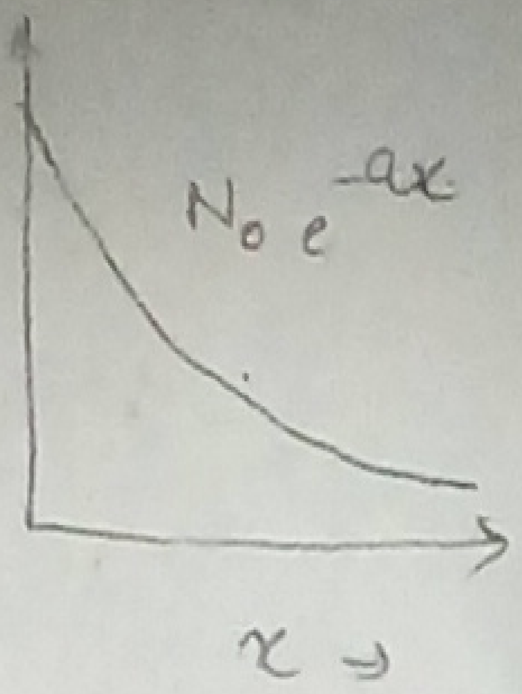
Solution

a) $N = N_0 e^{-ax}$ $\quad N_0 = 1.5\times10^{16}/cm^3$



Acceptor impurity

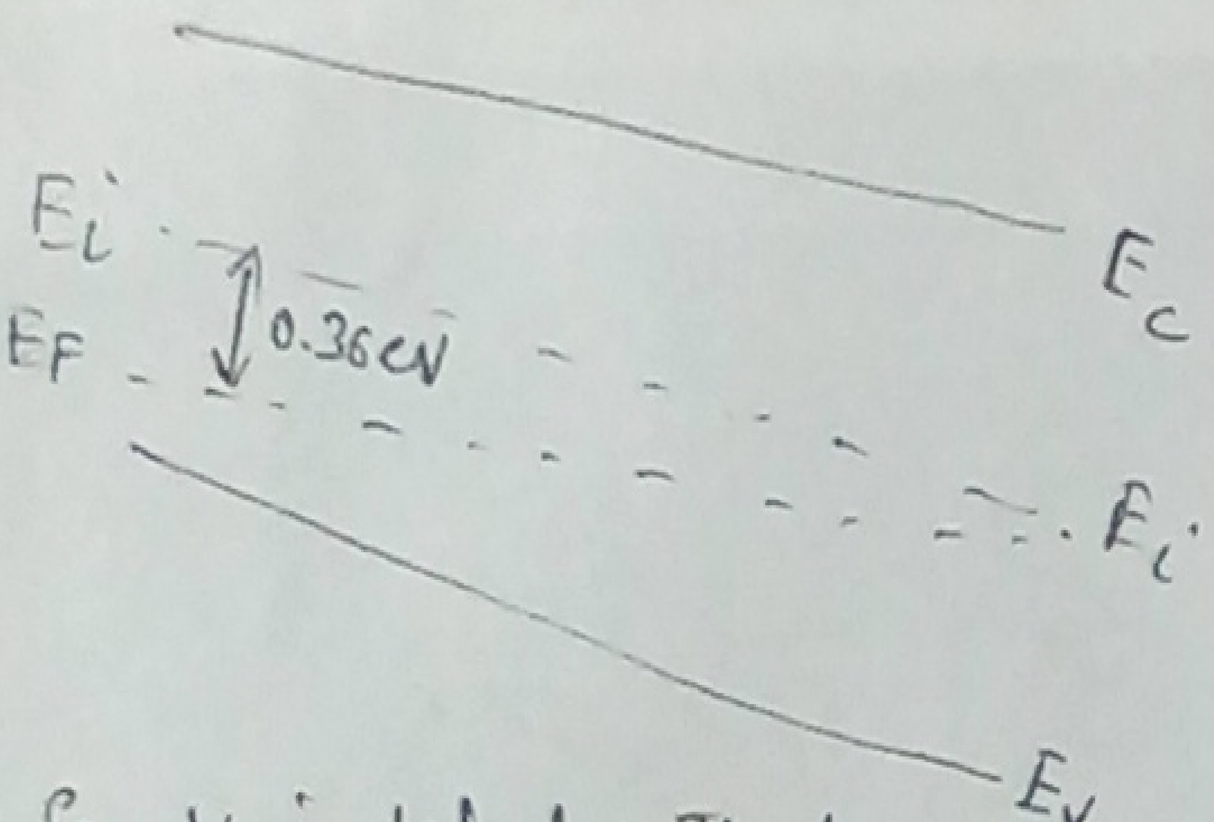
$p_0 = n_i e^{(E_i-E_F)/kT}$

$\Rightarrow E_i - E_F = kT\ln\left(\frac{p_0}{n_i}\right)$

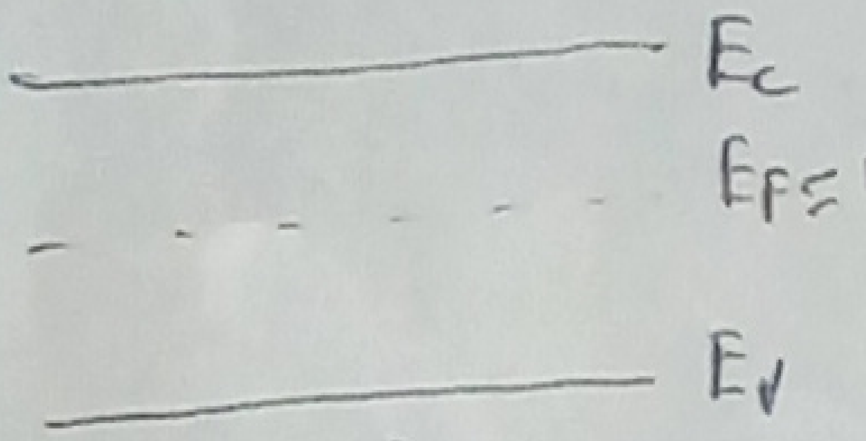
$= 0.026\ln\left[\frac{1.5\times10^{16}}{1.5\times10^{10}}\right]$

