HW3

I Semiconductor fundamentals

1

* $N_D = 2.3 \times 10^{17}\ cm^{-3} \gg n_i$

$\Rightarrow \boxed{n \simeq N_D = 2.3 \times 10^{17}\ cm^{-3}}$

$\boxed{p = \frac{n_i^2}{n} = \left(\frac{2 \times 3.10^{17}}{(1.8 \times 10^6)^2}\right)^{-1} = 1.4 \times 10^{-5}\ cm^{-3}}$

* $E_C - E_F$?

we suppose that the SC is non-degenerate $[E_g = 1.42\ eV]$

$E_C - E_F = \underbrace{E_C - E_i}_{\frac{E_g}{2}} + E_i - E_F = \frac{E_g}{2} - \frac{1}{q\beta} \ln\left(\frac{n}{n_i}\right) \simeq +0.05e$

However the condition $E_C - E_F > 3k_BT$ is not satisfied.
E_F is very close to E_C.

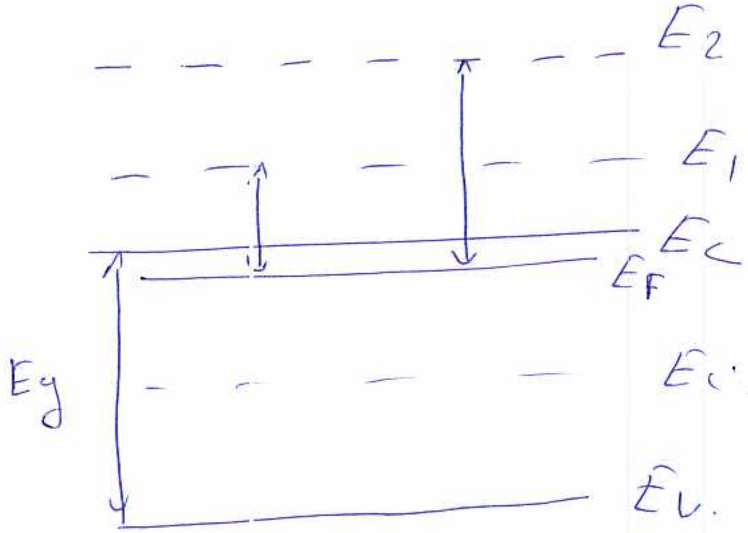
Let us then use the other formula $E_C - E_F = E_V - E_F + \underbrace{E_C - E_V}_{E_g}$.

$E_V - E_F = \frac{1}{\beta} \ln\left(\frac{p}{N_V}\right)$ $\quad [N_V = 7 \times 10^{18}\ cm^{-3}]$

$= -1.41$

so $\boxed{E_C - E_F = -1.41 + 1.42 = 0.01\ eV}$

*



Occupancy $f_{FD} = \dfrac{1}{1+e^{\beta(E-E_F)}}$

one needs to know $E_1 - E_F$
$E_2 - E_F$

$E_1 - E_F = 0.0793$ eV $\quad$ $\underline{f_{FD} \simeq 4.46\%}$

$E_2 - E_F = 0.287$ eV. $\quad$ $\underline{f_{FD} \simeq 1.5 \times 10^{-3}\%}$

2 For the infinite quantum well, we get the following energy levels: $\boxed{E_n = \dfrac{\hbar^2 n^2 \pi^2}{2 m^* L^2}}$ we set $\boxed{\alpha = \dfrac{\hbar^2 \pi^2}{2 m^* L^2} \cdot \dfrac{1}{q}}$ with

$\Longrightarrow$
$E_n = \alpha n^2$

(3)

* conduction band $m^* = m^*_n = 0.067\, m_e$ for GaAs.

