MSE/EE 5201 Phys of Semiconductor Devices HW# 5 ANSWERS

3.11. (a) $\sigma = q(n\mu_n + p\mu_p) = q(n\mu_n + \frac{n_i^2}{n}\mu_p) = \sigma(n)$ ...... (1)

$\frac{d\sigma}{dn} = q(\mu_n - \frac{n_i^2}{n^2}\mu_p) = 0 \Rightarrow \boxed{n^* = n_i \left(\frac{\mu_p}{\mu_n}\right)^{1/2}}$ ...... (2)

i.e. $\sigma_{min} = \sigma\big|_{n=n^*}$ ...... (3)

(b) $\sigma_{min} = q(n^*\mu_n + \frac{n_i^2}{n^*}\mu_p)$

$= q\left(n_i \cdot \left(\frac{\mu_p}{\mu_n}\right)^{1/2}\mu_n + \frac{n_i^2}{n_i\left(\frac{\mu_p}{\mu_n}\right)^{1/2}}\mu_p\right)$

$\boxed{\sigma_{min} = 2q n_i \sqrt{\mu_p \mu_n}}$ ...... (4)

(c) $T = 300°K$ $n_i = 1.5 \times 10^{10}\ cm^{-3}$ for Si

$\mu_n = 1350\ cm^2 \cdot V^{-1} s^{-1}$ $\mu_p = 480\ cm^2 \cdot V^{-1} \cdot s^{-1}$

$\sigma_{min} = 2 \times 1.6 \times 10^{-19} C \times 1.5 \times 10^{10} cm^{-3} \times \sqrt{1350 \times 480}\ cm^2 \cdot V^{-1} s^{-1}$

$\boxed{\sigma_{min} = 3.86 \times 10^{-6}\ (\Omega \cdot cm)^{-1}}$ ...... (5)

while $\sigma_{intrinsic} = q n_i (\mu_n + \mu_p)$

$= 1.6 \times 10^{-19} \times 1.5 \times 10^{10} \times (1350 + 480)$

$\boxed{\sigma_{intrinsic} = 4.39 \times 10^{-6}\ (\Omega \cdot cm)^{-1}}$ ...... (6)

$\boxed{\sigma_{min} < \sigma_{intrinsic}}$ ...... (7)

MSE/EE 5201 Phys of Semiconductor Devices HW# 5 ANSWERS

3.12. (a) $N_d = 10^{17}\ cm^{-3}$ $\mu_n \cong 700\ cm^2 \cdot V^{-1} s^{-1}$

$$I = JA = \sigma \cdot \frac{V}{L} A = q(n\mu_n + p\mu_p)\frac{V}{L}\cdot A \quad \cdots\cdots (1)$$

$$n \approx N_d = 10^{17} \gg p \quad \cdots\cdots (2)$$

so, $$I = q N_d \mu_n \cdot \frac{V}{L} A \quad \cdots\cdots (3)$$

~~Ohm's Law~~

$$I = 1.6\times10^{-19} C \times 10^{17} cm^{-3} \times 700\ cm^2 \cdot V^{-1} s^{-1} \times \frac{10\ V}{0.1\ cm} \times 100\ \mu m^2 \times 10^{-8}\ cm^2/\mu m^2$$

$$\boxed{I = 1.12\times10^{-3} A = 1.12\ mA} \quad \cdots\cdots (4)$$

(b) $L = 1\mu m = 10^{-4}\ cm$

$$\boxed{I = 1.12\times10^{-3} \times \frac{0.1}{10^{-4}} = 1.12\ A} \quad \cdots\cdots (5)$$

(c) $L = 1\ \mu m = 10^{-4}\ cm$

$$t = \frac{L}{v} = \frac{L}{\mu_n \cdot \frac{V}{L}} = \frac{L^2}{\mu_n \cdot V}$$

$$\boxed{t = \frac{(10^{-4})^2\ cm^2}{1350\ cm^2 \cdot V^{-1} \cdot s^{-1} \times 10\ V} = 7.4\times10^{-10}\ s} \quad \cdots (6)$$

