

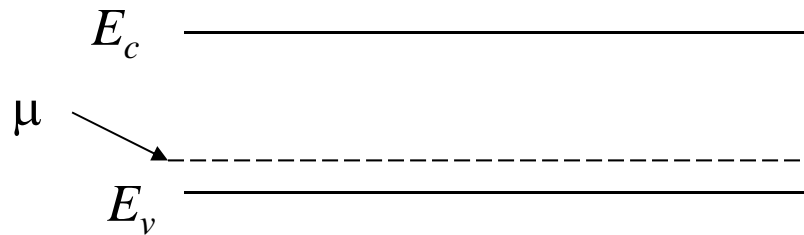
Semiconductor Devices

pn junction

under normal operation conditions

p-type

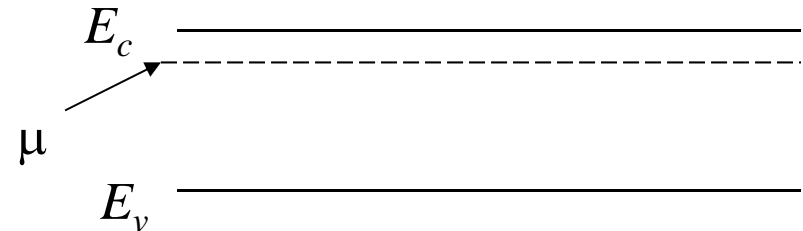
$$N_A > N_D \quad p = N_A - N_D$$



$$n = \frac{n_i^2}{p} = \frac{n_i^2}{N_A - N_D}$$

n-type

$$N_D > N_A \quad n = N_D - N_A$$

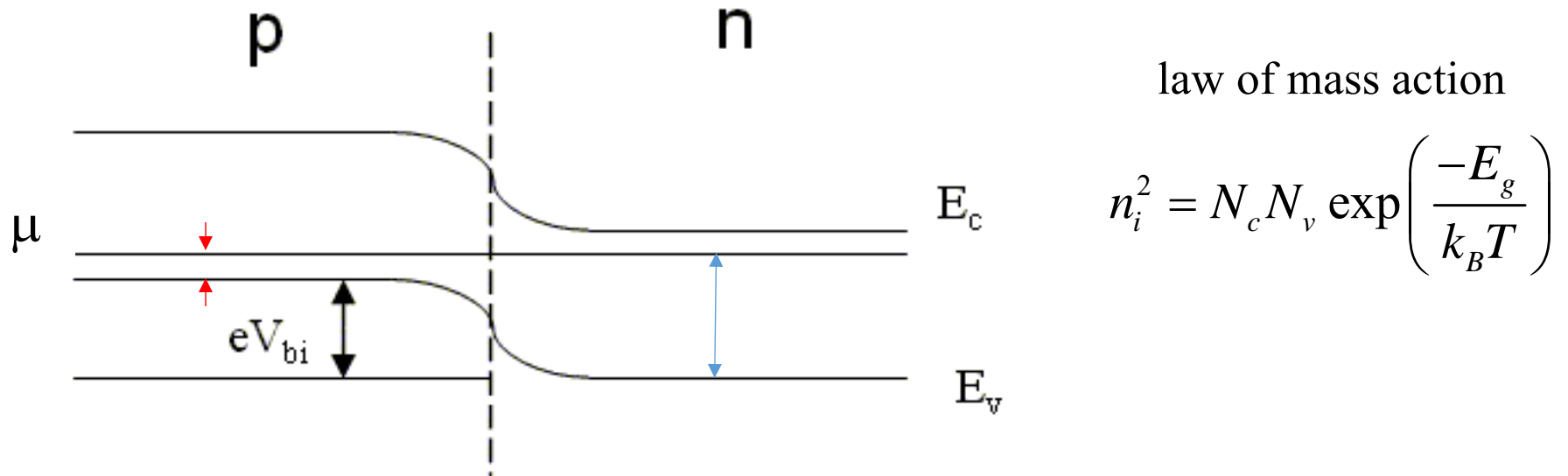


$$p = \frac{n_i^2}{n} = \frac{n_i^2}{N_D - N_A}$$

$$\mu = E_v + k_B T \ln \left(\frac{N_v}{N_A - N_D} \right)$$

$$\mu = E_c - k_B T \ln \left(\frac{N_c}{N_D - N_A} \right)$$

