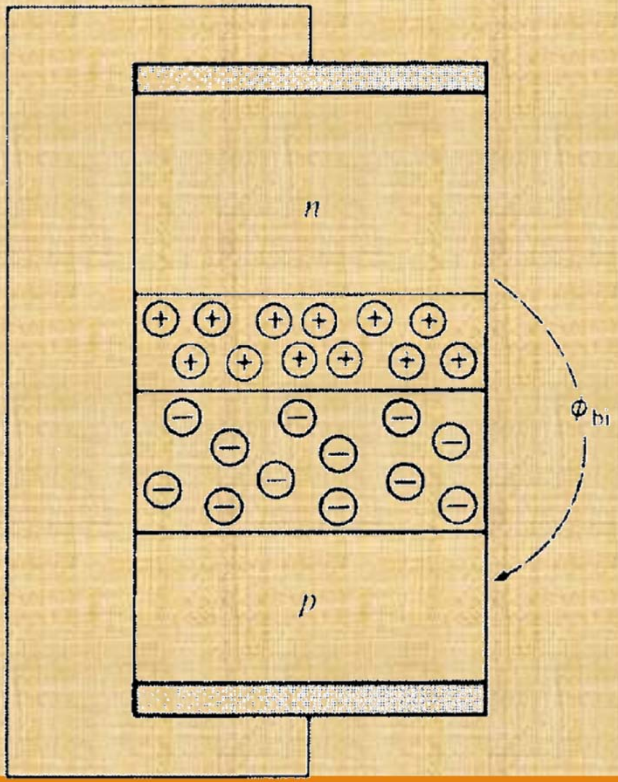
The pn junction

The pn junction

- Abrupt and Graded junction
- Zero bias condition
    - Zero external bias
    - Free electron and hole movement
    - Charged ions
    - Depletion region approximation
    - Electric field formation – Anti-movement mechanism
    - Zero Current
    - Three contact potential
    - Zero electrostatic potential across the device!



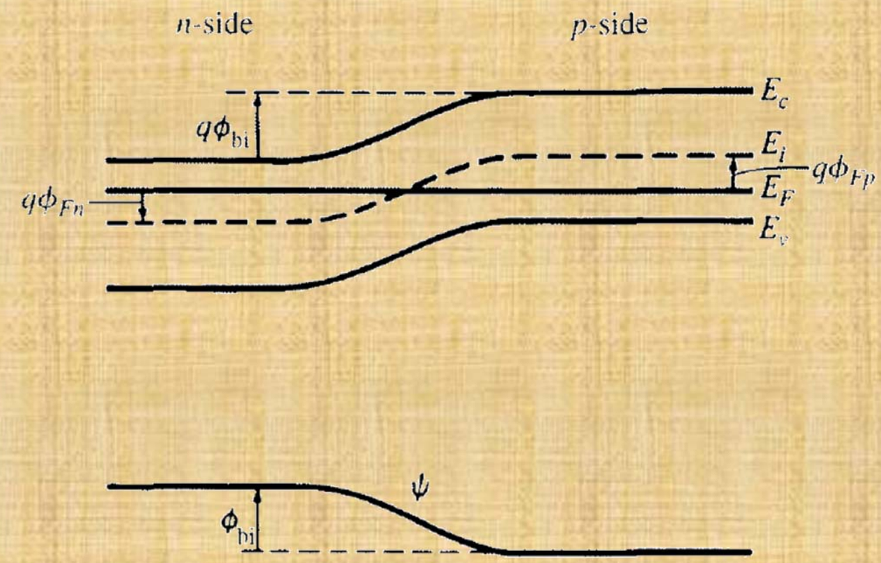
The pn junction

- Zero bias contact potential—Built in potential

$$\phi_{bi} = \phi_{Fp} - \phi_{Fn}$$

- Assume that then side is degenerate, and the doping of the *p* side is Io^{17} cm^{-3}. Find the value of the contact potential Φ_{bi} at room temperature:

$$\phi_{bi} = \phi_{Fp} - \phi_{Fn}=0.42-(-0.56)=0.98$$

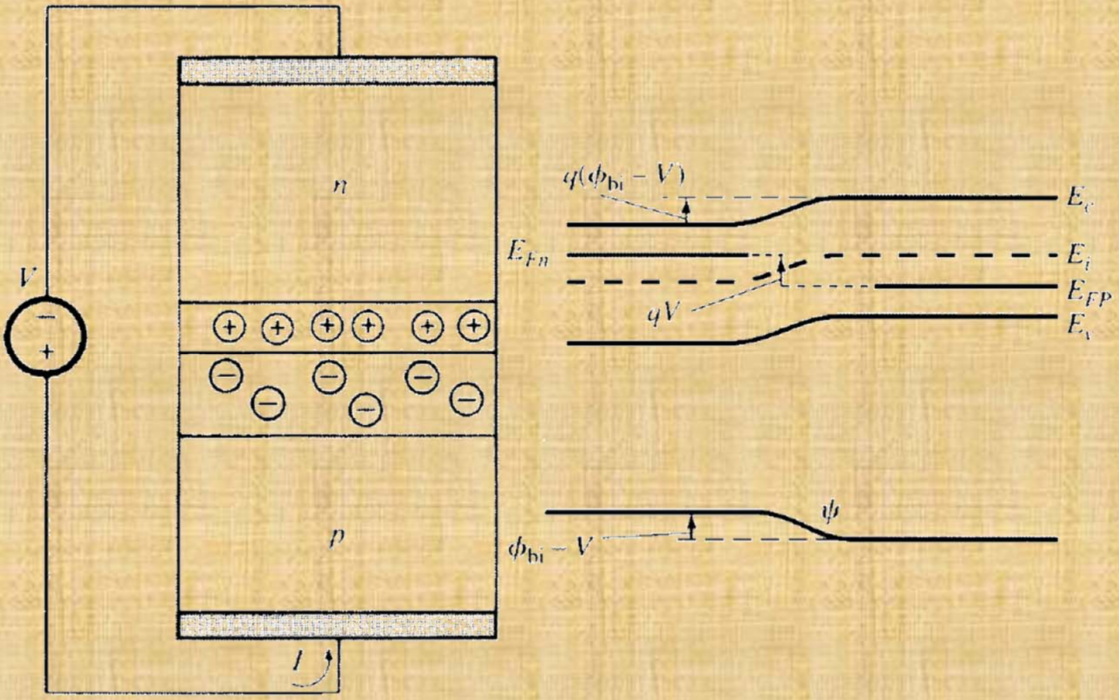


The pn junction…

- Forward bias: V>0
- Equilibrium is now destroyed
- External field is opposite the internal field.
- Current established due to decrease of potential barrier
- How can current flow in depletion region?
- Why it increases exponentially?

$$I = I_0(e^{(V/\phi_T)}-1)$$

- I_0 is a quantity dependent on junction geometry and physical parameters of the semiconductor material and is an increasing function of temperature
- Depletion region reduction



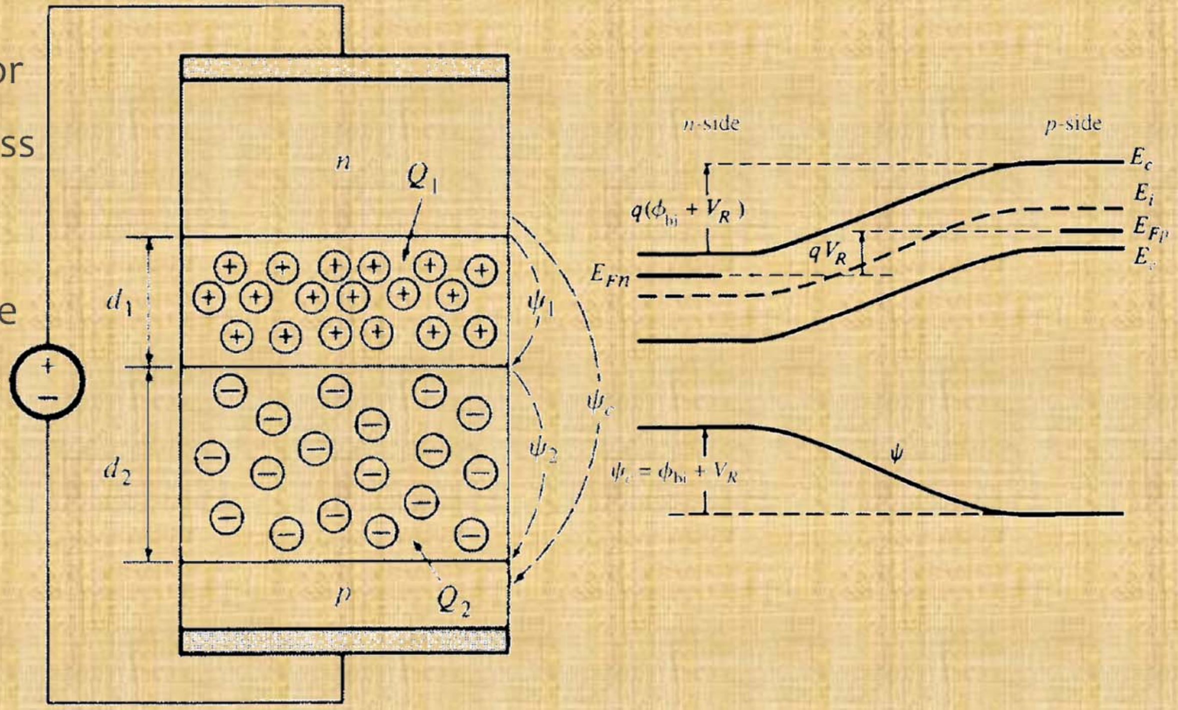
The pn junction…

- Reverse bias : V<0
- Same as what happen in MOS transistor
- Increase of electrostatic potential across the depletion region:

$$\phi_c = \phi_{bi} + V_R$$

- More band bending—electron and hole movement
- Local charge densities:

$$Q_1 = +q(d_1 A)N_D$$
$$Q_2 = -q(d_2 A)N_A$$
$$Q_1 = -Q_2 \Rightarrow {}^{d_1}/_{d_2} = {}^{N_A}/_{N_D}$$