$= 0.026\ln[10^6] = 0.36\,eV$

So, p type sample → E_F close to E_v



(i) Sample is doped with donor impurity with same profile, so opposite charge carriers will cause compensation and $E_F \approx E_i$



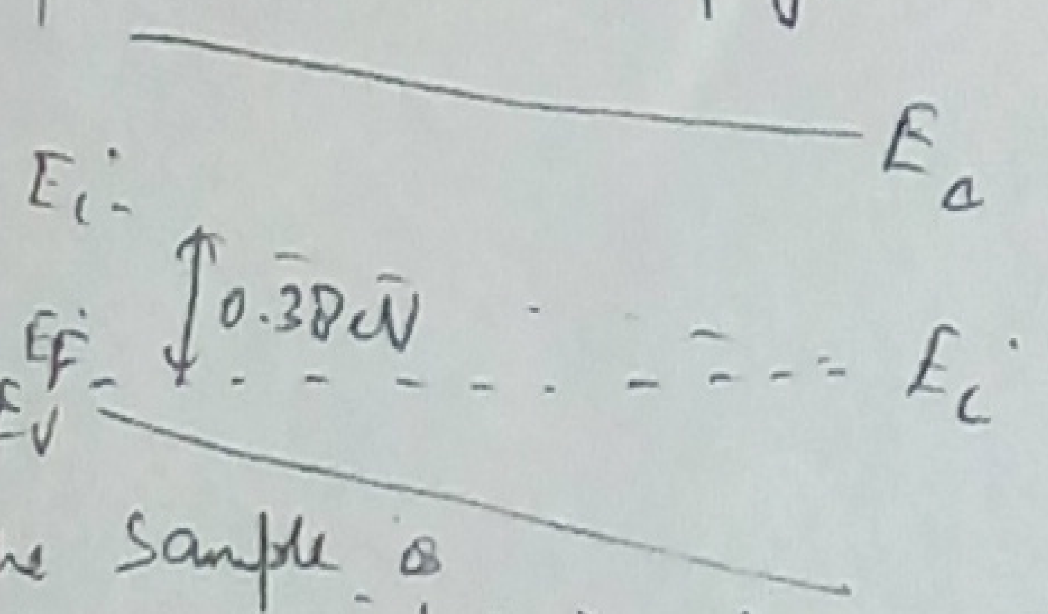
ii) Sample A is doped with acceptor atoms having the same profile

