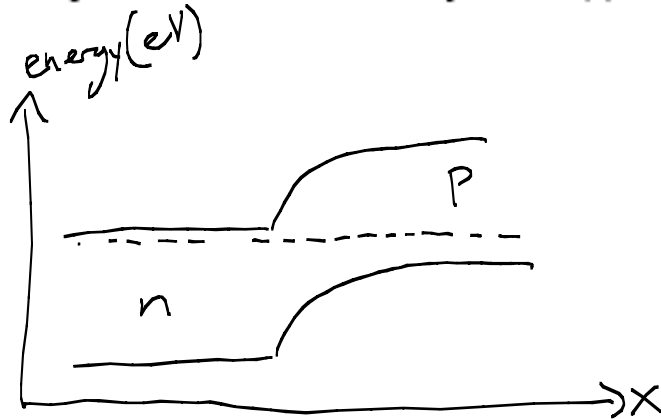


1. An abrupt pn junction with $N_d=10^{19}\text{cm}^{-3}$ on the n-side and $N_a=10^{16}\text{cm}^{-3}$ on the p-side which extend to infinity. Assume 1.1eV bandgap, intrinsic carrier concentration 10^{10}cm^{-3} , and conduction and valence DOS are equal.

(a) Draw the band diagram. Label n- and p-side, and pay close attention to the correct shape of the bands close to the junction. (5)



(b) What is built-in potential barrier qV_0 ? (5)

$$qV_0 = E_F^n - E_F^p$$

$$n_0 = n_i e^{(E_F - E_i)/KT}$$

$$E_F^n - E_i = KT \ln \frac{n_0}{n_i} = 0.026 \text{ eV} \cdot \ln \frac{10^{19}}{10^{10}}$$

$$p_0 = n_i e^{(E_i - E_F^p)/KT} \approx 0.026 \cdot 9 \cdot 2.3 \approx 0.55 \text{ eV}$$

$$E_i - E_F^p = KT \ln \frac{p_0}{n_i} \approx 0.026 \cdot 6 \cdot 2.3 \approx 0.35 \text{ eV}$$

(c) On which side (n or p) is the depletion region wider? (5) $qV_0 \approx 0.9 \text{ eV}$

$N_d \gg N_a$, so
most of depletion
region is in p-side

(d) By what ratio is the answer in (c) larger? (5)

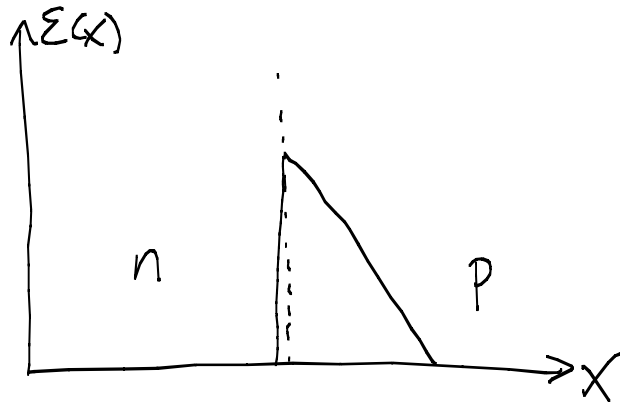
$$X_{no} \propto \sqrt{\frac{N_a}{N_d(N_a+N_d)}} \quad X_{po} \propto \sqrt{\frac{N_d}{N_a(N_a+N_d)}}$$

$$\frac{X_{po}}{X_{no}} = \frac{N_d}{N_a} = \frac{10^{19}}{10^{16}} = 10^3$$

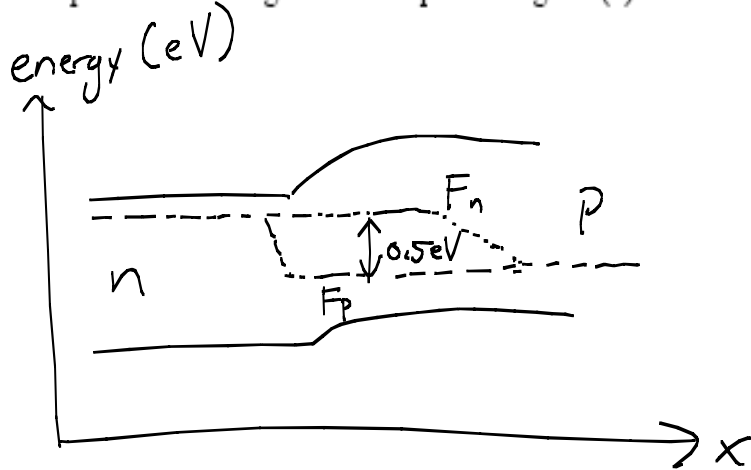
OR
 since $qN_a A X_{po} = qN_d A X_{no}$,