The pn junction…

- Calculation of electric field in the depletion region

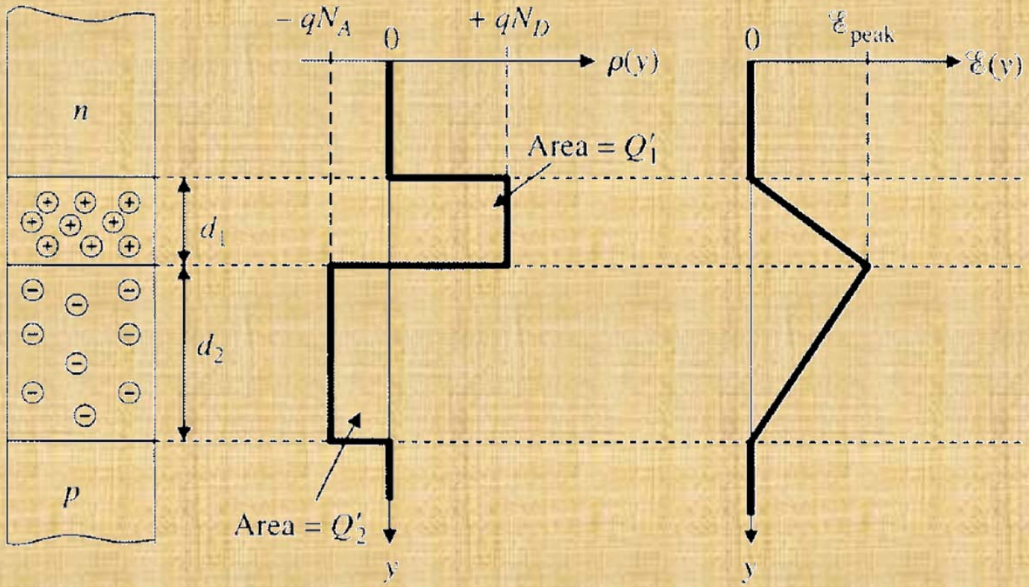
$$\frac{dE(x)}{dx}=\frac{\rho}{\varepsilon_s}$$

$$E(y)=E(y_0)+\frac{1}{\varepsilon_s}\int_{y_0}^{y}\rho(y')dy'$$

$$\rho = qN_D\ for\ Q_1'$$

$$E_{\max(peak)}=\frac{qN_D d_1}{\varepsilon_s}$$

$$=\frac{qN_A d_2}{\varepsilon_s}$$



The pn junction…

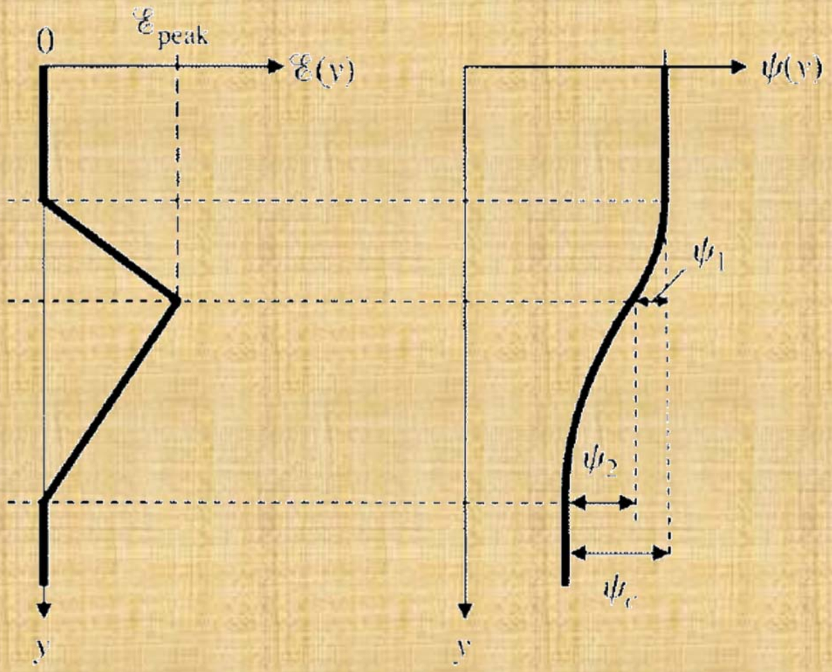
- Calculation of electrostatic potential in the depletion region:

