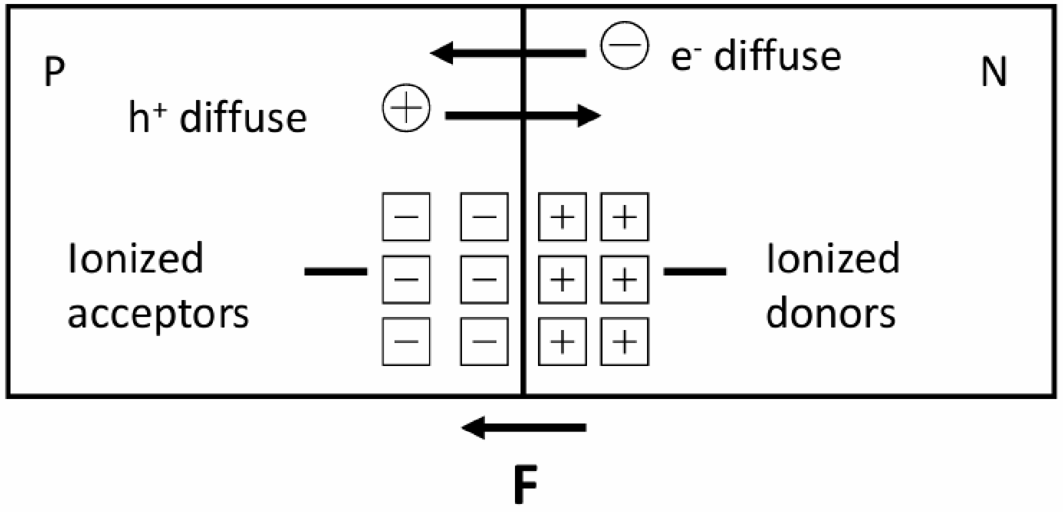
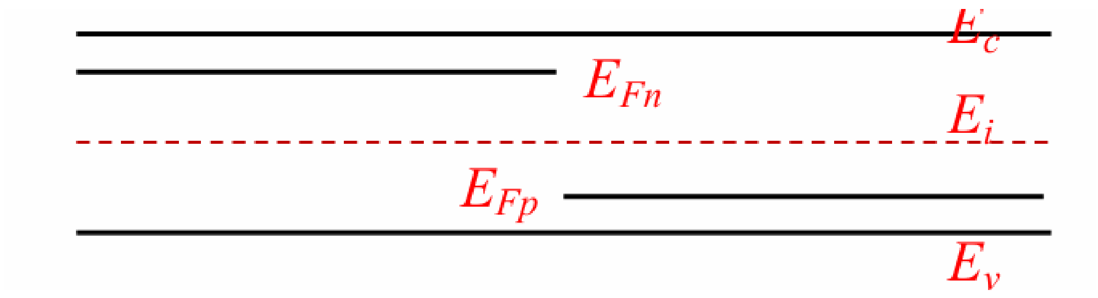
RC6

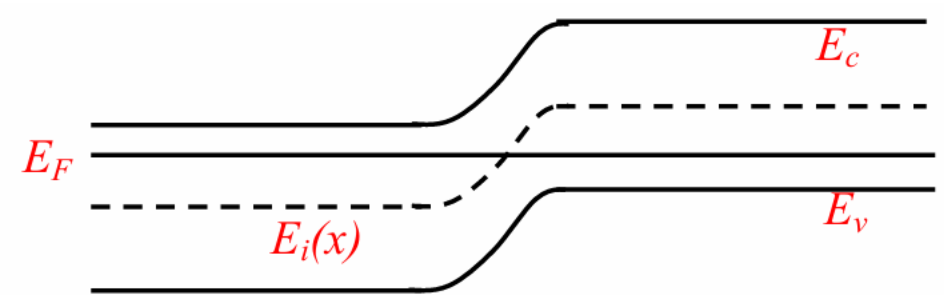
What happens when you join p-type and n-type material?



