9/26/2000 Tutorial #2

Poisson's Equation:

$$\frac{d^2\phi(x)}{dx^2} = -\frac{dE(x)}{dx} = -\frac{\rho(x)}{\epsilon}$$

In thermal equilibrium, there is no net electron or hole current. $\Rightarrow$

$$J_n = q n_o \mu_n E_o + q D_n \frac{dn_o}{dx} = 0$$

$$\frac{dn_o}{dx} = \underbrace{\left(\frac{-\mu_n}{D_n}\right)}_{\frac{q}{kT}} n_o \underbrace{E_o}_{-\frac{d\phi}{dx}} \quad \Rightarrow \quad d\phi_o = \frac{kT}{q}\frac{1}{n_o}\,dn_o$$

$$\phi_o(x) - \phi_{ref} = \frac{kT}{q}\ln\left(\frac{n_o(x)}{n_o(x_{ref})}\right)$$

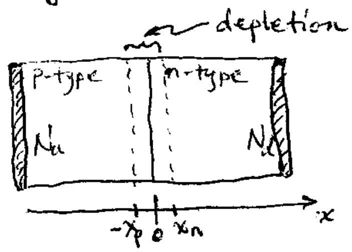
Pick $\phi_{ref} = 0$ when $n_o(x_{ref}) = n_i$ ← intrinsic carrier concentration.

$$\phi_o(x) = \frac{kT}{q}\ln\left(\frac{n_o(x)}{n_i}\right) \Rightarrow n_o(x) = n_i \exp\left\{\frac{q\,\phi_o(x)}{kT}\right\}$$

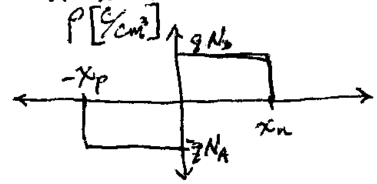
Similarly $J_p = 0 \Rightarrow \phi_o(x) = -\frac{kT}{q}\ln\left(\frac{p_o(x)}{n_i}\right)$ & $p_o(x) = n_i \exp\left\{\frac{-q\phi}{kT}\right.$

$$\left.\begin{aligned} \phi_o(x) &= (60\,mV)\log_{10}\left(\frac{n_o(x)}{n_i}\right) \\ \phi_o(x) &= -(60\,mV)\log_{10}\left(\frac{p_o(x)}{n_i}\right) \end{aligned}\right\} \text{60 mV Rule.}$$

p-n junction: - in thermal equilibrium → no voltage applied.

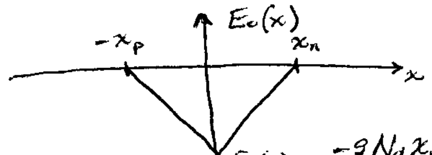


Depletion approximation:
Depletion region is completely devoid of mobile carriers:



$$\frac{dE_o}{dx} = \frac{\rho_o(x)}{\epsilon_{Si}} \Rightarrow \quad E_o = \begin{cases} -\frac{qN_a}{\epsilon_s}(x-(-x_p)) & \text{for } -x_p \le x \le 0 \\ -\frac{qN_d}{\epsilon_s}(x_n - x) & \text{for } 0 \le x \le x_n \end{cases}$$

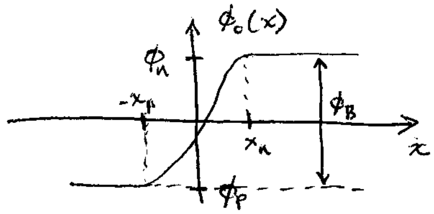
$$\frac{d^2\phi(x)}{dx^2} = -E_o(x) \Rightarrow \quad \phi_o = \begin{cases} \frac{qN_a}{2\epsilon_s}(x+x_p)^2 + \phi_p & \text{for } -x_p \le x \le 0 \\ \phi_n - \frac{qN_d}{2\epsilon_s}(x_n - x)^2 & \text{for } 0 \le x \le x_n \end{cases}$$



$$E_o(0) = \frac{-qN_d x_{no}}{\epsilon_s} = \frac{-qN_a x_p}{\epsilon_s} \Rightarrow N_d x_n = N_a x_p$$

Charge neutrality

Built in potential $\Rightarrow \phi_B = \phi_n - \phi_p$



By setting $\phi(0^+) = \phi(0^-)$

$$x_n = \sqrt{\left(\frac{2\epsilon_s\phi_B}{qN_d}\right)\left(\frac{N_a}{N_d+N_a}\right)}$$

$$x_p = \sqrt{\left(\frac{2\epsilon_s\phi_B}{qN_a}\right)\left(\frac{N_d}{N_d+N_a}\right)}$$

Depletion region larger on lightly doped side. Why? To maintain charge neutrality! If $N_d > N_a$, $x_p > x_n$ for $N_d x_n = N_a x_p$ to be true.

$$X_{do} = x_{no} + x_{po} = \sqrt{\left(\frac{2\epsilon_s\phi_B}{q}\right)\left(\frac{1}{N_a}+\frac{1}{N_d}\right)}$$

If diode in reverse bias, replace above equations ϕ_B with $\Phi_j = \phi_B - V_D \leftarrow$ applied reverse bias.

Why is this valid?

$\Rightarrow$ At RB, diode current very small.

$\rightarrow$ Applied RB voltage drops across depletion region.

↳ Results in a more negative $E_o(0) = E_{Max}$.

↳ Results in a bigger depletion region.

If we short an unbiased diode will we get a current?

No, there is a potential difference across the ohmic contacts the sum of which is equal and opposite of ϕ_B.