$$\psi(y) = \psi(y_0) - \int_{y_0}^{y} E(y')dy'$$

$$\psi_1 = \frac{E_{max}d_1}{2} = \frac{qN_D d_1^2}{2\varepsilon_s}$$

$$\psi_2 = \frac{E_{max}d_2}{2} = \frac{qN_A d_2^2}{2\varepsilon_s}$$

$$\psi_c = \psi_1 + \psi_2$$



The pn junction…

- Equation for highly doped sided such as n^+p junction we have:

$$N_D \gg N_A \Rightarrow d_1 \ll d_2$$

$$\psi_1 \ll \psi_2 \Rightarrow \psi_c = \psi_2$$

- Nearly all voltage drop will be on low level doping region

$$d_2 = \sqrt{\frac{2\varepsilon_s}{qN_A}}\sqrt{\psi_c}$$

$$Q_2' = \frac{Q_2}{A} = \sqrt{2q\varepsilon_s N_A}\sqrt{\psi_c}$$

- Minority and Majority carrier motion! – Small current flow. Why?
- Saturation current – $V<3\Phi_T$

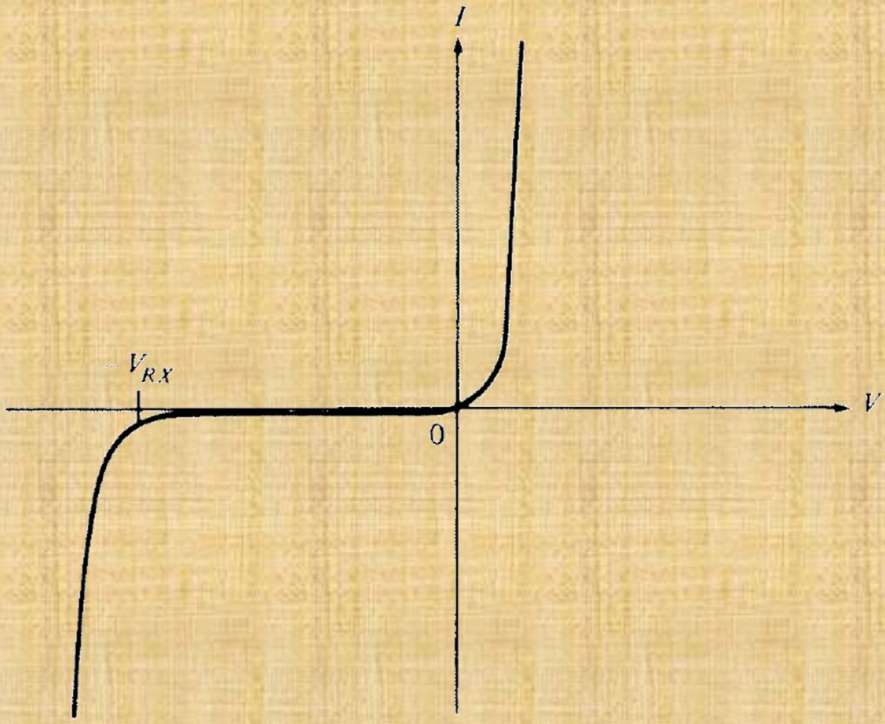
$$I = -I_0$$

- Can we assume it as a constant value?
- Saturation current dependency to temperature -- double for every 8° C
- Reverse break down voltage– V_{RX} from 5 V to 100 V

The pn junction…

- I/V characteristics of pn junction

$$I = I_0(e^{(V/\phi_T)} - 1)$$



The pn junction…

- Junction capacitance – Small signal overview
- The change in reverse voltage ⇒ Change in depletion region
- If ΔV_R Increases then depletion region increases and vise versa
- As we know: $C = \frac{Q}{V}$
- For small signal capacitance we have:

$$C_j = \frac{\Delta Q}{\Delta V_R} = \frac{dQ}{dV_R}$$

$$C_j' = \frac{dQ'}{dV_R} = \frac{\sqrt{2q\varepsilon_s N_A}}{2\sqrt{V_R + \phi_{bi}}}\ or\ \frac{\varepsilon_s}{d_2}$$

$$C_j' = \frac{C_{j0}'}{\sqrt{\frac{V_R}{\phi_{bi}} + 1}}$$

The pn junction…

- Other type of junction capacitance:

$$C'_j = \frac{C'_{j0}}{\left(\frac{V_R}{\phi_{bi}} + 1\right)^{\alpha}}$$

- α is ½ for abrupt highly doped junction
- α is 1/3 for gradually linearly doped junction
- for other type of junction can be extracted from fitting results