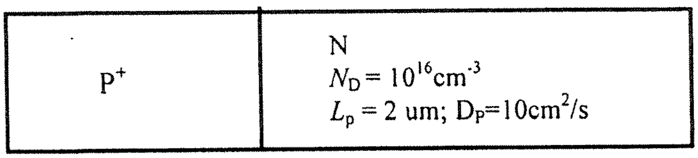
ECSE 2210 Microelectronics Technology
Review Questions for Quiz 2

Problem 1 (25 points)

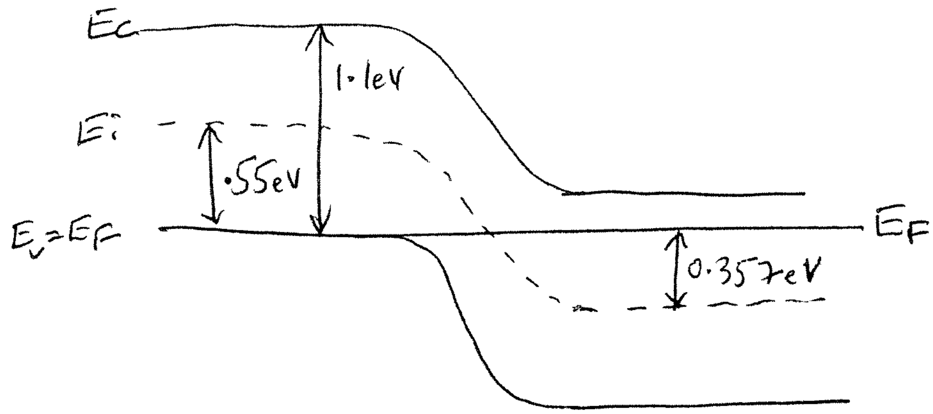
The figure below shows a Si p$^+$n diode maintained at room temperature. The donor concentratio n N_D and the hole diffusion length L_P in the n-side are given. Assume that $E_F = E_V$ on the p-side of the diode.



$A = 1$ cm^2
$\varepsilon = 10^{-12}$ C/(Vcm)
$q = 1.6\times10^{-19}$C

(a) Draw the equilibrium band diagram for this junction. Mark the energy levels E_C, E_F, E_i, and E_V in the diagram. Also, determine the built-in voltage.

$E_F - E_i = kT \ln \frac{10^{16}}{10^{10}} = 0.357$ eV



Built-in voltage: 0.55 + 0.357 = 0.907 V

(b) In this diode, most of the depletion layer will be in the (**p^+-side, n-side, distributed equally in the two sides: choose one**). Calculate this depletion layer width at thermal equilibrium.