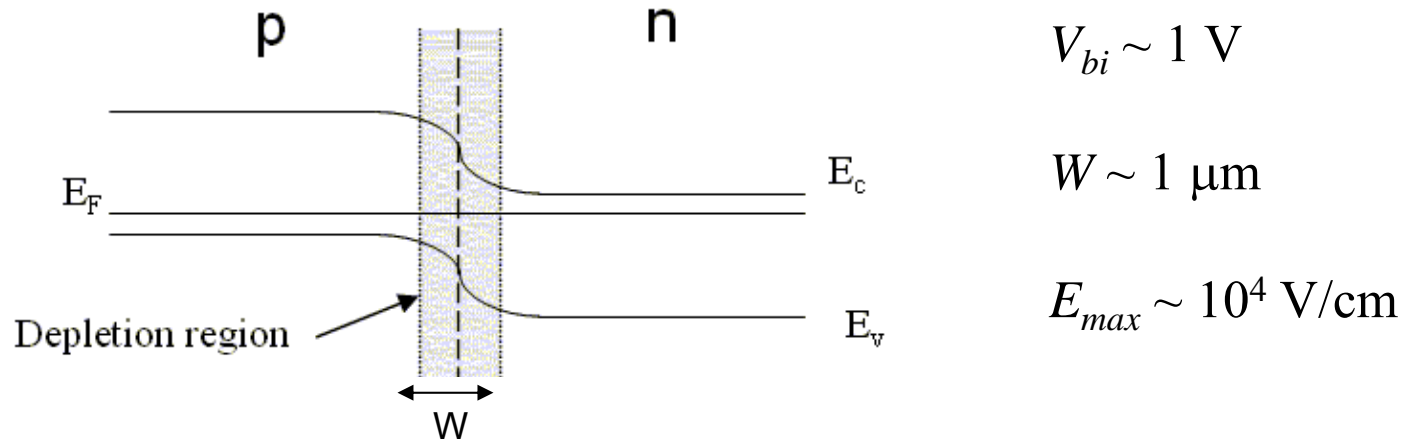
V_{bi} built-in voltage



$$eV_{bi} = E_v + E_g - k_B T \ln\left(\frac{N_c}{N_D}\right) - E_v - k_B T \ln\left(\frac{N_v}{N_A}\right)$$

$$eV_{bi} = E_g - k_B T \ln\left(\frac{N_c N_v}{N_D N_A}\right) = k_B T \ln\left(\frac{N_D N_A}{n_i^2}\right)$$

Depletion width



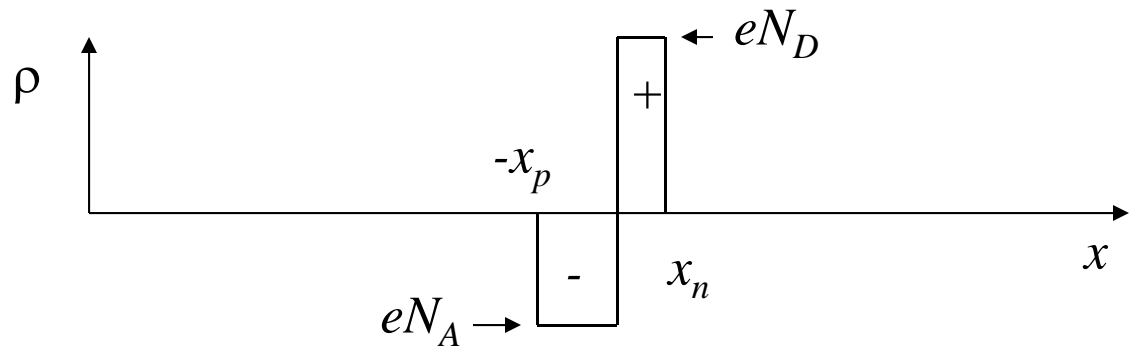
The electric field pushes the electrons towards the n-region and the holes towards the p-region.

Diffusion sends electrons towards the p-region and holes towards the n-region.

