ECE 6453 HW4 Solution key

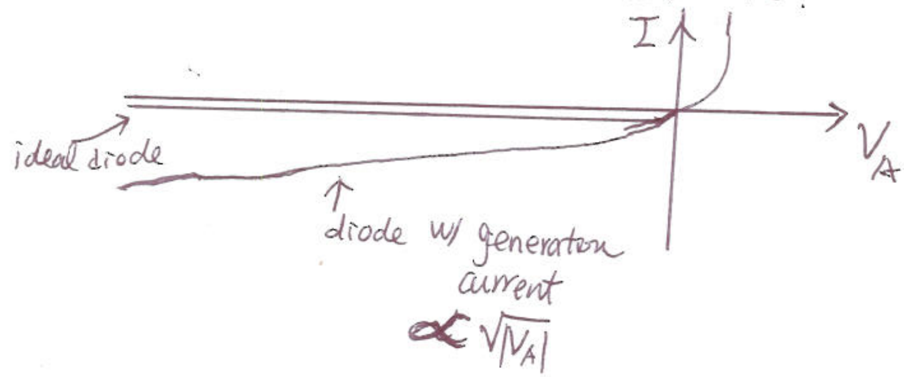
1. a. ① depletion approximation
② abrupt junction
③ uniform doping
④ Zero electric field in QNR
⑤ low-level injection

These assumptions must be imposed to arrive the equation given in ideal PN junction theory

b. From SRH theory the generation rate under reverse bias $\approx +\frac{n_i}{2\tau}$.

$$I_{gen} = qA_D \int_{-X_p}^{X_N} \frac{n_i}{2\tau}\,dx \approx qA_D W \frac{n_i}{2\tau}.$$

where W is the depletion width, A_D is the junction area.
This leads to a modified I-V curve for PN junction diode under reverse bias. i.e.



 GT ECE.

2. a.

$\epsilon_P = 13.9$ (InGaAs LM to InP)

$\epsilon_N = 12.5$ (InP)

n_i (InGaAs) $= 6.3\times10^{11}$ cm^{-3}, N_V(InGaAs) $= 5.477\times10^{18}$ cm^{-3}

n_i (InP) $= 1.3\times10^{7}$ cm^{-3}, N_C(InP) $= 5.716\times10^{17}$ cm^{-3}

Calculate $E_F - E_V|_{(InGaAs)}$ & $E_C - E_F|_{InP}$ using Fermi-Dirac integral.:

$$E_F - E_V|_{InGaAs} \Rightarrow F_{1/2}\left(\frac{E_V - E_F}{kT}\right) = \frac{P}{N_V} = \frac{2e19}{5.477e18} = 3.65$$

$$\Rightarrow E_V - E_F|_{InGaAs} \cong 2.52 \cdot kT/q \approx 0.065\ (eV)$$

$$E_C - E_F|_{InP} \Rightarrow F_{1/2}\left(\frac{E_F - E_C}{kT}\right) = \frac{10^{16}}{5.716e17} = 0.017$$

$$\Rightarrow E_F - E_C \approx -4.0\ kT = -0.103\ (eV)$$

$\Rightarrow \Phi_P = 0.065$ (eV), $\Phi_N = 0.103$ (eV), $\Delta E_C = (1.35 - 0.75)\times\frac{1}{3} = 0.2$ (eV)

$$\phi_{bi} = \frac{E_{gp} + \Delta E_C - \Phi_p - \Phi_n}{q} = 0.75 + 0.2 - 0.065 - 0.103 = 0.782\ (V)$$

$$\frac{\epsilon_P N_A}{\epsilon_N N_d} = \frac{13.9\times2\times10^{19}}{12.5\times10^{16}} = 2.224\times10^{3} \Rightarrow \phi_{po} = 0.782\times\frac{1}{2225} = 3.51\times10^{-4}\ (V)$$

$$\phi_{No} = +0.7816\ (V)$$

(In fact, from your physical intuition, the DR will fall "entirely" on the lower-doping side. This calculation just to show you that you may not need this extra step to ~~reach~~ get your solution.)

so.

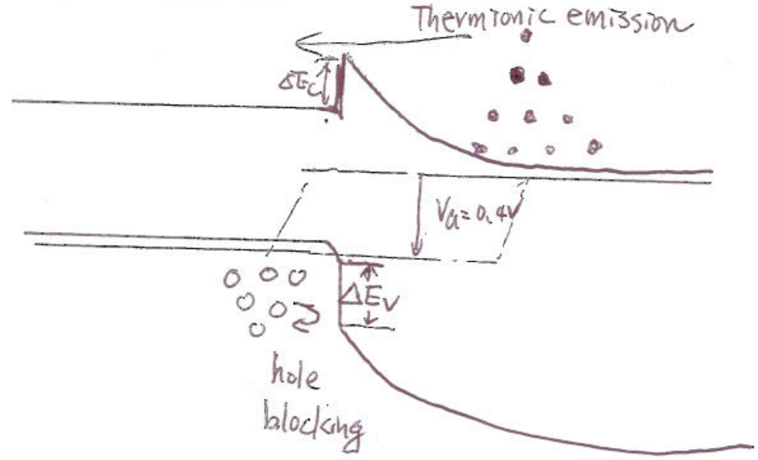
$$x_{po} = \sqrt{\frac{2\epsilon_P}{qN_A}\left(\phi_{bi}\cdot\frac{1}{1+\epsilon_P N_A/\epsilon_N N_D}\right)} \approx 0$$