So new $p_0 = p_0' = 2\times1.5\times10^{16}$

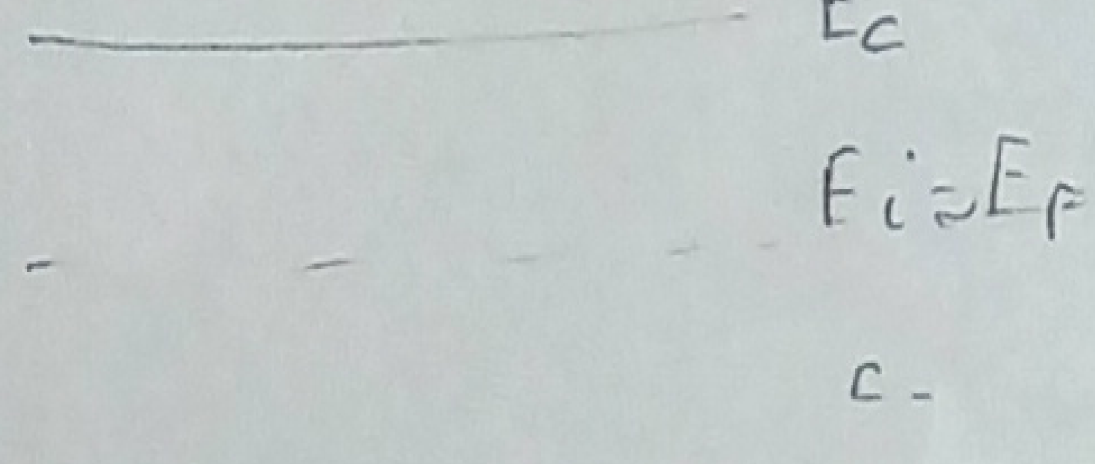
$\Rightarrow E_i - E_F = kT\ln\left[\frac{p_0'}{n_i}\right] = 0.026\ln\left[\frac{2\times1.5\times10^{16}}{1.5\times10^{10}}\right]$

$= 0.377 = 0.38\,eV$

So, sample becomes more p type



iii) As the sample is heated, more intrinsic charge carriers are generated, causing E_i to merge with E_F.



Q1 (b) $n = N_c \exp^{-(E_c-E_i)/kT}$ — (1)

$p = N_v \exp^{-(E_i-E_v)/kT}$ — (2)

So $-(E_c-E_i) = kT\ln\left[\frac{n}{N_c}\right]$ — (3)

& $-(E_i-E_v) = kT\ln\left[\frac{p}{N_v}\right]$ — (4)

Subtracting (4) from (3)

$-E_c+E_i+E_i-E_v = kT\ln\left[\frac{n}{N_c}\right] - kT\ln\left[\frac{p}{N_v}\right]$

$\Rightarrow 2E_i = E_c+E_v+kT\ln\left[\frac{n/N_c}{p/N_v}\right]$

As, sample is intrinsic $n \approx p$

$\Rightarrow 2E_i = E_c+E_v+kT\ln\left[\frac{N_v}{N_c}\right]$

or $E_i = \frac{E_c+E_v}{2} + \frac{kT}{2}\ln\left[\frac{N_v}{N_c}\right]$ — (5)

We know

$\frac{N_v}{N_c} = \left(\frac{m_n^*}{m_p^*}\right)^{-3/2}$ — (6)

Using (6) in (5), and adding & subtracting $\frac{E_v}{2}$

$E_i = \underbrace{\frac{E_c}{2} - \frac{E_v}{2}}_{E_g/2} + \frac{E_v}{2} + \frac{E_v}{2} + \frac{kT}{2}\ln\left[\frac{m_n^*}{m_p^*}\right]^{-3/2}$

Rearranging

$E_i = E_v + \frac{E_c-E_v}{2} - \frac{3}{4}kT\left[\frac{m_n^*}{m_p^*}\right]$

$\boxed{E_i = E_v + \frac{E_g}{2} - \frac{3}{4}kT\left[\frac{m_n^*}{m_p^*}\right]}$ — (7)

For $m_n^* > m_p^*$ dashed term +ive, so Fermi level will be lower than middle of Band gap (i.e towards VB)

For $m_n^* < m_p^*$ → dashed term will be negative, so E_i ↑ → So Fermi Level will be higher than middle of Band gap [i.e toward CB]

(Q2)

(a) Doping increases charge carriers. So conductivity increases and resistivity decreases.

(b) Though the reverse saturation current remains nearly constant, but small increase is there due to thermal generation incorporating larger depletion width.

(c) Reverse saturation current in short diode model increases due to shorter quasi-neutral region (lesser than diffusion length)

(d) The range of proper operation increases because for higher doping concentration larger temperature is needed to make n_i equal to larger N_D.

