Last Time:

p-n junctions Intro

This Time:

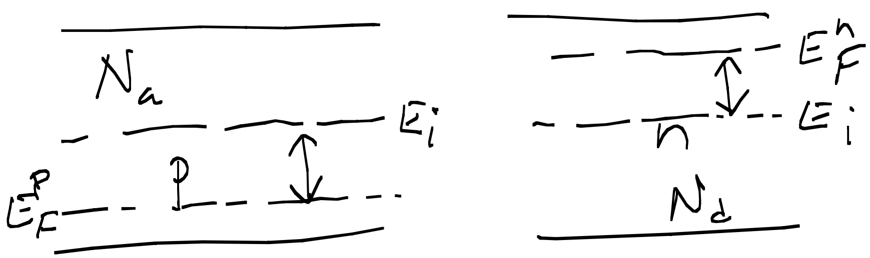
barrier height calc.

find $\mathcal{E}$-field

find $V(x)$

find band-diagram shape $[(-q)V(x)]$

Barrier height Calculation



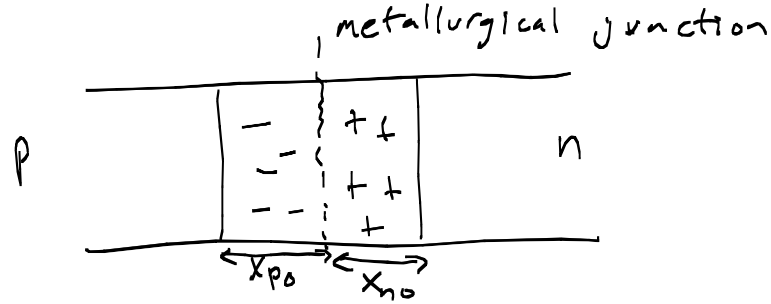
$$qV_o = \underbrace{\left(E_F^n - E_i\right)} + \underbrace{\left(E_i - E_F^p\right)}$$

$$n_n = n_i e^{(E_F^n - E_i)/kT} \qquad p_p = n_i e^{(E_i - E_F^p)/kT}$$

$$E_F^n - E_i = KT \ln \frac{n_n}{n_i} \qquad E_i - E_F^p = KT \ln \frac{p_p}{n_i}$$

$$qV_o = KT\left(\ln \frac{n_n}{n_i} + \ln \frac{p_p}{n_i}\right) = KT \ln \frac{n_n p_p}{n_i^2} = KT \ln \frac{N_d N_a}{n_i^2}$$