$$x_{no} \cong \sqrt{\frac{2\epsilon_N}{qN_D}\phi_{bi}} = 0.328\ (\mu m)$$

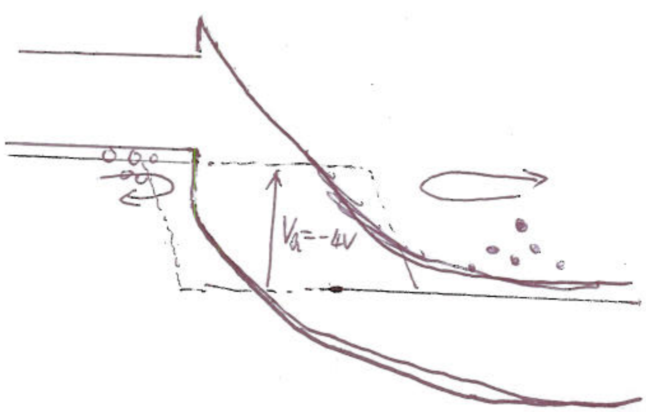
b. You do it.

c. See. P.81 of textbook, Fig. 2-5. The only difference is the Fermi level of the p-InGaAs in QNR.

d. $\underline{V_n \cong \phi_{bi} - V_A = 0.382\ (V)}$



e.



(Note: this graph is not drawn to scale ...)

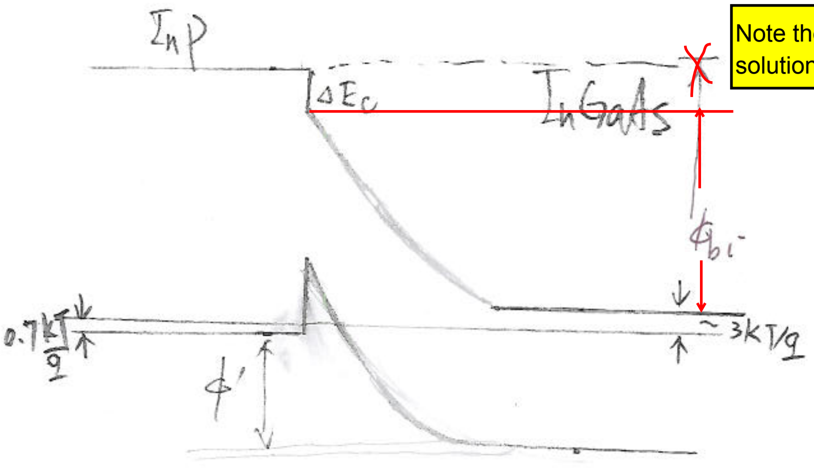
Both e's & h's are blocked by the rev. bias.
Since p-side is heavily doped, the dep. width on the p-side is still insignificant even under large reverse bias.

3. a. For InP, $N_C = 1.1 \times 10^{14} \times T^{3/2}$ (cm^{-3}), $N_V = 2.2 \times 10^{15} \cdot T^{3/2}$ (cm^{-3})

For $In_xGa_{1-x}As|_{x=0.53}$; $N_C = 4.01 \times 10^{13} \times T^{3/2}$, $N_V = 1.054 \times T^{3/2}$ (cm^{-3})

do the same calculation similar to those shown in prob. 2.

.... The Band diagram will look like: (Next page)



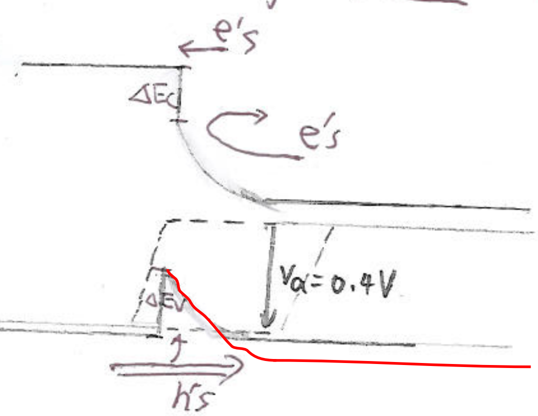
Note the error in the original solution for the definition of phi_bi..

$\phi_{bi} \cong 0.75 + \Delta E_c - 3.7\frac{kT}{q}$ ~~$\Delta E_c - 2.3kT/q$~~

$= 1.05\ (eV)$

$\phi' \cong 0.65$ ~~0.409~~ V

b. With an applied voltage of 0.4 V, the Band diagram becomes



Note that the holes still see a potential barrier of ~ 0.25 eV under 0.4V forward bias..

One may expect the following

<i> electron blocked by the ΔEc, only high energy electron can be injected.

<ii> hole injection from InP (p-type) to InGaAs (n-type) very little !!

<iii> hole being trapped by the potential well.

From spontaneous radiation theory, one will expect significant amount of light-emitting-related recombination current from this interface, provided that the trap-assisted recombination is much suppressed. ⇒ This structure can be good for light emitting diode!