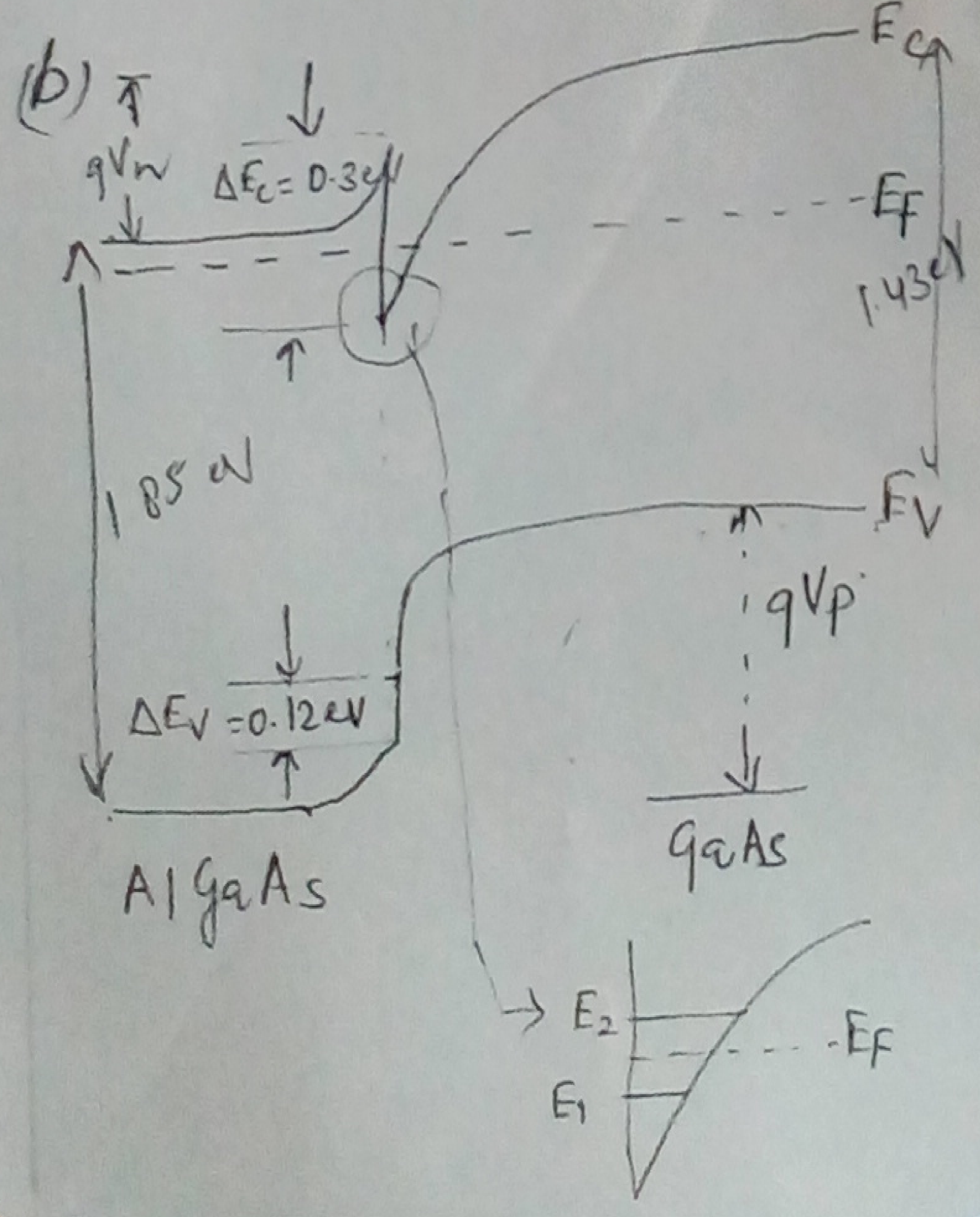
(e) $i = \boxed{I_R = -I_F = \frac{-E}{R}}$ as stored charge can't change instanteously.

$\Delta E_g = 1.85 - 1.43\,eV$
$= 0.42\,eV$

$\Delta E_c = 0.3\,eV$ (Given)

So $\Delta E_V = \Delta E_g - \Delta E_c$
$= 0.43 - 0.3$
$= 0.12\,eV$

(b)



Q3 (a):

Region 1: p type ($N_A = 6.5\times10^{16}\ cm^{-3}$)

$$\frac{\Delta E}{\Delta x} = \frac{-qN_A}{\epsilon_s}$$

$$= \frac{-1.6\times10^{-19}\times6.5\times10^{16}}{11.8\times8.854\times10^{-14}}$$