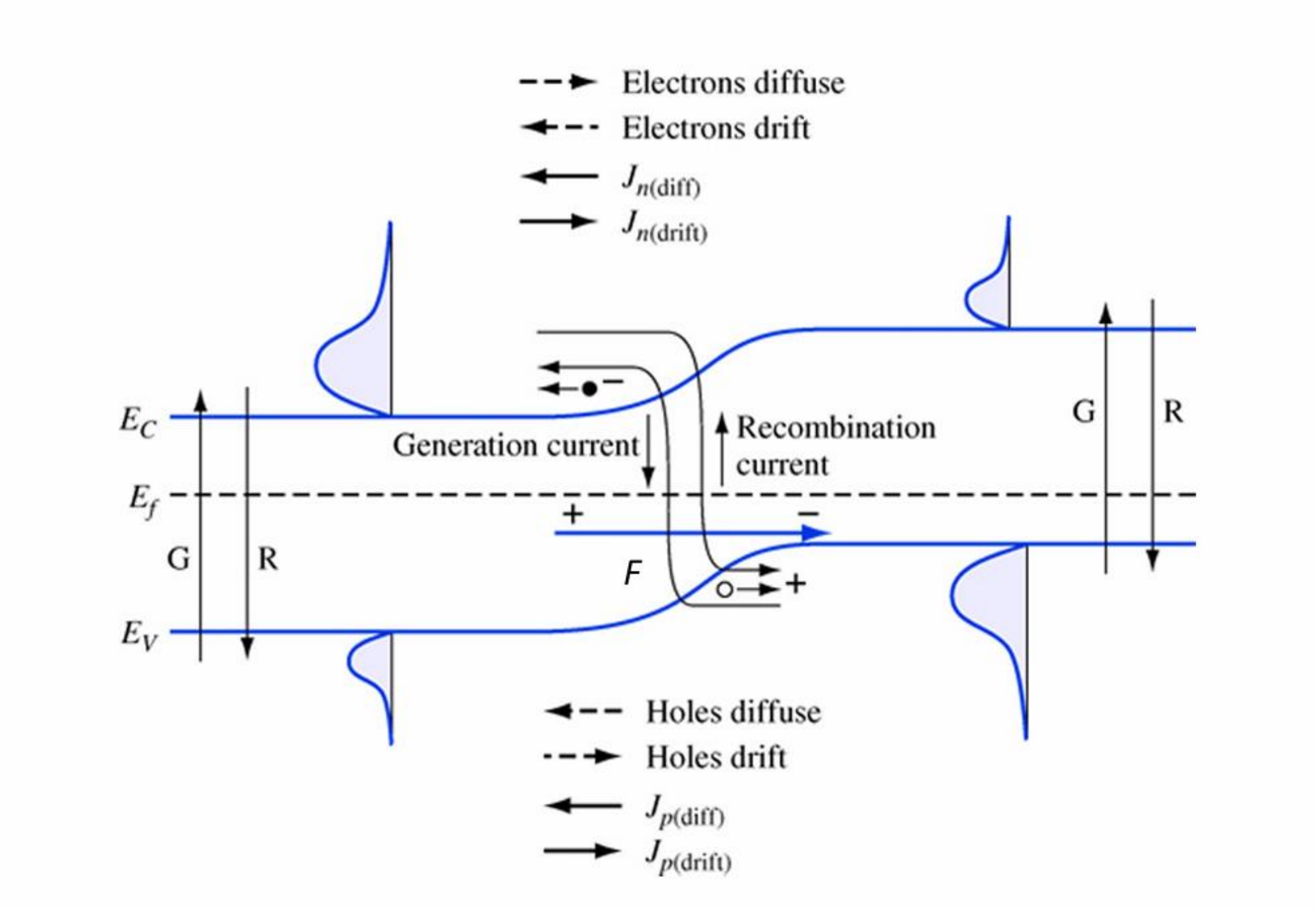
- Diffusion drives e's and h's to lower concentration regions
- Ionized dopants remain, creating an electric field
- Under equilibrium, diffusion and drift processes are balanced

