cm^{-3}$ to $10^{18}cm^{-3}$, what will happen to the common emitter current gain? Will it increase or [✓ decrease] or remains the same?

If the emitter doping is reduced from $10^{19}cm^{-3}$ to $10^{18}cm^{-3}$, what will happen to the base transport factor? Will it increase or decrease or [✓ remains the same]?

If the base doping is increased from $10^{16}cm^{-3}$ to $10^{17}cm^{-3}$, what will happen to the common emitter current gain? Will it increase or [✓ decrease] or remains the same?

If the base width is increased from 1um to 2um, what will happen to the base transport factor? Will it increase or [✓ decrease] or remains the same?