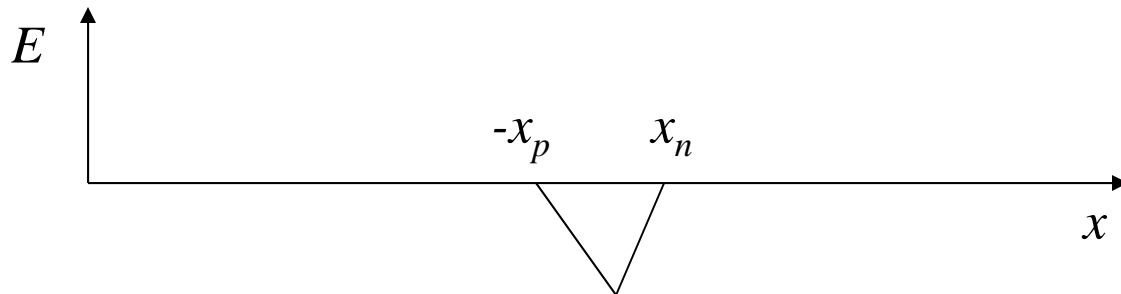
$$n = N_c \exp\left(\frac{\mu - E_c}{k_B T}\right)$$

$$p = N_v \exp\left(\frac{E_v - \mu}{k_B T}\right)$$

depletion approximation

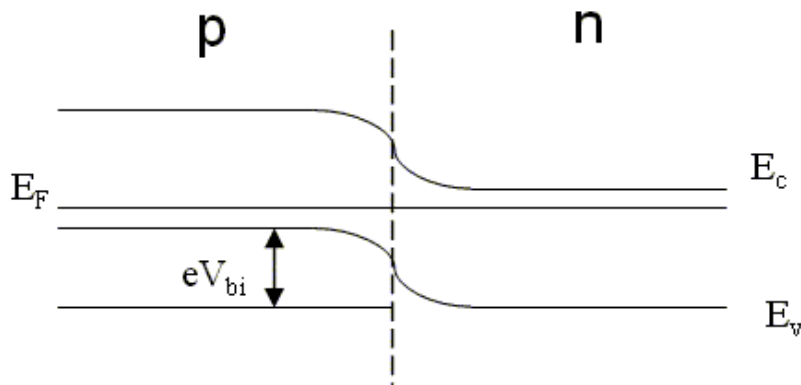


$$eV_{bi} = k_B T \ln \left(\frac{N_D N_A}{n_i^2} \right)$$



$$E = -\frac{eN_A}{\epsilon} (x + x_p) \quad -x_p > x > 0$$

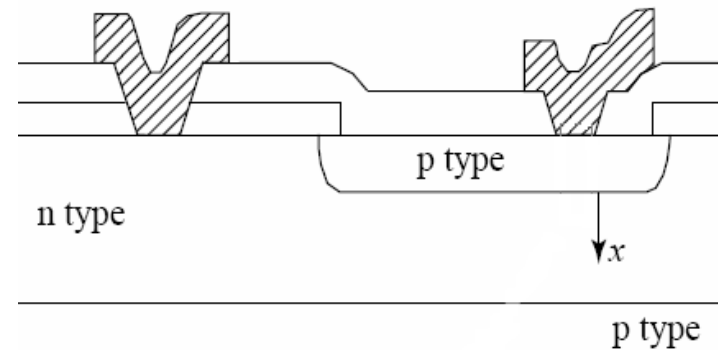
$$E = \frac{eN_D}{\epsilon} (x - x_n) \quad 0 > x > x_n$$



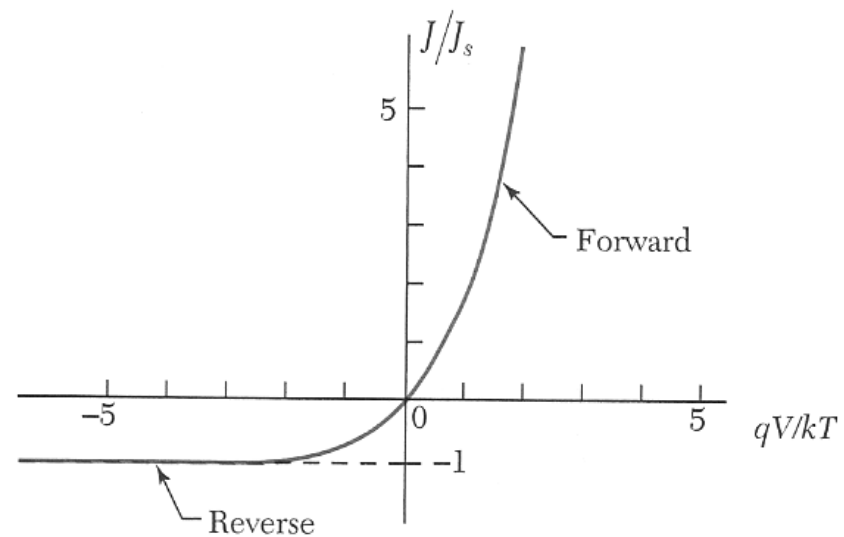
$$V = \frac{eN_A}{\epsilon} \left(\frac{x^2}{2} + xx_p \right) \quad -x_p > x > 0$$