$\alpha = 6.93 \times 10^{-2}\, eV$

$n=1$ $E_1 = 6.93 \times 10^{-2}\, eV$
$n=2$ $E_2 = 0.277\, eV$
$n=3$ $E_3 = 0.624\, eV$

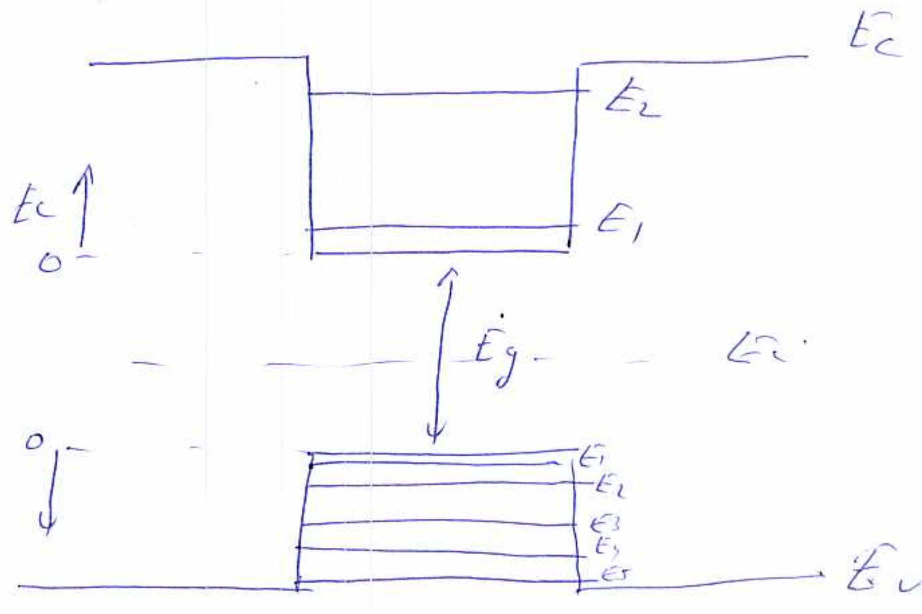
only E_1, E_2 are allowed inside the quantum well since $E_3 > 0.3\, eV$

* valence band $m = m^*_p = 0.48\, m_e$ for GaAs.
[energy levels for holes].

$\alpha = 9.67 \times 10^{-3}\, eV$.

$E_1 = 9.67 \times 10^{-3}\, eV$
$E_2 = 3.86 \times 10^{-2}\, eV$
$E_3 = 8.7 \times 10^{-2}\, eV$
$E_4 = 0.155\, eV$
$E_5 = 0.242\, eV$
$E_6 = 0.348\, eV$

only E_1 to E_5 are allowed since $E_6 > 0.3\, eV$.



II Theory of Electrical conduction

1

$$\tau_c = \frac{\mu_n m_e^*}{q} = 0.34\,ps$$

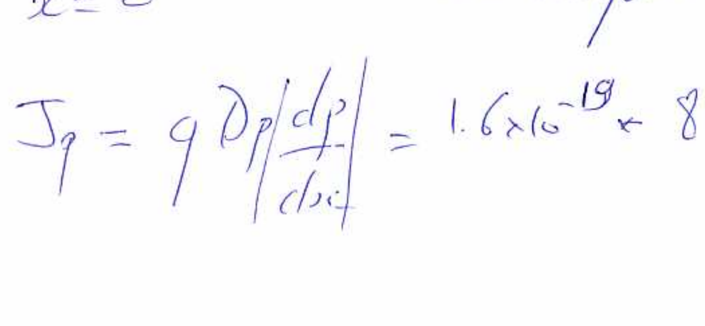
mean free path $\quad l = v \times \tau_c = 34\,nm.$

2

$$\boxed{\rho = \frac{1}{q p \mu_p} = 0.197\ \Omega/cm.}$$

$p \simeq N_A.$

3



$$D_p = \frac{k_B T}{q}\mu_p = 8.2\ cm^2/s$$

$$J_p = q D_p \left|\frac{dp}{dx}\right| = 1.6\times10^{-19} \times 8.2 \times \frac{9.9\times10^{13}}{1.5\times10^{-4}} \simeq 0.866\ A/cm^2$$

III P-N junctions

(1)

* $V_0 = \frac{k_B T}{q} \ln\left(\frac{N_a N_d}{n_i^2}\right) = \underline{0.508V}$

* $W = \sqrt{\frac{2\epsilon (N_A+N_D) V_0}{q N_a N_d}} = 8.62 \times 10^{-2}\, cm \equiv \underline{862\, \mu m}$.