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

$V_A \to 0$

$\frac{N_A+N_D}{N_A N_D} \to \frac{1}{N_D}$

$$= \left[\frac{2\epsilon}{q} \frac{1}{N_D} V_{bi}\right]^{1/2}$$

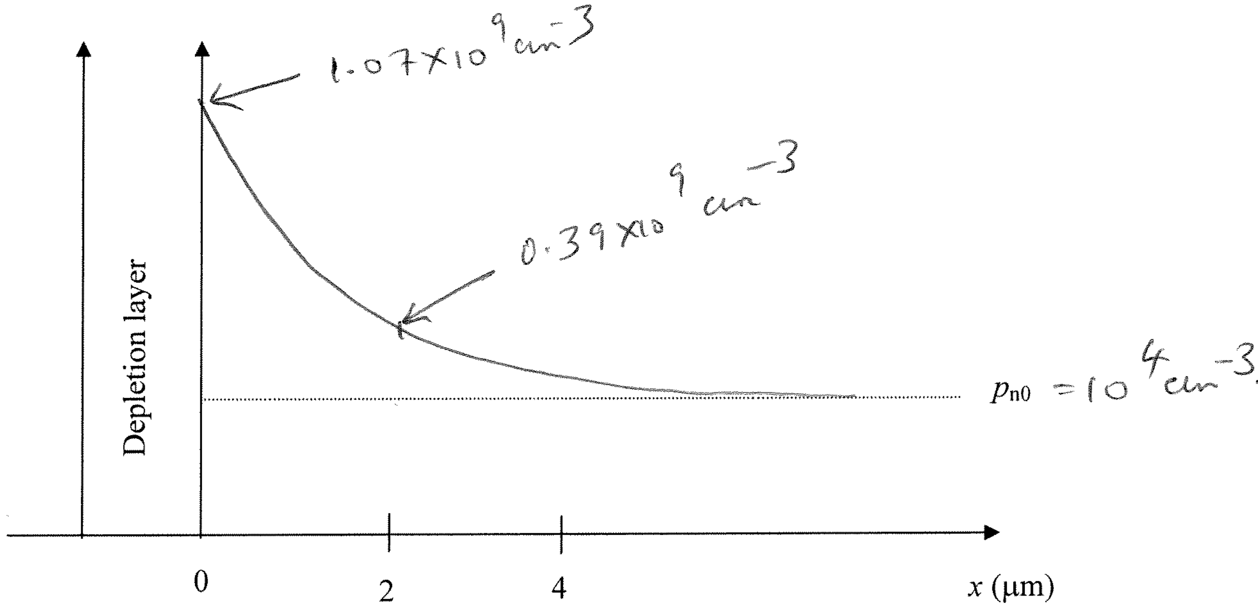
$$= 0.34\ \mu m$$

(c) Calculate the reverse saturation current, I_o, for this diode. This current I_O through the junction will be comprised of (mostly holes, mostly electrons, equally both electrons and holes: choose one).

$$I_o = qA \frac{D_p}{L_p} \cdot p_{no} = 1.6\times10^{-19} \times 1 \times \frac{10}{2\times10^{-4}} \times 10^4$$

$$= 8\times10^{-11}\ A$$

(d) A forward voltage $V_F = +0.3$ V is now applied to the diode. Plot the minority carrier concentration profile on the n-side of the diode as a function of x (use the graph below). Mark the values of $\boldsymbol{p_n(x=0)}$, $\boldsymbol{p_n(x = 2\ \mu m)}$, **and** $\boldsymbol{p_{n0}}$.