$$\frac{X_{po}}{X_{no}} = \frac{N_d}{N_a} = 10^3$$

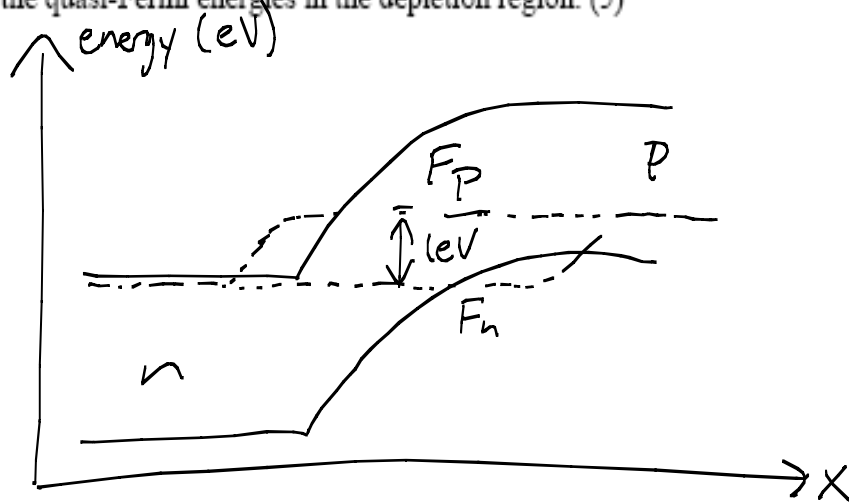
(e) Plot the electric field as a function of distance near the junction (5)



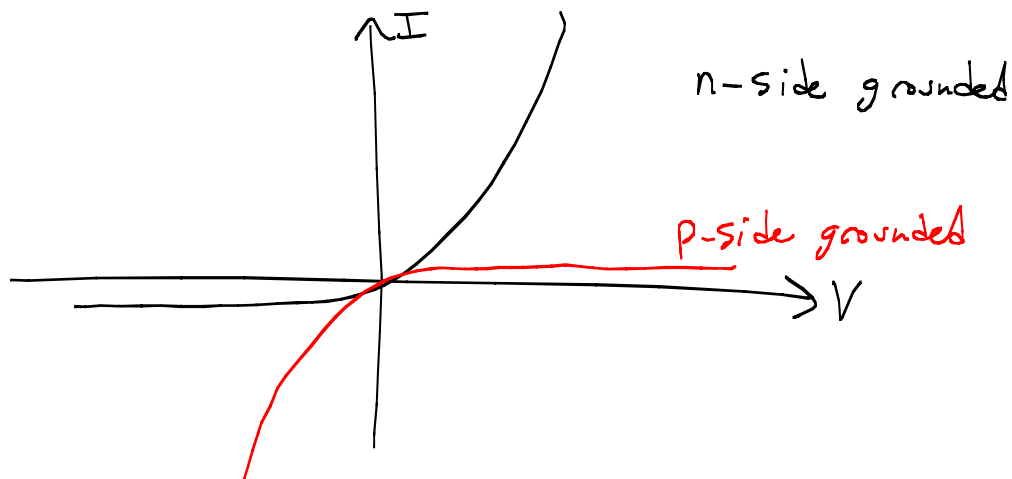
(f) Re-draw the band diagram for this device with 0.5V forward bias. Draw and label the quasi-Fermi energies in the depletion region. (5)



(g) Re-draw the band diagram for this device in 1V reverse bias. Draw and label the quasi-Fermi energies in the depletion region. (5)



(h) Plot the current as a function of voltage across the junction. Identify which side you apply the voltage (n or p)(5)



(i) For this device, which dominates in forward bias, hole current or electron current? Use the ideal diode equation to explain why.(5)