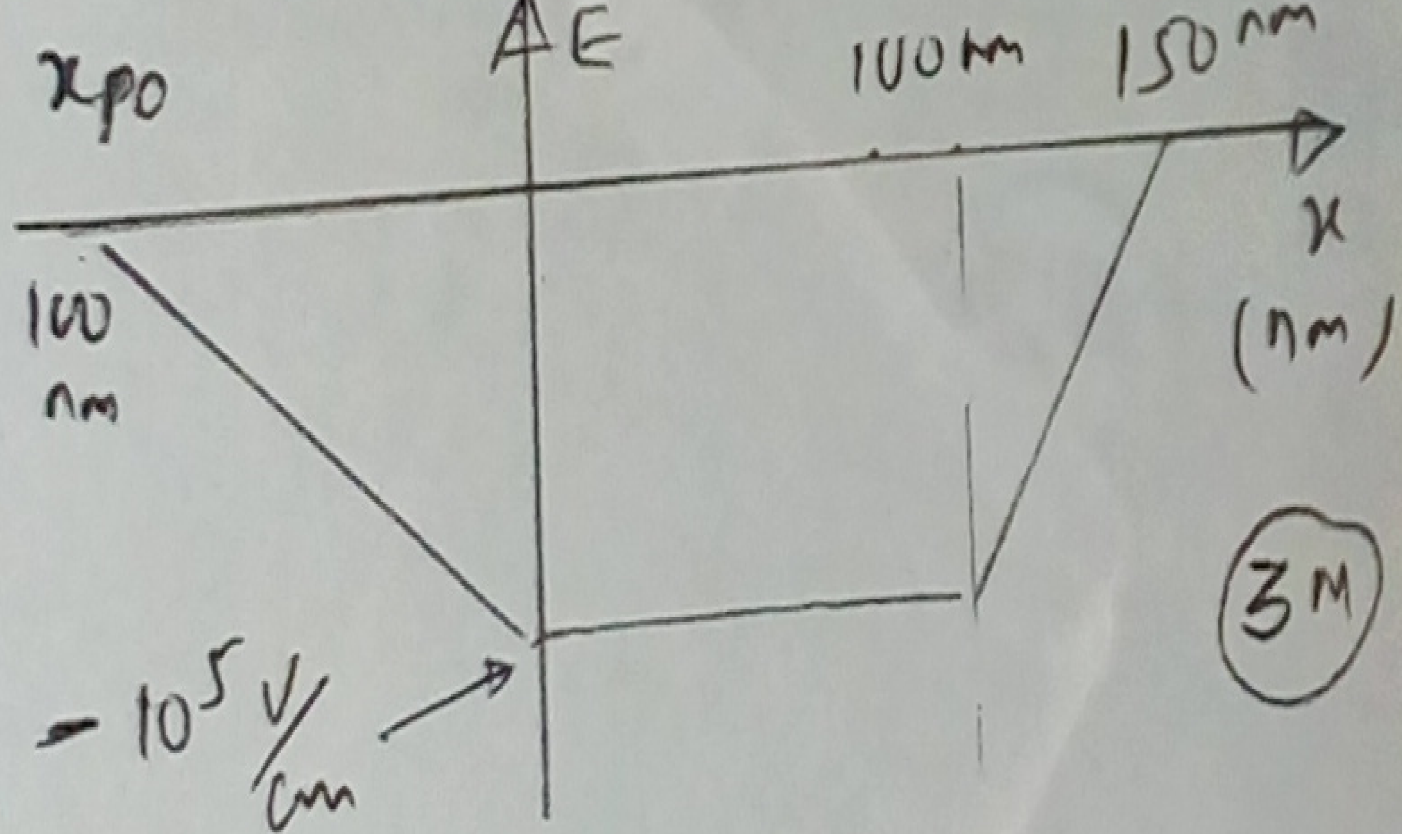
$$\Delta E \simeq 10^5\ V/cm \quad \{\Delta x = 100\times10^{-7}\ cm$$

Region 2: Intrinsic
Electric field is constant & continuous for this region. $\frac{dE}{dx} = 0$

Region 3: Since n-type depletion width is 1/2 times of p-type depletion width ($\Rightarrow N_D = 1.3\times10^{17}\ cm^{-3}$)

$$\frac{\Delta E}{\Delta x} = \frac{1.6\times10^{-19}\times1.3\times10^{17}}{11.8\times8.854\times10^{-14}}$$

$$\Delta E \cong 10^5\ V/cm \quad \{\Delta x = 50\times10^{-7}\ cm$$



(3M)

(ii) Built in potential,

$$V_0 = \int E\,dx$$

$$= 10^5\left[100\times10^{-7} + \frac{150}{2}\times10^{-7}\right]$$ (4M)

$$= 1.75\ V$$

(iii) $$C_j = \frac{\epsilon_s}{W} = \frac{11.8\times8.854\times10^{-14}}{250\times10^{-7}}$$

$$= 4.18\times10^{-8}\ F/cm^2$$

(3M)