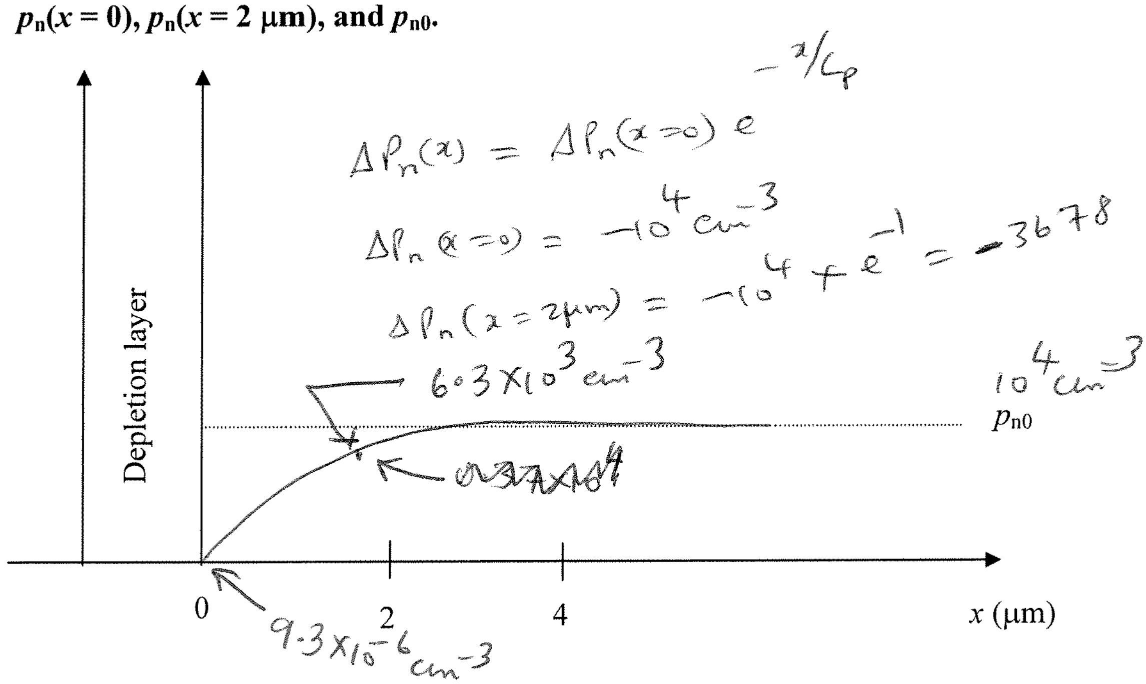


$p_n(0) = p_{n0} e^{qV/kT} = 1.07\times10^{9}\ cm^{-3}$

$\Delta p_n(0) \approx 1.07\times10^{9}\ cm^{-3}$

$\Delta p_n(x=2\mu m) = 0.39\times10^{9}\ cm^{-3}$

(e) A reverse bias $V_R = -0.3$ V is now applied to the diode. Plot the minority carrier concentration profile on the n-side of the diode as a function of x (use the graph below). Mark the values of $\boldsymbol{p_n(x=0)}$, $\boldsymbol{p_n(x = 2\ \mu m)}$, **and** $\boldsymbol{p_{n0}}$.



Problem 2 (25 points)

Consider an abrupt GaAs n^+p junction with a cross sectional area of 10μm X 10μm. The n-region is 100μm thick with negligible thickness for n^+ region.

n^+	p $N_A = 2\times10^{16}\text{cm}^{-3}$ D_n=196 cm^2/s, D_p=9 cm^2/s $\tau_n = \tau_p = \tau_o = 10^{-8}$ s

$\varepsilon(GaAs) = 10^{-12}$ F/cm
$q = 1.6\times10^{-19}$ C
$n_i(GaAs)=2\times10^6\text{cm}^{-3}$

(a) Calculate the diode capacitance at a reverse bias $V_R = -10$ V. (You can neglect V_{bi} for this calculation)

$$W = \left[\frac{2\epsilon}{q}\frac{1}{N_A}(V_{bi}-V_A)\right]^{1/2} = 0.8\ \mu m$$

$$C_J = \frac{\epsilon_{GaAs} A}{W} = \frac{1\times10^{-12}\times10\times10\times10^{-8}}{0.8\times10^{-4}} = 1.25\times10^{-14}\text{F}$$

$$= \underline{0.0125\ \text{pF}}$$

(b) Calculate the ideal diode current I at a forward voltage $V_F = +0.8$ V.

$$I_o = qA\frac{D_n}{L_n}\cdot n_{po}$$

$$= 1.6\times10^{-19}\times100\times10^{-8}\times\frac{196}{\sqrt{196\times10^{-8}}}\times\frac{4\times10^{12}}{2\times10^{16}}$$

$$= 4.48\times10^{-24}\ A$$

$$I = 4.48\times10^{-24}\, e^{\frac{0.8}{.0259}} = 1.16\times10^{-10}\ A$$

(c) Calculate the diffusion capacitance C_D at a forward voltage V_F = +0.8 V.

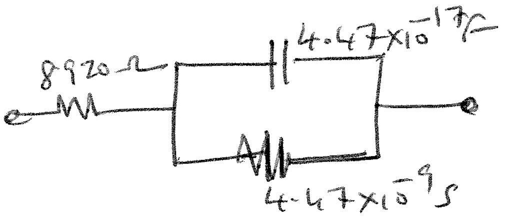
$$C_D = \frac{q}{KT} I \tau_n = 4.47 \times 10^{-17} \text{ F}$$

(d) Calculate the parasitic series resistance and then draw the equivalent circuit for the diode for a forward bias condition of 0.8V.