At $\mathcal{E} = 10^5\ V/cm$ $v = v_{saturation} = 10^7\ cm/s$

$$\boxed{t = \frac{10^{-4}\ cm}{10^7\ cm/s} = 10^{-11}\ s} \quad \cdots\cdots (7)$$

4.7. $n = n_0 + \delta n \cong N_d + \tau_n \cdot G = 10^{15} + 10^{-6} \times 10^{21} = 2\times 10^{15}\ cm^{-3}$

$p = p_0 + \delta p \cong \tau_p G = 10^{-6} \times 10^{21} = 10^{15}\ cm^{-3}$

Since $p_0 = \frac{n_i^2}{n_0} = \frac{(1.5\times 10^{10})^2}{10^{15}} = 2.25 \times 10^5 \ll 10^{15}$

$n = n_i \exp[(E_{Fn} - E_i)/kT] \Rightarrow \boxed{E_{Fn} - E_i = kT \ln\left(\frac{n}{n_i}\right)}$

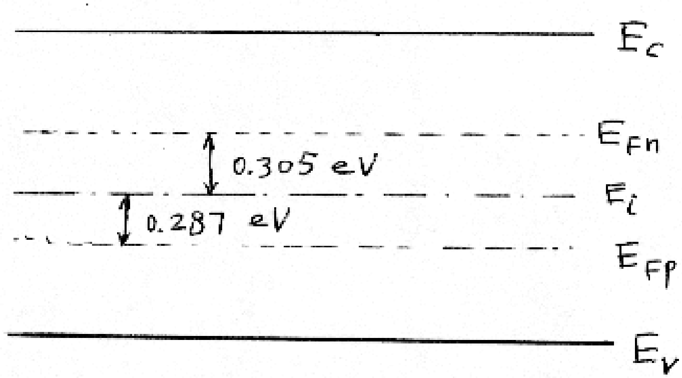
$p = n_i \exp[(E_i - E_{Fp})/kT] \Rightarrow \boxed{E_i - E_{Fp} = kT \ln\left(\frac{p}{n_i}\right)}$

At 300°K, $kT \cong 0.0258\ eV$

$E_{Fn} - E_i = 0.0258 \times \ln \frac{2\times 10^{15}}{1.5\times 10^{10}} = 0.305\ eV$

$E_i - E_{Fp} = 0.0258 \times \ln \frac{10^{15}}{1.5\times 10^{10}} = 0.287\ eV$

$\therefore\ E_{Fn} - E_{Fp} = 0.305 + 0.287 = 0.592\ eV$



4.8. (a) without generation $n \cong N_d = 10^{16}\ cm^{-3}$ $p \ll n$

$$I = \sigma \cdot \frac{V}{L} A = q(n\mu_n + p\mu_p)\cdot\frac{V}{L}\cdot A \approx q n\mu_n \cdot \frac{V}{L} A$$

$$I = 1.6\times10^{-19} \times 10^{16} \times 1100 \times \frac{10}{2} \times 0.05 = 0.44\ A$$

(b) Consider EHP generation

$$n = N_d + \tau_n \cdot G = 10^{16} + 10^{-4}\times10^{20} = 2\times10^{16}\ cm^{-3}$$

$$p = \frac{n_i^2}{N_d} + \tau_p \cdot G \approx 10^{-4}\times10^{20} = 10^{16}\ cm^{-3}$$

$$I = q(n\mu_n + p\mu_p)\cdot\frac{V}{L} A$$

$$I = 1.6\times10^{-19}\times(2\times10^{16}\times1100 + 10^{16}\times500)\times\frac{10}{2}\times0.05 = 1.08\ A$$

(c) With EHP generation at $V = 10^5$ Volts

$$V/L = 10^5/2cm = 5\times10^4\ V/cm$$

From Figure, get v_d (electron) $\simeq 10^7 cm/s$

Assume v_d (hole) $\simeq 10^7 cm/s$

Then $I = q(n+p)v_d \cdot A$

$$I = 1.6\times10^{-19}\times(2\times10^{16}+10^{16})\times10^7\times0.05$$

$$I = 2400\ A$$