Q3 (b):

$$I_p = \frac{Aq D_p p_{no}}{L_p}\left[\exp\frac{qV_0}{kT} - 1\right]$$

$$I_n = \frac{Aq D_n n_{po}}{L_n}\left[e^{\frac{qV_0}{kT}} - 1\right]$$

I_p 90% ∴ I_n is 10%

$$\frac{I_p}{I_n} = \frac{D_p p_{no} L_n}{D_n n_{po} L_p}$$

$$9.0 = \frac{9\times N_A\times L_n}{49\times N_D\times L_p} \quad \{N_A = 10^{17}\ cm^{-3}$$

$$L_n = \sqrt{D_n \tau_n} = \sqrt{49\times10^{-8}}$$
$$= 7\times10^{-4} = 7\ \mu m$$

$$L_p = \sqrt{D_p \tau_p} = \sqrt{9\times10^{-8}}$$
$$= 3\ \mu m$$

$$\frac{N_A}{N_D} = 21 \quad (\Rightarrow N_D = 4.76\times10^{15})$$

(i) for long diode model the length ie critical physical thickness n side > L_p
critical physical thickness p-side > L_n (4M)

(ii) $$I_s = qA\left[\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right]$$

$$p_n = \frac{n_i^2}{N_D} = \frac{2.25\times10^{20}}{4.76\times10^{15}} = 4.72\times10^4\ cm^{-3}$$

$$n_p = \frac{n_i^2}{N_A} = \frac{2.25\times10^{20}}{10^{17}} = 2.25\times10^3\ cm^{-3}$$

$$I_s = 1.6\times10^{-23}\left[\frac{9\times4.72\times10^4}{3\times10^{-4}} + \frac{49\times2.25\times10^3}{7\times10^{-4}}\right]$$

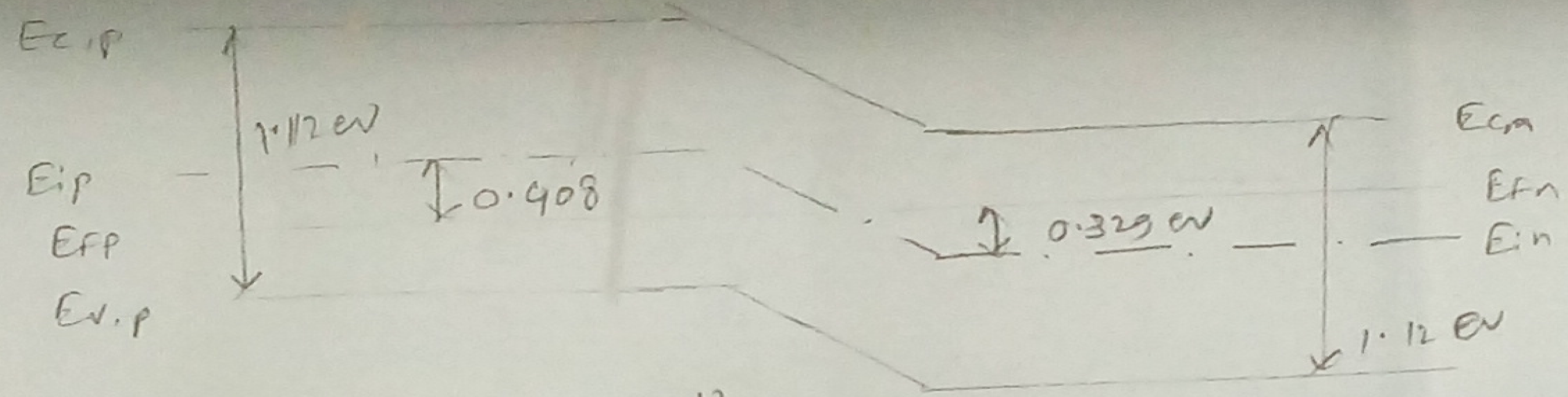
$$= 1.6\times10^{-23}\left[1.416\times10^9 + 0.157\times10^9\right]$$

$$= 251.7\times10^{-12} = 251.7\ pA$$ (4M)

(iii) $$I = |I_s|\left(e^{qV/kT} - 1\right)$$
$$= |I_s|\left(e^{23.07} - 1\right)$$
$$= 2.64\ Amp$$ (3M)

PTO

(iv)