$$V = \frac{-eN_D}{\epsilon} \left(\frac{x^2}{2} - xx_n \right) \quad 0 > x > x_n$$

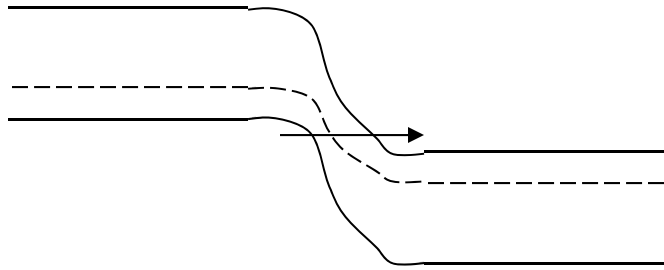
Diode



$$I = I_s \left(\exp\left(\frac{eV}{k_B T}\right) - 1 \right)$$



Zener tunneling

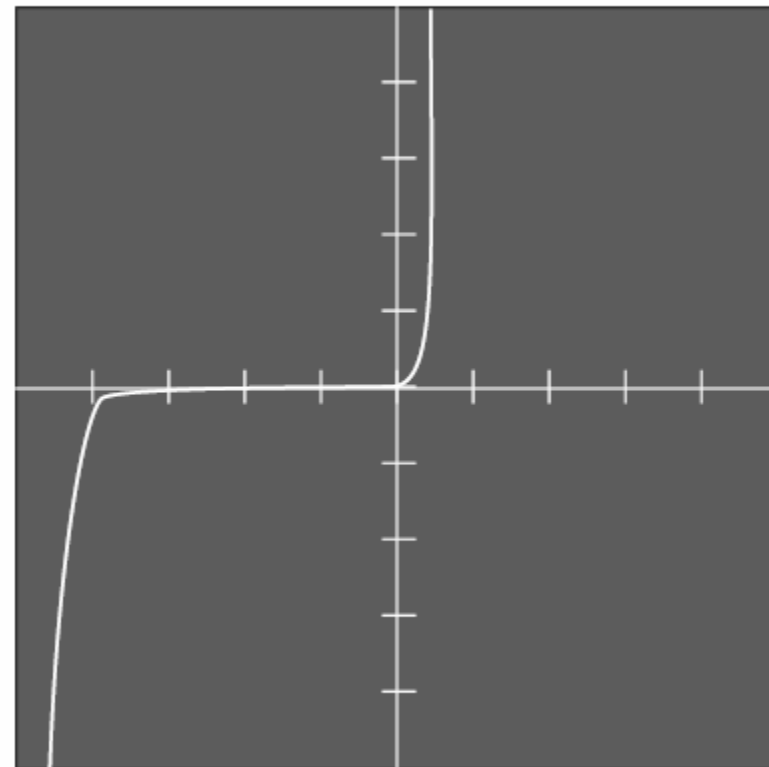