$$R_S = \frac{\rho l}{A} = 8920 \,\Omega \qquad \rho = \frac{1}{q\mu_p P} = \frac{1}{q \times 350 \times 2 \times 10^{16}}$$

$$G_D = \frac{q}{KT} I = \frac{1.16 \times 10^{-10}}{0.0259} \qquad = 0.892 \,\Omega\,\text{cm}$$

$$= 4.47 \times 10^{-9} \text{ S} \qquad \mu_p = \frac{D}{KT/q} = \frac{9}{0.0259} = 350 \text{ cm}^2/\text{Vs}$$



(It is ok if you neglect C_J but ideally C_J also should be included)

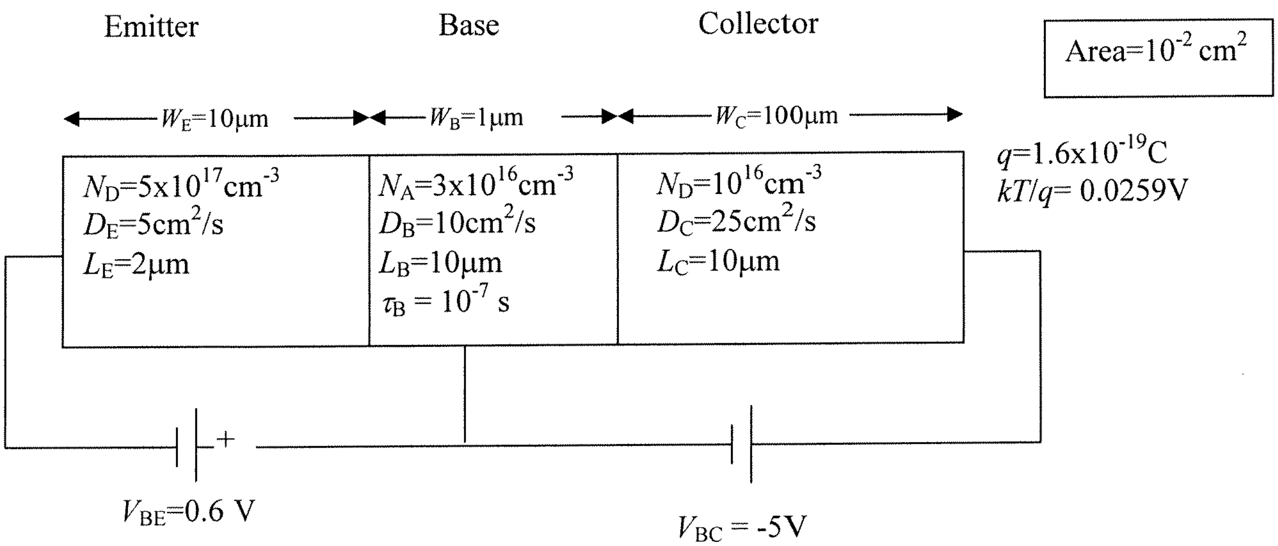
(e) Now assume that the diode is not ideal. Calculate the generation-recombination current $I_{R\text{-}G}$ at a reverse bias V_R = -10 V.

$$I_{R\text{-}G} = \frac{qAn_iW}{2\tau_0} = \frac{1.6 \times 10^{-19} \times 100 \times 10^{-8} \times 2 \times 10^{6} \times 0.8 \times 10^{-4}}{2 \times 10^{-8}}$$

$$= 1.28 \times 10^{-15} \text{ A.}$$

Problem 3 (25 points)

A silicon npn transistor has the following parameters. The transistor is biased with $V_{BE} = 0.6$ V and the C-B junction is reverse biased.



(a) Calculate the collector current I_c under the above biasing conditions. Ignore the effect of base-width-modulation for this calculation.

