Announcements

• HW #1 due Friday in class.
• If you want comments on Lab 0, turn it in to your TA.
Minority Carrier Continuity Equations

\[ j_{n}^{\text{tot}} = qn\mu_{n}\mathbf{E} + qD_{n}\nabla n \]
\[ j_{p}^{\text{tot}} = qp\mu_{p}\mathbf{E} - qD_{p}\nabla p \]

\[ \frac{\partial n}{\partial t} = -\frac{1}{-q} \nabla \cdot j_{n}^{\text{tot}} + G - R \quad (G \text{ is generation,} \]
\[ \frac{\partial p}{\partial t} = -\frac{1}{q} \nabla \cdot j_{p}^{\text{tot}} + G - R \quad R \text{ is recombination} \]

For **minority carriers**, in low level injection \((p<<n)\): \(G - R \approx \frac{(p_0-p)}{\tau_p} = -\frac{\Delta p}{\tau_p} \]
\[ j_{p}^{\text{tot}} \approx j_{p}^{\text{diff}} \text{ (neglect drift since } p \text{ small)} \]
**Minority Carrier Continuity Equations**

\[
j_p^{tot} = q \mu_p E_x - q D_p \frac{dp}{dx} \approx -q D_p \frac{dp}{dx}
\]

\[
\frac{\partial p}{\partial t} = -\frac{1}{q} \frac{d}{dx} \left( -q D_p \frac{dp}{dx} \right) - \frac{\Delta p}{\tau_p}
\]

\[
= D_p \frac{d^2 p}{dx^2} - \frac{\Delta p}{\tau_p}
\]

Similarly in p-type material under low level injection (1D):

\[
\frac{\partial n}{\partial t} = D_n \frac{d^2 n}{dx^2} - \frac{\Delta n}{\tau_n}
\]
p-n Junction – Minority carrier injection

\[ \varphi_j - v_d = \frac{kT}{q} \ln \frac{p(-x_p)}{p(x_n)} = \frac{kT}{q} \ln \frac{n(x_n)}{n(-x_p)} \]

\[ p(x_n) = p(-x_p) \exp \left[ - \frac{q(\varphi_j - v_d)}{kT} \right] \]

\[ = N_A \frac{n_i^2}{N_A N_D} \exp \left[ - \frac{q(-v_d)}{kT} \right] = \frac{n_i^2}{N_D} \exp \left[ \frac{qv_d}{kT} \right] \]

\[ n(-x_n) = \frac{n_i^2}{N_A} \exp \left[ \frac{qv_d}{kT} \right] \]
Diode reverse leakage current

Short base $W_p \ll L_n, W_n \ll L_p$:

$$I_s = qA n_i^2 \left[ \frac{D_n}{N_A W_p} + \frac{D_p}{N_D W_n} \right]$$

Long base $W_p \gg L_n, W_n \gg L_p$:

$$I_s = qA n_i^2 \left[ \frac{D_n}{N_A L_n} + \frac{D_p}{N_D L_p} \right]$$

Current dominated by minority carrier injection into the lightly-doped and/or narrower side.

Minority carrier diffusion length: $L_n = \sqrt{D_n \tau_n}, L_p = \sqrt{D_p \tau_p}$
Diffusion charge (forward bias)

Short base $W_p << L_n, W_n << L_p$:

$$Q_D = qA n_i^2 \left[ \frac{W_p}{2N_A} + \frac{W_n}{2N_D} \right] \left( e^{qV_d/kT} - 1 \right)$$

Long base $W_p >> L_n, W_n >> L_p$:

$$Q_D = qA n_i^2 \left[ \frac{L_n}{N_A} + \frac{L_p}{N_D} \right] \left( e^{qV_d/kT} - 1 \right)$$

Stored charge dominated by minority carrier injection into the lightly-doped and/or wider side.