(2)

* $J_{tot} = J_s \left[\exp(q\beta V_A) - 1\right]$.

$V_A = 0.5V \longrightarrow \quad J_{tot} = \underline{2.24 \times 10^{-4}\, A/m^2}$

$V_A = 1V \longrightarrow \quad J_{tot} = \underline{5.05 \times 10^{4}\, A/m^2}$

* $n_p(-\ell_p) = n_{po}\left[\exp(q\beta V_A) - 1\right]$ excess of electron

$\underline{n_{po}?}$ for the P side $N_A \gg n_i$ so $\underline{p_{po} = 10^{12}\, cm^{-3}}$.

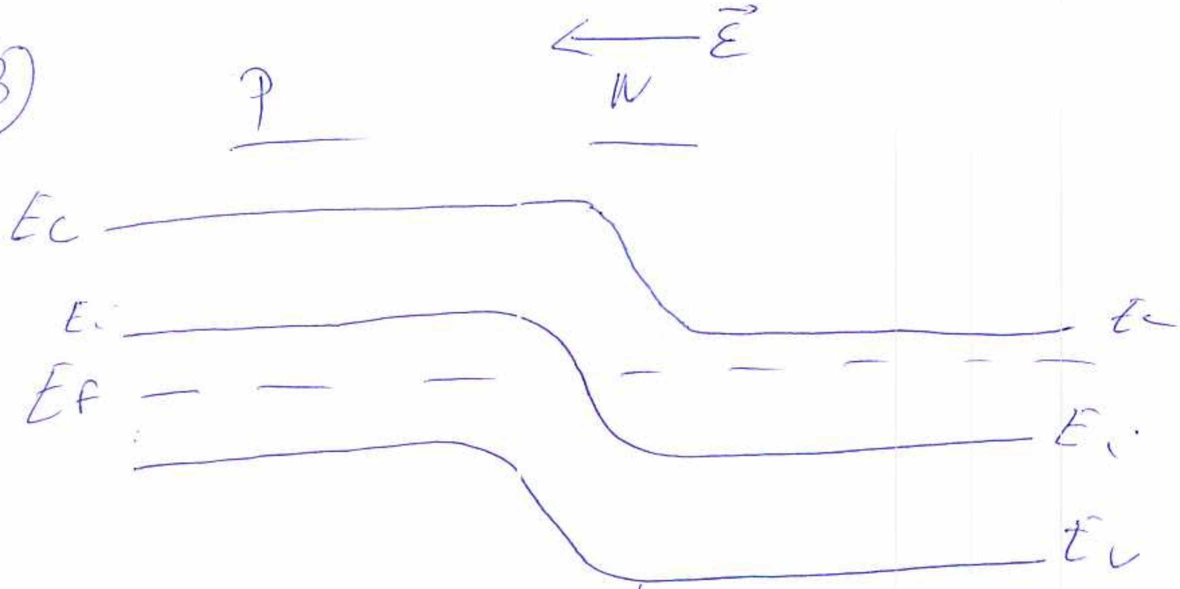
we have $p_{po}\, n_{po} = n_i^2 \Rightarrow n_{po} = \frac{n_i^2}{p_{po}} = 3.24\, cm^{-3}$

$\Longrightarrow$

$V_A = 0.5V \longrightarrow n'_{p} = \underline{7.3 \times 10^{8}\, cm^{-3}}$

$V_A = 1V \longrightarrow n'_p = \underline{1.64 \times 10^{17}\, cm^{-3}}$

(3)



electrons

$\longrightarrow$ $\vec{J}$ diffusion

$\longleftarrow$ $\vec{J}$ drift

holes

$\longrightarrow$ $\vec{J}$ diffusion

$\longleftarrow$ $\vec{J}$ drift

(4) $N_a l_p = N_d l_n$ because of neutrality (depletion approx.)

so $l_n = 0.103$ mm; $l_n \ll l_p$ since N side is heavily doped.

the PN junction is strongly asymmetrical.

[p103 textbook]