Assuming $D_n \approx D_p$, and $\tau_n \approx \tau_p$,
electron current dominates in forward,
because

$$J = q \left(\overset{\text{electron}}{\sqrt{\frac{D_n}{\tau_n} n_p}} + \overset{\text{hole}}{\sqrt{\frac{D_p}{\tau_p} p_n}} \right) \left(e^{\frac{qV}{kT}} - 1 \right)$$

and $n_p \gg p_n$

- (j) Assuming electron and hole diffusion coefficient and lifetimes are equal, by what ratio is the answer in (i) larger? (5)

$$p_n = \frac{(10^{10})^2}{10^{19}} \quad n_p = \frac{(10^{10})^2}{10^{16}}$$

So

$$\frac{n_p}{p_n} = \frac{10^{19}}{10^{16}} = 10^3$$

2. For pn junctions, circle one answer (5 each)

(a) Dominates in forward bias: (drift, diffusion, tunneling)

(b) Dominates in reverse bias: (drift, diffusion, tunneling)

(c) Dominates in Zener breakdown: (drift, diffusion, tunneling)

3. A "narrow-base" (or "short") p-n diode has n thickness l , shorter than the hole diffusion length L_p . This therefore alters the boundary conditions when solving the diffusion equation for the excess minority hole distribution on the n-side: Although $\delta p(0) = \Delta p$ for both, the excess minority carrier distribution must fall to zero at l , not at infinity as in a "long" diode which has a thick ($\gg L_p$) n-type layer.

(a) Solve the diffusion equation $\frac{\partial p}{\partial t} = D_p \frac{\partial^2 p}{\partial x^2} - \frac{\delta p}{\tau_p}$ for excess minority holes on the n-side in steady state and apply boundary conditions for (i) "long" diode and (ii) "short" diode. (10)

$$0 = D_p \frac{\partial^2 p}{\partial x^2} - \frac{\delta p}{\tau_p}$$

$$\delta p = A e^{\frac{x}{L}} + B e^{-\frac{x}{L}} \quad (L = \sqrt{D_p \tau_p})$$

(i) ^{1:} $\delta p(0) = \Delta p$, ^{2:} $\delta p(\infty) = 0$

BC1: $A + B = \Delta p$

BC2: $A = 0$

$B = \Delta p$

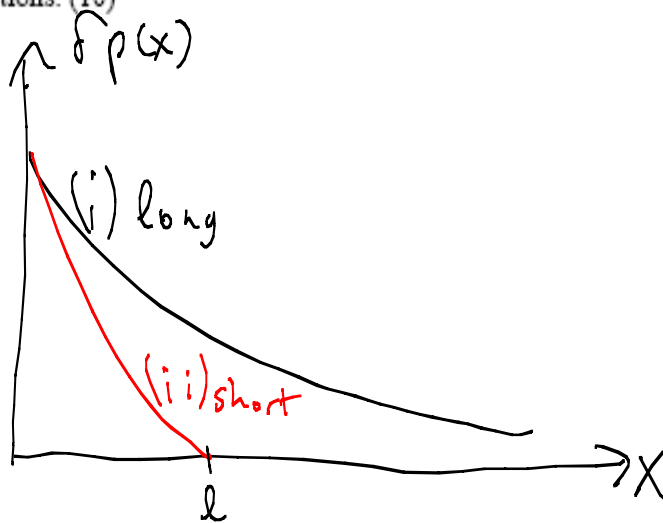
(ii) ^{1:} $\delta p(0) = \Delta p$, ^{2:} $\delta p(l) = 0$

BC1: $A + B = \Delta p$, BC2: $A e^{\frac{l}{L}} + B e^{-\frac{l}{L}} = 0$

$A = -B e^{-2l/L}$

$B = \frac{\Delta p}{1 - e^{-2l/L}} \quad A = \frac{-\Delta p}{e^{2l/L} - 1}$

(b) Use the result of (a) to plot the excess minority holes on the n-side in forward bias as a function of distance from the depletion region for both (i) "long" and (ii) "short" pn junctions. (10)



(4 points each) Which one (long, short, or neither) has

(c) smaller minority charge-storage in forward? Why?

Short. Area under curve smaller

(d) higher breakdown voltage in reverse? Why? long. Depletion region ^{short}

(e) smaller current at fixed forward voltage? Why? Can't grow too much
long. Slope @ $x=0$ smaller

(f) higher depletion capacitance (at zero voltage bias)? Why?

Neither. depletion region size is same.

(g) smaller reverse recovery transient time? Why?

Short. less charge storage.