Band diagram before and after equilibrium

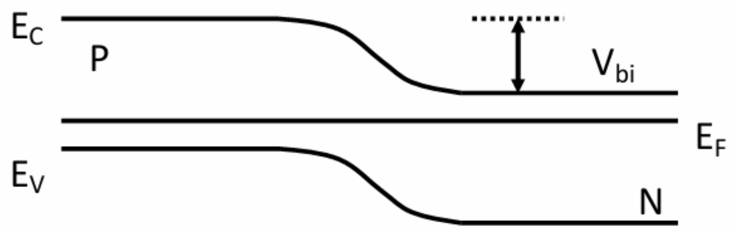




Equilibrium current flow in P-N junction



Built-in potential



$$qV_{bi} = E_G - (E_C - E_F)_n - (E_F - E_V)_p$$

$$(E_C - E_F)_n = -kT \ln\left(\frac{N_D}{N_C}\right)$$

$$(E_F - E_V)_p = -kT \ln\left(\frac{N_A}{N_V}\right)$$

$$n_i^2 = N_C N_V \exp\left(-\frac{E_G}{kT}\right)$$

$$\Rightarrow E_G = kT \log\left(\frac{N_C N_V}{n_i^2}\right)$$

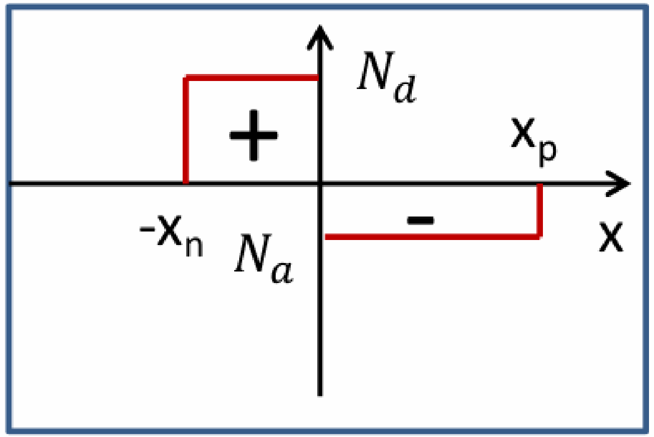
$$\boxed{V_{bi} = \frac{kT}{q} ln\left(\frac{N_D N_A}{n_i^2}\right)}$$

The depletion approximation

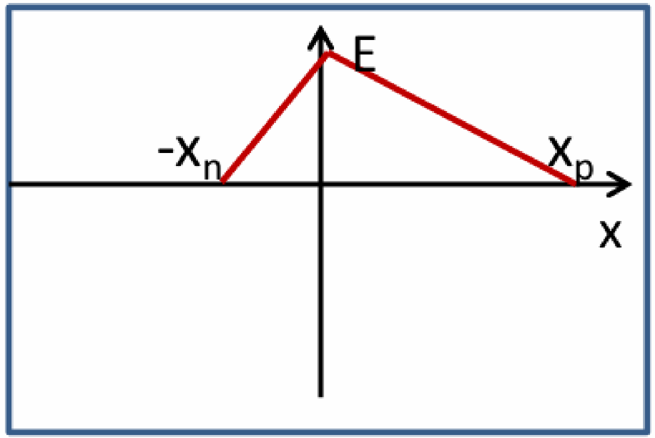
- Analyze p-n junction using electrostatics (Poisson’s equation)
- Depletion approximation – no mobile charge in depletion region, only fixed charge from the ionized impurities
- **Depletion region is necessary to generate the electric field that cancels out the diffusion current.**

Zero applied bias-charge density and electric field

$$\frac{d^2V(x)}{dx^2} = \begin{cases} \frac{q}{\varepsilon} N_a & 0 \le x \le x_p \\ -\frac{q}{\varepsilon} N_d & -x_n \le x < 0 \end{cases}$$



$$E = -\frac{dV(x)}{dx} = \begin{cases} -\frac{q}{\varepsilon} N_a \ x + \frac{q}{\varepsilon} N_a \ x_p & 0 \le x \le x_p \\ \frac{q}{\varepsilon} N_d \ x + \frac{q}{\varepsilon} N_d \ x_n & -x_n \le x < 0 \end{cases}$$



Zero applied bias-potential and space charge width

After applying two restrictions to the potential, we can get the space charge width.