Electrical Neutrality



$$|Q_-| = |Q_+|$$

charge density · volume = charge

$$\cancel{q} N_a \cancel{A} x_{po} = \cancel{q} N_d \cancel{A} x_{no}$$

$$\boxed{N_a x_{po} = N_d x_{no}}$$

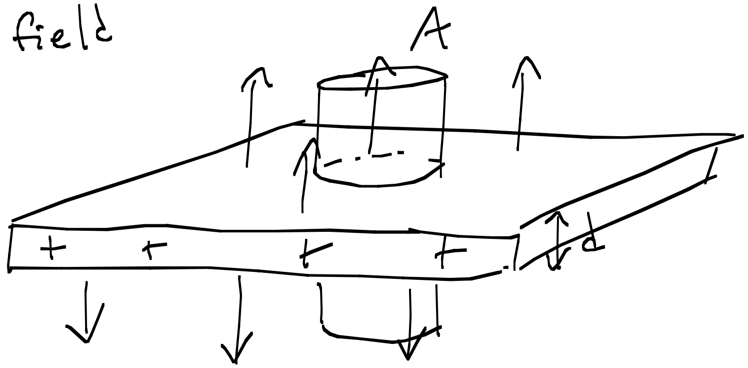
Gauss' Law

$$\oint \vec{\mathcal{E}} \cdot d\vec{S} = \frac{Q}{\varepsilon}$$

permittivity

electric field

charge density ρ

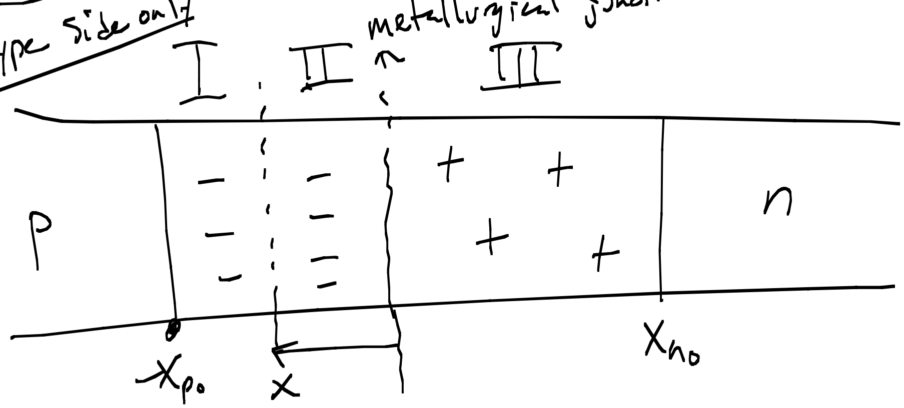


$$2\cancel{A}\mathcal{E} = \frac{\rho \cancel{A} d}{\varepsilon}$$

$$\mathcal{E} = \frac{\rho d}{2\varepsilon}$$

Electric field in p-n junction:

p-type side only



$$\mathcal{E}(x) = \frac{1}{2\varepsilon}\left(qN_a(-x_{p0}-x) - qN_a x - qN_d x_{n0}\right)$$

$$= -\frac{q}{2\varepsilon}\left(N_a x_{p0} + N_a x + N_a x + N_d x_{n0}\right)$$

$N_d x_{n0} = N_a x_{p0}$

$$= -\frac{q}{2\varepsilon}\left(2N_a x + 2N_a x_{p0}\right)$$

$$= -\frac{qN_a}{\varepsilon}(x + x_{p0})$$

for n-side

$$\mathcal{E}(x) = \frac{qN_d}{\varepsilon}(x - x_{n0})$$

Shape of bands:

$$P.E. = (-q)V(x) = (-q)\left(-\int \mathcal{E}(x)\,dx\right) = q\int \mathcal{E}(x)\,dx$$

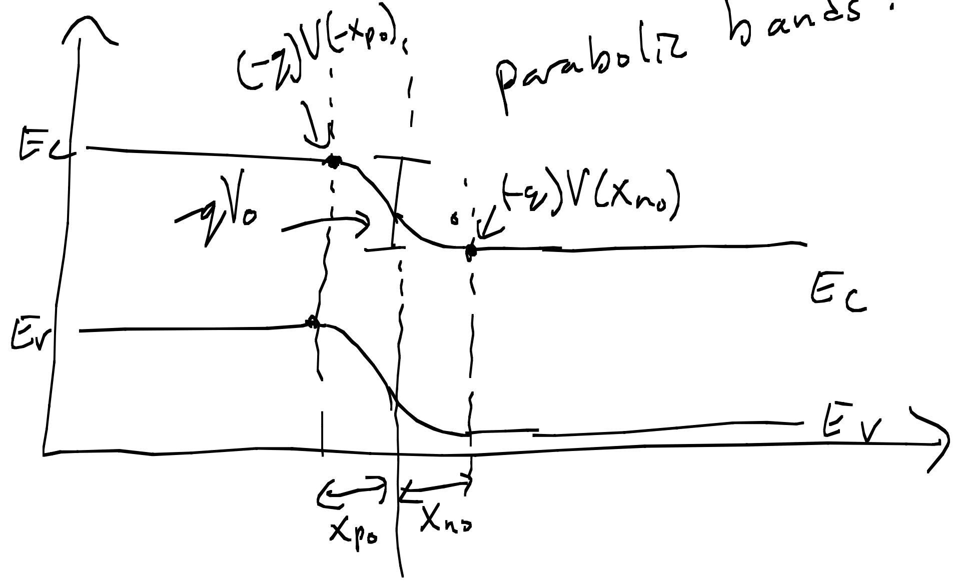
p-side:

$$P.E. = q\int -\frac{qN_a}{\varepsilon}(x + x_{p0})\,dx = -\frac{q^2 N_a}{\varepsilon}\left(\frac{x^2}{2} + x_{p0}x\right)$$

n-side

$$P.E. = q\int \frac{qN_d}{\varepsilon}(x - x_{n0})\,dx = \frac{q^2 N_d}{\varepsilon}\left(\frac{x^2}{2} - x_{n0}x\right)$$

parabolic bands!



