Tutorial # 1 : 9/18 & 9/19/2000

Carrier concentrations in thermal equilibrium:

n-type compensated:

$$n_o = \frac{N_d - N_a}{2} + \frac{N_d - N_a}{2}\sqrt{1 + \frac{4n_i^2}{(N_d - N_a)^2}}$$

$$p_o = \frac{n_i^2}{n_o}$$

p-type compensated:

$$p_o = \frac{N_a - N_d}{2} + \frac{N_a - N_d}{2}\sqrt{1 + \frac{4n_i^2}{(N_a - N_d)^2}}$$

$$n_o = \frac{n_i^2}{p_o}$$

Limiting cases: (n-type):

if $(N_d - N_a) \gg n_i$ then $n_o \approx N_d - N_a$ & $p_o \approx \frac{n_i^2}{N_d - N_a}$

if $(N_d - N_a) \ll n_i$ then $n_o \approx p_o \approx n_i$

Carrier Current: Drift & Diffusion.

$v_{dn}\left[\frac{cm}{s}\right] = -\mu_n\left[\frac{cm^2}{V \cdot s}\right] E\left[\frac{V}{cm}\right]$ ← e^- flows opposite direction of E-field.

$v_{dp} = \mu_p E$ ← h^+ flows in same direction as $\vec{E}$-field.

At a certain E-field, these expressions no longer valid. Velocity saturation takes place.

$J_n^{dr} = -q n v_{dn} = q n \mu_n E$ units: $[C][cm^{-3}]\left[\frac{cm^2}{V \cdot s}\right]\left[\frac{V}{cm}\right] = \left[\frac{C}{cm^2 \cdot s}\right]$

|Charge of e^-|$(1.6 \times 10^{-19}$ C)

Current flows in opposite direction of e^- flow

Above valid when $v_{dn} \ll v_{sat}$. $J_p^{dr} = q p \mu_p E$ for $v_{dp} \ll v_{sat}$

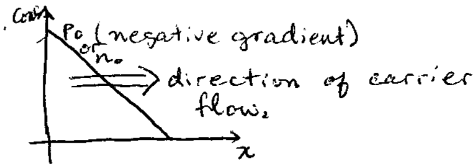
Note that the drift current is proportional to the carrier concentration.

$J_p^{diff} = -q D_p \frac{dp}{dx}$ ← Concentration gradient of holes.

D_p ← Diffusion coefficients

Positive carriers move opposite to concentration gradient.

units $[C]\left[\frac{cm^2}{s}\right][cm^{-4}] = \left[\frac{C}{cm^2 \cdot s}\right]$



$J_n^{diff} = q D_n \frac{dn}{dx}$

Note: Diffusion current is proportional to the gradien[t] but not the total number of carriers.

Total Current:

$$J_n = J_n^{dr} + J_n^{diff} = q n \mu_n E + q D_n \frac{dn}{dx}$$

$$J_p = J_p^{dr} + J_p^{diff} = q p \mu_p E - q D_p \frac{dp}{dx}$$

Einstein Relatio[n]

$$\frac{D}{\mu} = \frac{kT}{q}$$

IC Resistor:

Voltage Applied between two points on semiconductor.

$E = \frac{V}{L}$ ← V: voltage applied, L: distance between points.

We expect drift current.

$$J^{dr} = J_n^{dr} + J_p^{dr} = q(\mu_n n + \mu_p p)\frac{V}{L} = \sigma \frac{V}{L}$$

$\sigma = q n \mu_n + q p \mu_p \Rightarrow$ conductivity

$\rho = \frac{1}{\sigma} = \frac{1}{(q n \mu_n + q p \mu_p)} \Rightarrow$ resistivity

n-type: $\rho_n \approx \frac{1}{q n \mu_n}$. p-type: $\rho_p \approx \frac{1}{q p \mu_p}$

For n-type: $R = \rho_n \left(\frac{L}{Wt}\right) \approx \left(\frac{1}{q N_d \mu_n}\right)\left(\frac{1}{t}\right)\left(\frac{L}{W}\right) = R_\square \left(\frac{L}{W}\right)$

Sheet Resistance:

$R_\square = \frac{1}{q N_d \mu_n t}$

$t \Rightarrow$ thickness

$W \Rightarrow$ Width

$L \Rightarrow$ Length.