Drift and Diffusion Current in PNJ

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Reference Sedra / Smith *Microelectronics*

Charge carriers move in semiconductor in 2 ways : Drift & Diffusion

1 Diffusion

1.1 Fick's Law

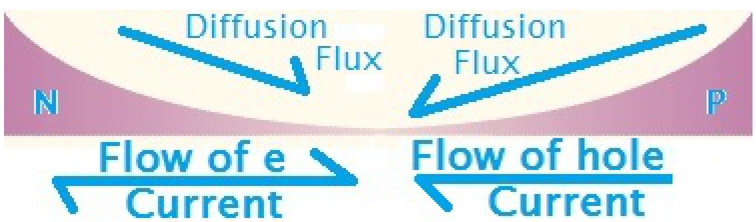
If the distribution of charge carriers are not even in the semiconductor, there is diffusion current. i.e. Concentration gradient exists ⇒ Diffusion

Fick's Law : Diffusion Flux ∝ − Concentration Gradient

$$J = -D\nabla\phi \quad \text{(3D Case)} \qquad J = -D\frac{\partial \phi}{\partial x} \quad \text{(1D Case)}$$

Where J : Diffusion Flux, D : Diffusivity , ϕ : Concentration

1.2 Diffusion Current



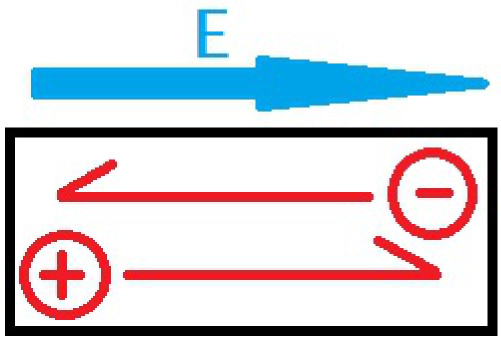
Consider 1D case in PN-Junction

$$\begin{cases} J_n = -D_n\left[-e\right]\dfrac{dn}{dx} & \text{N-Type} \\ J_p = -D_p\left[+e\right]\dfrac{dp}{dx} & \text{P-Type} \end{cases} \Rightarrow \begin{cases} J_n = eD_n\dfrac{dn}{dx} & \text{N-Type} \\ J_p = -eD_p\dfrac{dp}{dx} & \text{P-Type} \end{cases}$$

$$J_{\text{Diffusion Total}} = J_P + J_n = e\left(D_n\frac{\partial n}{\partial x} - D_p\frac{\partial p}{\partial x}\right)$$

2 Drift

2.1 External Electric Field & Drift Velocity



Drift is due to the *External Applied* $E - field$
Charge carrier velocity $\propto E$ (At low field)

$$\begin{cases} \bar{v_n} = -\mu_n \bar{E} \\ \bar{v_p} = \mu_p \bar{E} \end{cases}$$

Where : v drift velocity, μ mobility
$\mu_n > \mu_p \iff$ As e^- are easier to move

2.2 Drift Current

$$\bar{J} = Q^\star \bar{v}$$

Where : $\bar{J}$ current density , $Q^\star$ charge density , $\bar{v}$ drift velocity

$$\begin{cases} \bar{J_n} = Q_n^\star \bar{v}_n \\ \bar{J_p} = Q_p^\star \bar{v}_p \end{cases} \Rightarrow \begin{cases} \bar{J_n} = (-en)\left(-\mu_n \bar{E}\right) \\ \bar{J_p} = (+en)\left(\mu_p \bar{E}\right) \end{cases} \Rightarrow \begin{cases} \bar{J_n} = en\mu_n \bar{E} \\ \bar{J_p} = en\mu_p \bar{E} \end{cases}$$

$$\bar{J}_{Total,drift} = \underbrace{e\left(n\mu_n + p\mu_p\right)}_{\sigma} \bar{E} = \sigma \bar{E} \qquad \text{Differential Ohm's Law}$$

$$\rho = \frac{1}{\sigma} = \frac{1}{e\left(n\mu_n + p\mu_p\right)} \qquad \text{Resistivity}[\Omega\text{cm}^{-1}]$$

3 Total Current

$$J_{Total} = J_{Total,Drift} + J_{Total,Diffusion}$$

$$J_T = e\left(n\mu_n + p\mu_p\right)\bar{E} + e\left(D_n \frac{\partial n}{\partial x} - D_p \frac{\partial p}{\partial x}\right) = \left[en\mu_n \bar{E} + eD_n \frac{\partial n}{\partial x}\right] + \left[ep\mu_p \bar{E} - eD_p \frac{\partial p}{\partial x}\right]$$

$$J_{n,Total} = en\mu_n \bar{E} + eD_n \frac{\partial n}{\partial x} \qquad J_{p,Total} = ep\mu_p \bar{E} - eD_n \frac{\partial p}{\partial x}$$

$$\text{With } \textit{Einstein's Relation} : \frac{D_p}{\mu_p} = \frac{D_n}{\mu_n} = \frac{kT}{e} = V_T \simeq 26mV_{\text{(in RC)}}$$

$$J_{n,Total} = e\mu_n \left(n\bar{E} + V_T \frac{\partial n}{\partial x}\right) \qquad J_{p,Total} = e\mu_p \left(p\bar{E} + V_T \frac{\partial p}{\partial x}\right)$$

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