Electrons tunnel from
valence band to
conduction band

Occurs at high doping



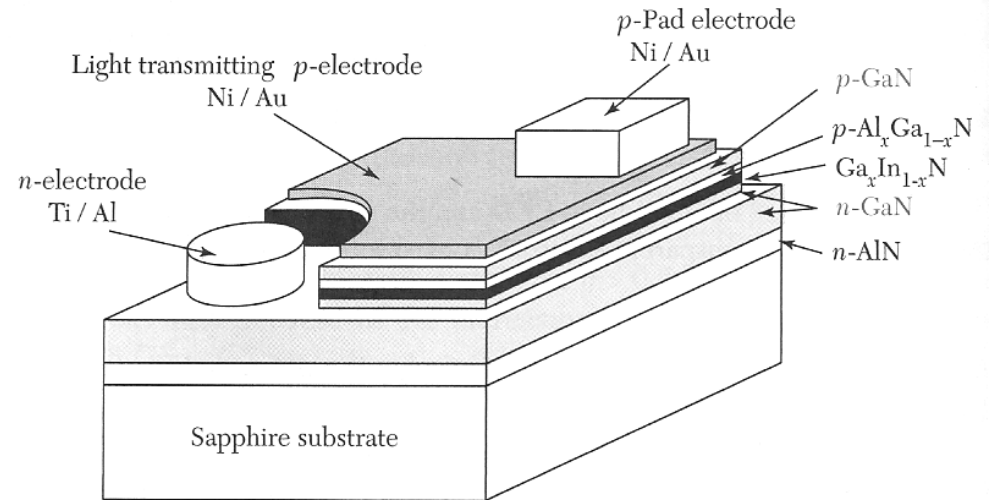
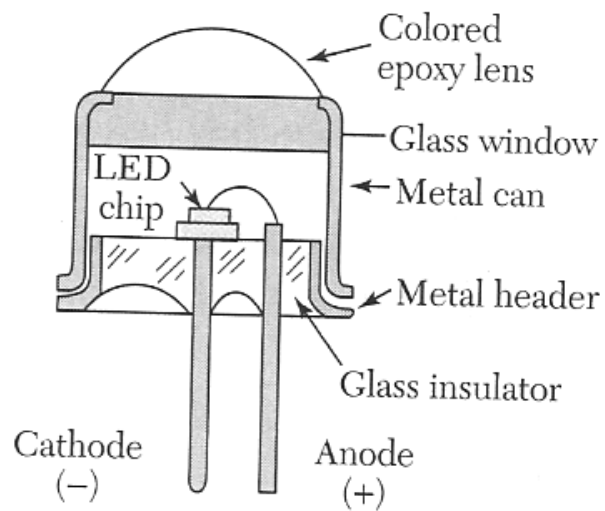
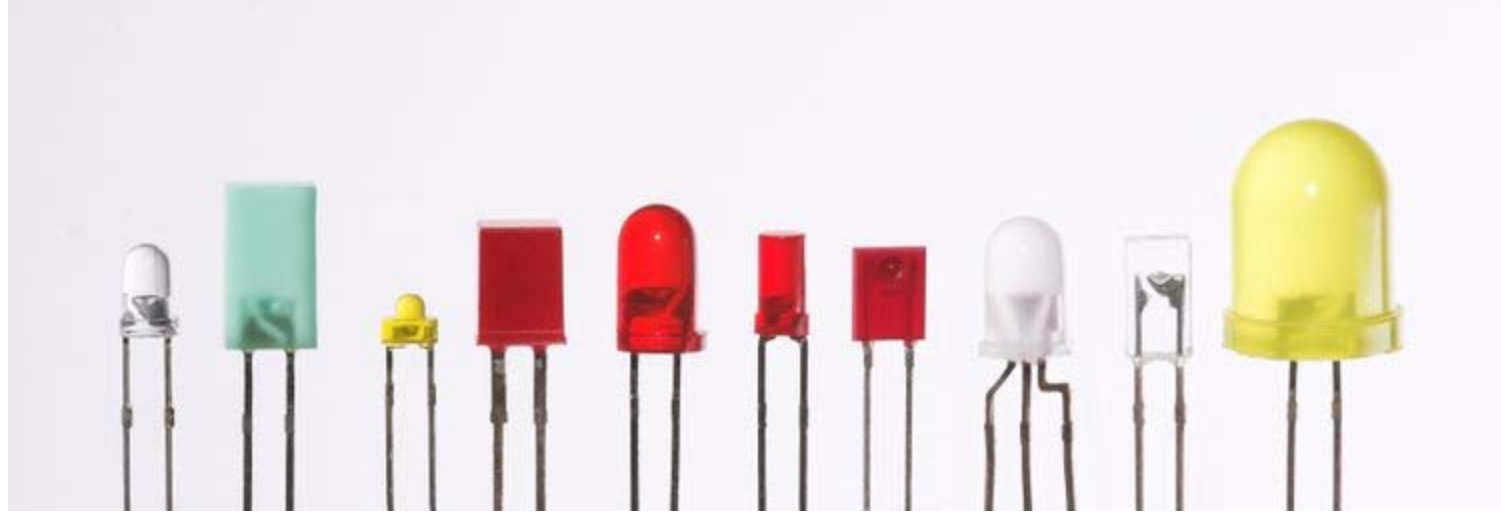
(Zener diode)