<u>Space charge width</u>

$$\boxed{x = 0 \Rightarrow N_d \ x_n = N_a \ x_p}$$

$$\boxed{V(x = x_n) = V_{bi} = \frac{kT}{q} ln(\frac{N_d \ N_a}{n_i^2})}$$

$$V(x) = \begin{cases} \frac{q}{\varepsilon} N_a \ (\frac{1}{2}x^2 - x_p x + \frac{{x_p}^2}{2}) & 0 \le x \le x_p \\ -\frac{q}{\varepsilon} N_d \ (\frac{1}{2}x^2 + x_n x - \frac{N_a}{N_d}\frac{{x_p}^2}{2}) & -x_n \le x < 0 \end{cases}$$

Zero applied bias-space charge width

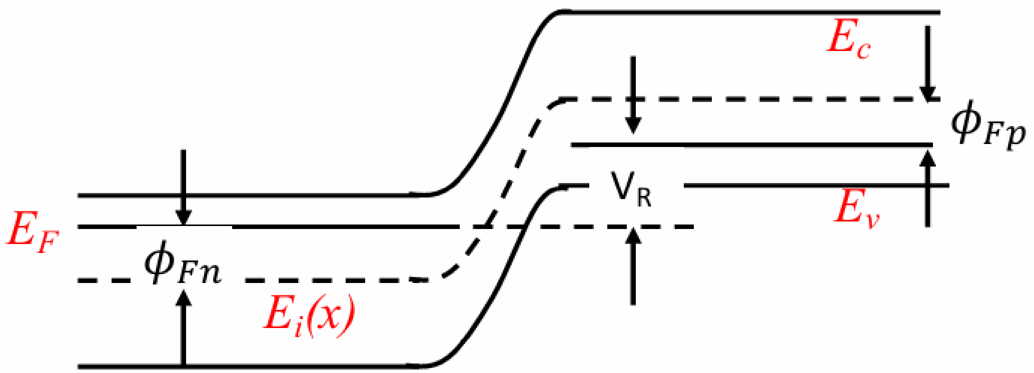
<u>Space charge width</u>

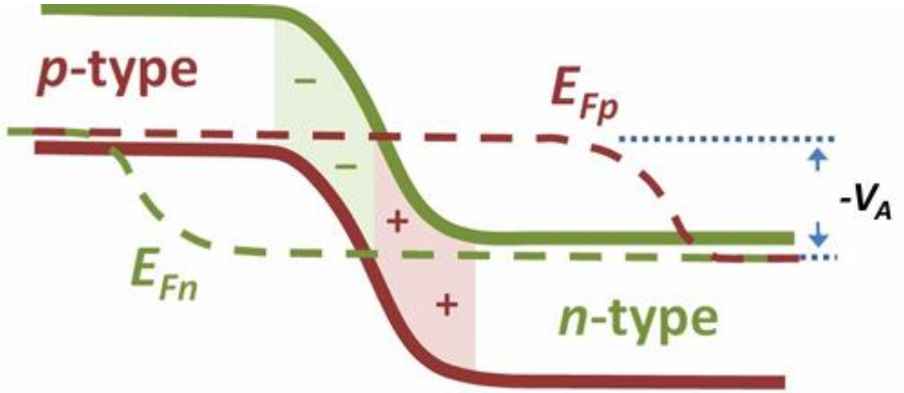
$$\boxed{x_p = \sqrt{\frac{2\varepsilon V_{bi}}{q}\frac{N_d}{N_a}\frac{1}{N_a + N_d}}}$$

$$\boxed{N_d\ x_n = N_a\ x_p \Rightarrow x_n = \sqrt{\frac{2\varepsilon V_{bi}}{q}\frac{N_a}{N_d}\frac{1}{N_a + N_d}}}$$

$$\boxed{W = x_p + x_n = \sqrt{\frac{2\varepsilon V_{bi}}{q}\frac{N_d + N_a}{N_a N_d}}}$$

Reversed applied bias-band diagram





Reversed applied bias

Just replace all the built in voltage with built in voltage plus bias voltage.