$E_{ip} - E_{FP} = 0.026 \ln\left(\frac{10^{17}}{1.5\times10^{10}}\right)$

$= 0.408 \text{ eV}$

$E_{Fn} - E_{ip} = 0.026\left(\frac{4.76\times10^{15}}{1.5\times10^{10}}\right)$

$= 0.329 \text{ eV}$

4

4

Q4 (a):

$R_H = 31.25 \ \text{cm}^3/C$

$V_{AB} = W \cdot R_H \cdot J_x B_z$

(i) $J_x = \frac{V_{AB}}{W \cdot R_H B_z} = \frac{200\times10^{-6}}{0.1\times31.25\times10^{-4}}$

$= 0.64 \ \text{A/cm}$ (3M)

$R_H = \frac{1}{qP_0} \Rightarrow P_0 = 2\times10^{17} \ \text{cm}^{-3}$

$V_0 = \frac{KT}{q}\ln\left(\frac{N_A N_D}{n_i^2}\right)$

$0.7 = 0.026 \ln\left(\frac{N_A N_D}{n_i^2}\right)$

$N_D = \frac{4.926\times10^{11}\times2.25\times10^{20}}{2\times10^{17}}$

$= 5.54\times10^{14}$ donors. (2)

Dopant Type = N-type.

Dopant required $= 2\times10^{17} + 5.54\times10^{14}$

$\simeq 2.00554\times10^{17} \ \text{cm}^{-3}$ donors.

(ii)

$I_s = qA\left[\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right](e^{qV/KT} - 1)$

$\simeq qA\frac{D_p}{L_p}p_n(e^{qV/KT} - 1)$

$\simeq 1.6\times10^{-19}\times10^{-4}\times\frac{9}{3\times10^{-4}}\times4.06\times10^{5}(-1)$

$\equiv 19.48\times10^{-12}$ Amp

$p_n = \frac{n_i^2}{N_D} = \frac{2.25\times10^{20}}{5.54\times10^{14}} = 4.06\times10^{5} \ \text{cm}^{-3}$

$n_p = \frac{n_i^2}{N_A} = \frac{2.25\times10^{20}}{2\times10^{17}} = 1.125\times10^{3} \ \text{cm}^{-3}$

$p_n \gg n_p \quad \therefore \frac{D_p p_n}{L_p} \gg \frac{D_n n_p}{L_n}$

$L_p = \sqrt{D_p \tau_p} = \sqrt{9\times10^{-8}}$

$= 3\times10^{-4} \ \text{cm} = 3 \ \mu\text{m}$

4

(ii) $I = |I_s|(e^{qV/KT} - 1)$

$= 19.48\times10^{-12}(e^{0.5/0.026} - 1)$

$= 19.48\times10^{-12}\times(2.24\times10^{8})$

$= 4.37\times10^{-3}$ Amp (5M)

(iii) $I = |I_s|(e^{-2/0.026} - 1)$

$= |I_s| \ (-1)$

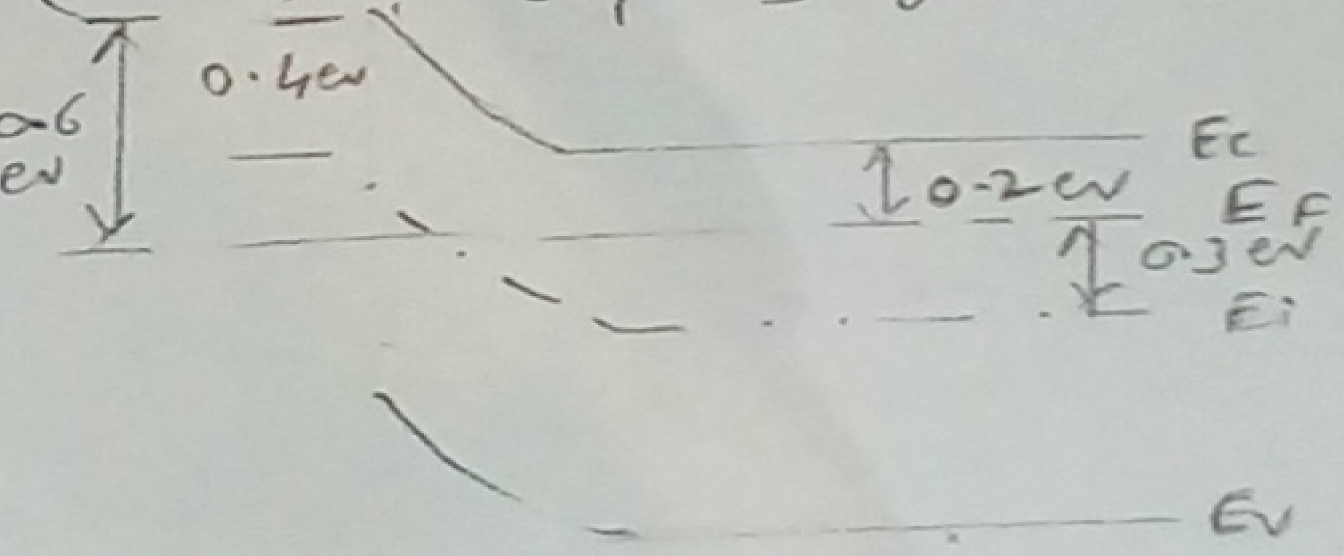
$= -19.48\times10^{-12}$ Amp. (3M)