Vertical: 5 mA/div

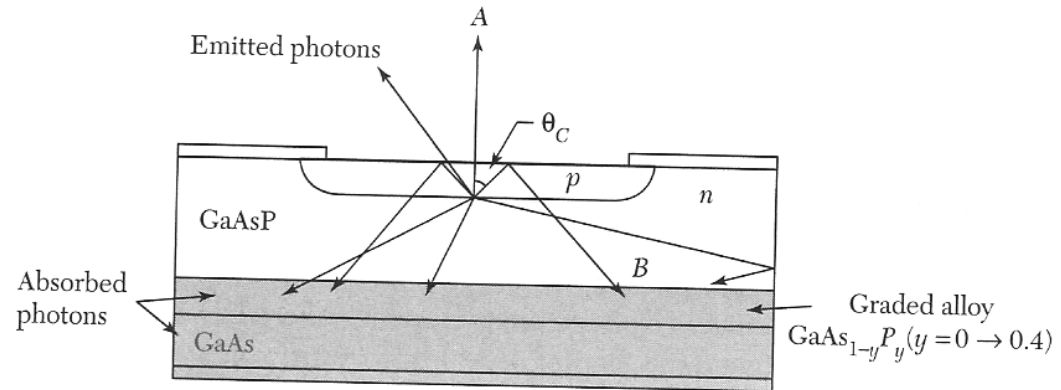
Horizontal: 5 V/div

Light emitting diodes

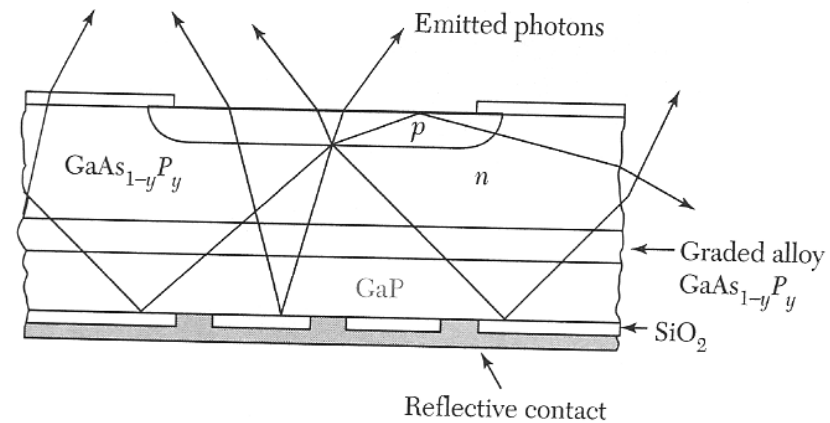


Solid state lighting is efficient.