Built-in potential II:

$$-qV(-x_{p0}) = \frac{qN_a}{\varepsilon}\frac{x_{p0}^2}{2}$$

$$-qV(x_{n0}) = -\frac{qN_d}{\varepsilon}\frac{x_{n0}^2}{2}$$

$$qV_0 = -qV(-x_{p0}) - (-q)V(x_{n0}) = \frac{q^2}{2\varepsilon}\left(N_a x_{p0}^2 + N_d x_{n0}^2\right)$$

$N_a x_{p0} = N_d x_{n0}$

$$= \frac{q^2}{2\varepsilon}\left(N_a x_{p0} x_{p0} + N_a x_{p0} x_{n0}\right)$$

$$= \frac{q^2 N_a x_{p0}}{2\varepsilon}\left(x_{p0} + x_{n0}\right)$$

$$W = x_{p0} + x_{n0}$$

$$\cancel{q}V_0 = \frac{q^{\cancel{2}} N_a x_{p0}}{2\varepsilon} W$$

depletion region width:

$$W = \frac{2\varepsilon V_0}{q N_a x_{p0}}$$

permittivity

$$= \frac{2\varepsilon V_0}{q N_a W}\left(1 + \frac{N_a}{N_d}\right)$$

$$W^2 = \frac{2\varepsilon V_0}{q}\left(\frac{N_d + N_a}{N_a N_d}\right)$$

$$W = \sqrt{\frac{2\varepsilon V_0}{q}\,\frac{N_d + N_a}{N_a N_d}}$$

$$x_{n0} + x_{p0} = W$$

$$\frac{N_a x_{p0}}{N_d} + x_{p0} = W$$

$$x_{p0}\left(1 + \frac{N_a}{N_d}\right) = W$$

$$x_{p0} = \frac{W}{1 + \frac{N_a}{N_d}}$$

$$\longrightarrow x_{n0} = \frac{W}{1 + \frac{N_d}{N_a}}$$

built-in potential:

$$\boxed{V_0 = kT \ln \frac{N_a N_d}{n_i^2}}$$

limiting case: $N_a \gg N_d$

$$W = \sqrt{\frac{2\varepsilon V_0}{q N_d}}$$

If $N_d \gg N_a$

$$W = \sqrt{\frac{2\varepsilon V_0}{q N_a}}$$

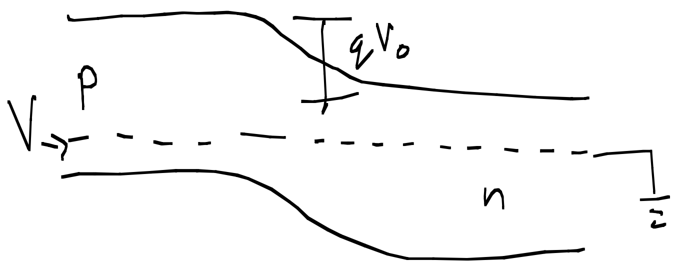
under bias V,

$$\boxed{V_0 \longrightarrow V_0 - V}$$

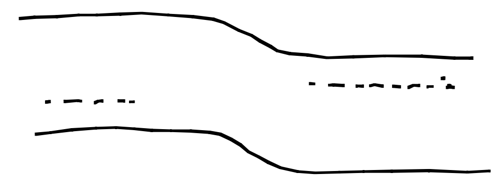
Applied Voltage:

n side grounded

$V=0$

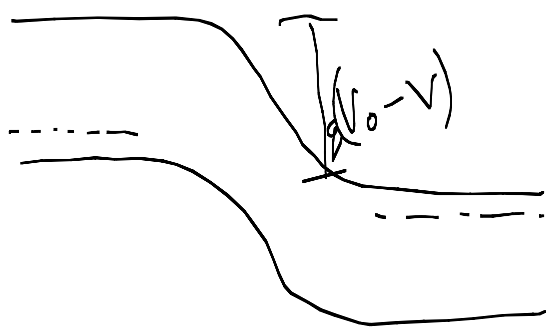


$V>0$



forward bias

$V<0$



reverse bias