Q 4(b):

(i) $q\phi_m = 4.4$ eV, $q\phi_s = 4$ eV

$q\phi_s = q\chi + (E_c - E_F)$

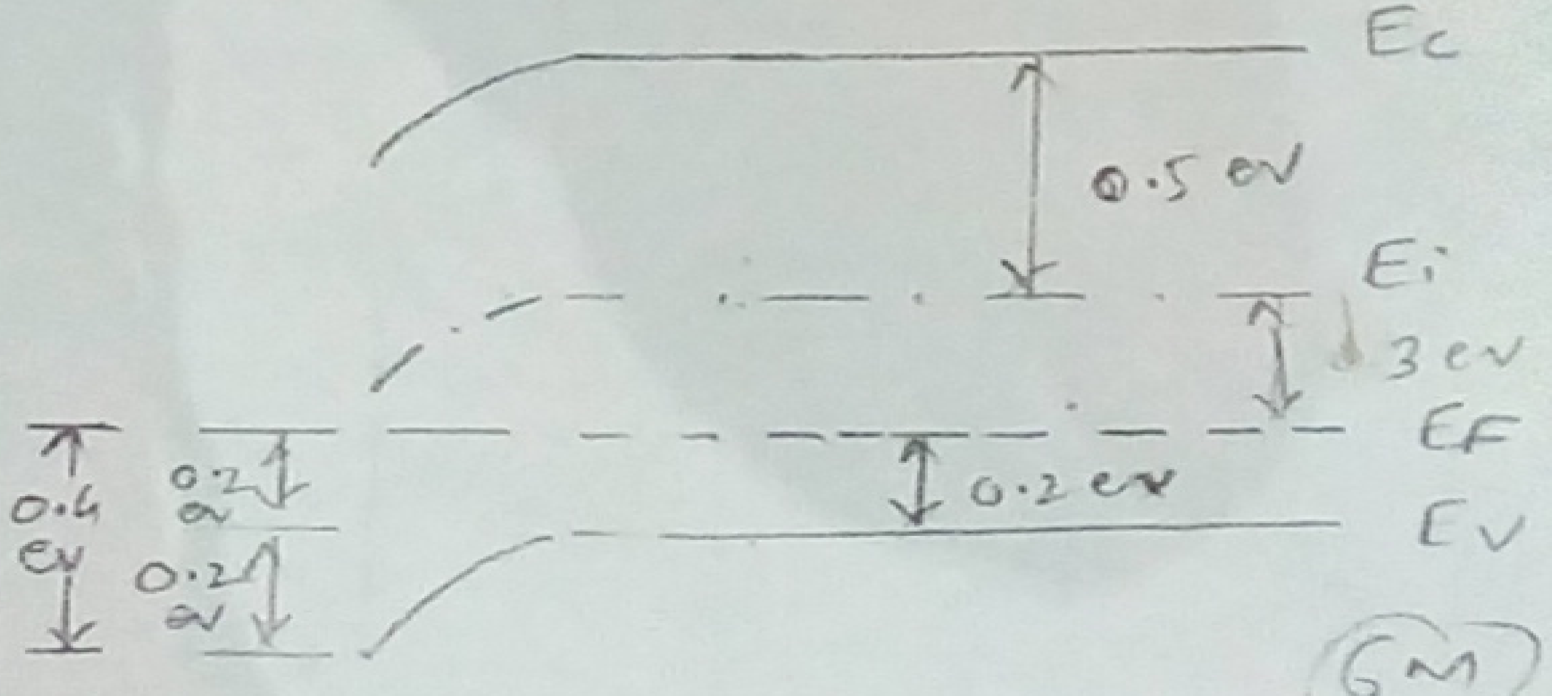
$(E_c - E_F) = 4 - 3.8 = 0.2$ eV



(6M)

(ii) $q\phi_m = 4.4$ eV

$q\phi_s = 3.8 + (0.5 + 0.3) = 4.6$ eV



(6M)

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