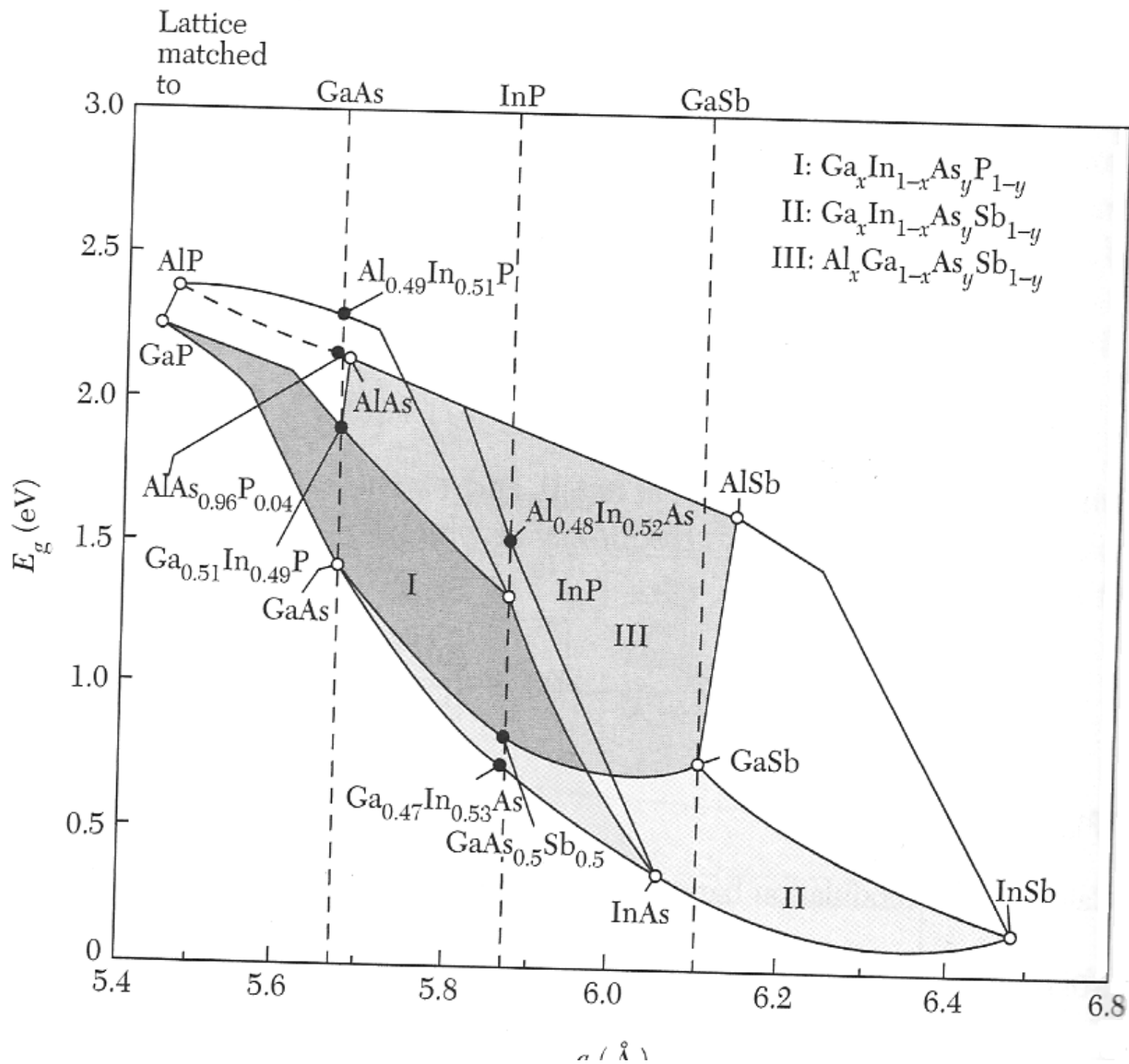
Light emitting diodes



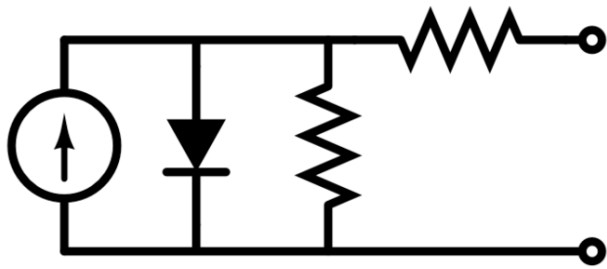
absorption
reflection
total internal reflection



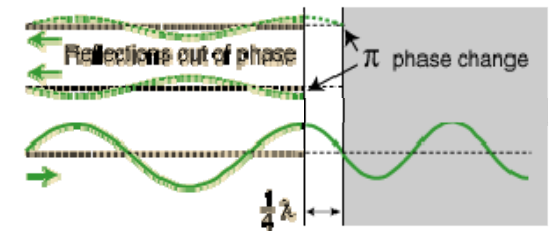
Electrons and holes are injected into the depletion region by forward biasing the junction. The electrons fall in the holes. For direct bandgap semiconductors, photons are emitted. For indirect bandgap semiconductors, phonons are emitted.



Solar cell



Equivalent circuit



Solar spectrum