Space charge width and electric field

$$x_p = \sqrt{\frac{2\varepsilon(V_{bi}+V_R)}{q}\frac{N_d}{N_a}\frac{1}{N_a+N_d}}$$

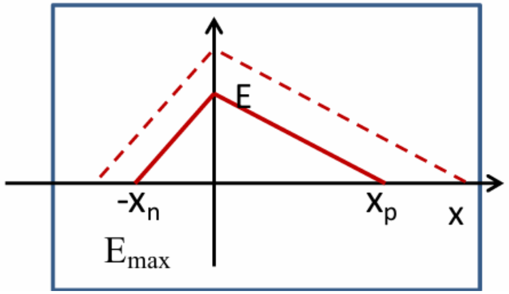
$$N_a^- x_n = N_d^+ x_p \Rightarrow x_n = \sqrt{\frac{2\varepsilon(V_{bi}+V_R)}{q}\frac{N_a}{N_d}\frac{1}{N_a+N_d}}$$

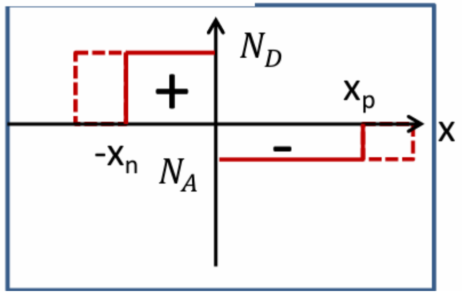
$$W = \sqrt{\frac{2\varepsilon(V_{bi}+V_R)}{q}\frac{N_d+N_a}{N_a N_d}}$$

$$E = -\frac{dV(x)}{dx} = \begin{cases} -\frac{q}{\varepsilon}N_a\ x + \frac{q}{\varepsilon}N_a\ x_p & 0 \le x \le x_p \\ \frac{q}{\varepsilon}N_d\ x + \frac{q}{\varepsilon}N_d\ x_n & -x_n \le x < 0 \end{cases}$$

$$E_{max} = \left\{\frac{2e(V_{bi}+V_R)}{\epsilon_s}\left(\frac{N_a N_d}{N_a+N_d}\right)\right\}^{1/2}$$

$$E_{max} = \frac{2(V_{bi}+V_R)}{W}$$





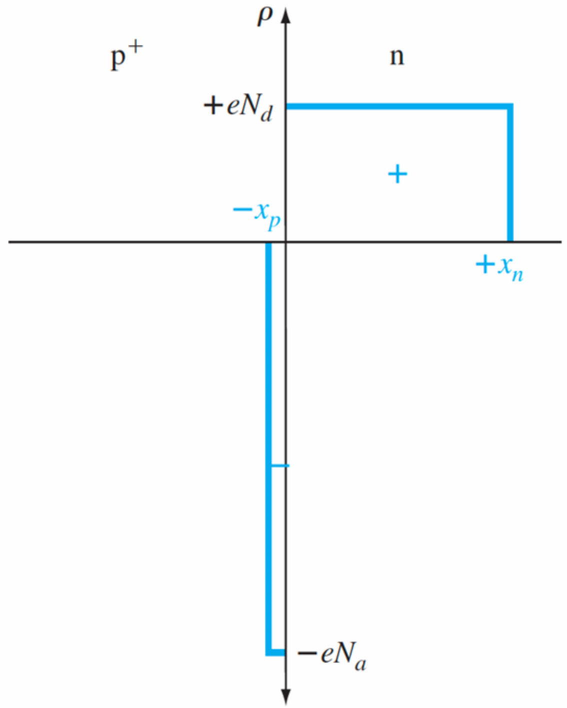
Reversed applied bias-junction capacitance

$$\boxed{C' = \frac{dQ}{dV_{\mathrm{R}}}|_{V_R=V_{R0}} = qN_d\frac{db}{dV_R}|_{V_R=V_{R0}} = \sqrt{\frac{q\varepsilon}{2(V_{bi}+V_{R_0})}\frac{N_dN_a}{N_a+N_d}} = \frac{\varepsilon}{W}}$$

One-sided junction

Either high concentration of donor or high concentration of acceptor

One-sided junction



$$\boxed{W = \sqrt{\frac{2\varepsilon(V_{bi}+V_R)}{q}\frac{N_d+N_a}{N_aN_d}}}$$

$$\Big\downarrow\; N_a \to \infty$$

$$\boxed{W = \sqrt{\frac{2\varepsilon(V_{bi}+V_R)}{q}\frac{1}{N_d}} \approx x_n}$$

$$\Big\downarrow$$

$$\boxed{C' = \frac{\varepsilon}{W} = \sqrt{\frac{q\varepsilon N_d}{2\,(V_{bi}+V_R)}}}$$