I_c = ______________

$$I_C = qA \frac{D_B}{W_B} p_{B0} e^{\frac{qV_{EB}}{kT}}$$

$$= 1.6\times10^{-19} \times 10^{-2} \times \frac{10}{1\times10^{-4}} \times \underbrace{\frac{10^{20}}{3\times10^{16}} \exp\left(\frac{0.6}{0.0259}\right)}_{3.8\times10^{13}}$$

$$= 6 \text{ mA}$$

(b) Calculate the base current due to recombination and the base transport factor α_T.

$$I_{BR} = qA \frac{W_B}{2\tau_B} p_{B0} \exp\frac{qV_{EB}}{kT}$$

$$= 1.6\times10^{-19} \times 10^{-2} \times \frac{1\times10^{-4}}{2\times10^{-7}} \times 3.8\times10^{13}$$

$$= 3.06\times10^{-5} \text{ A}$$

$$\alpha_T = \frac{0.006}{0.006 + 3\times10^{-5}} = 0.995$$

(c) calculate the total base current, I_B and hence the common emitter current gain, β.

$$I_{EN} = qA \frac{D_E}{L_E} n_{E0} \exp \frac{0.6}{0.0259}$$

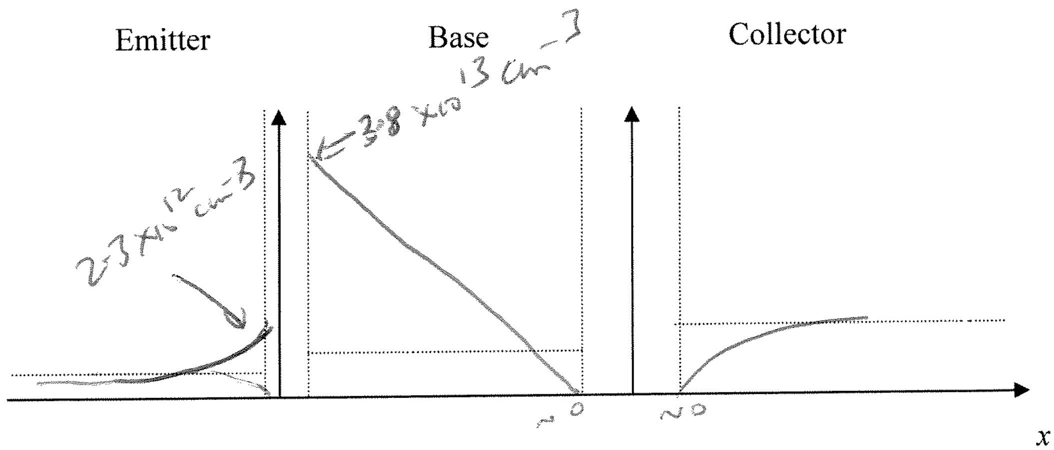
$$= 1.6\times10^{-19} \times 10^{-2} \times \frac{5}{2\times10^{-4}} \times 200 \underbrace{\exp\left(\frac{0.6}{0.0259}\right)}_{2.3\times10^{12}}$$

$$= 9.2\times10^{-5}\ A$$

$$I_B = I_{BR} + I_{EN} = 3\times10^{-5} + 9.2\times10^{-5} = 1.2\times10^{-4}\ A$$

$$\beta = \frac{I_C}{I_B} = 50$$

d) Plot the minority carrier concentration profiles in the emitter, base, and collector regions of the transistor shown above (Use the graph below). Mark the important numerical values on the graph. What type of minority charge carriers will you find in the base (**electrons** or **holes**)?



Problem 4 (30 points)

(a) Two pnp BJTs are identical except that the base dopings are different as shown below.

Which transistor will exhibit greater sensitivity to base-width modulation under forward active mode biasing? **Diode A or Diode B**

Which one will have higher punch-through voltage? **Diode A or Diode B**

A

10^{18} cm^{-3}	10^{16} cm^{-3}	10^{15} cm^{-3}

B

10^{18} cm^{-3}	10^{15} cm^{-3}	10^{15} cm^{-3}

(b) The delay in switching from the on-state to the off-state in a p-n junction diode is caused by the (**immobile charges in the depletion layer, stored minority carriers in the neutral region, stored minority carriers in the depletion layer: choose one**). If we increase the minority carrier lifetime, the turn-off time in a pn diode will (**increase, decrease, remain the same: choose one**).

(c) Consider three p^{+}-n-junctions as shown below.
Which one will have the lowest breakdown voltage V_{BR} ? diode B
Which one will have the highest R-G related current ($I_{R\text{-}G}$) at reverse bias? diode C
Which one will have lowest capacitance for given reverse bias? diode C

A

P^{+}	N$_D$=10^{15} cm^{-3}

B

P^{+}	N$_D$=10^{17} cm^{-3}

C

P^{+}	intrinsic	N$_D$=10^{15} cm^{-3}

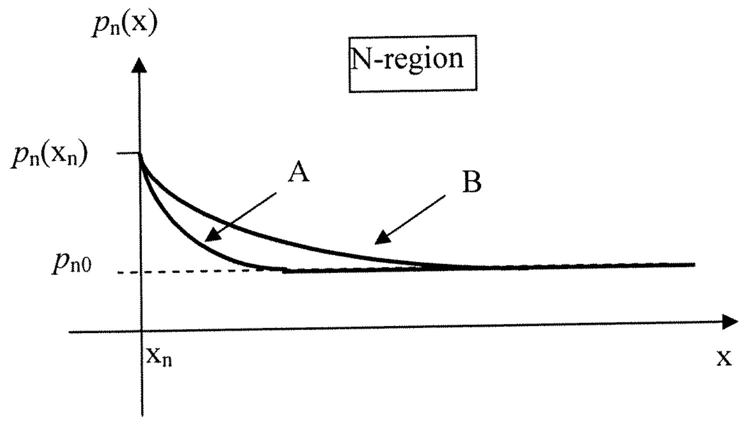
(d) Consider diodes made from Ge, Si and GaAs. Assume identical doping etc.

Which diode will have the lowest reverse leakage current? GaAs

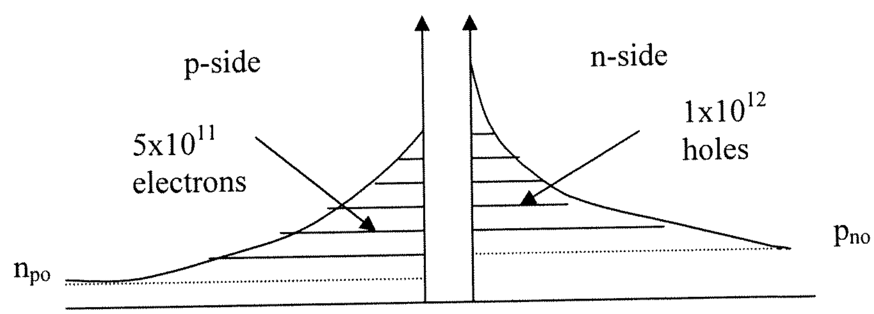
Which diode will have highest reverse Avalanche breakdown voltage? GaAs

Which diode will emit light when forward biased? GaAs

e. Linear plots of the minority carrier concentration on the n-side of two ideal p^+-n diodes maintained at room temperature are shown below. The n-side doping N_D and the cross-sectional area A are the same in both diodes. The diffusion coefficient of holes is the same for both diodes. The forward voltage applied to diode A is **(the same, larger than, smaller than: choose one)** the voltage applied to diode B. The current through the diode A is **(the same as, larger than, smaller than: choose one)** the current through the diode B .



f. The minority carrier concentration profile in the neutral region of a pn junction diode is as shown below. The lifetime is $1\text{x}10^{-6}$s for electrons and $2\text{x}10^{-6}$s for holes. The excess minority carrier concentration (shaded area) is marked in the figure. Calculate the current flowing through the diode.



$$I = \frac{Q_n}{\tau_n} + \frac{Q_p}{\tau_p} = \frac{q \times 5\times10^{11}}{10^{-6}} + \frac{q\times10^{12}}{2\times10^{-6}} = 0.16\,A$$

g. The reverse saturation current of a diode does not vary much with the temperature. True or False?