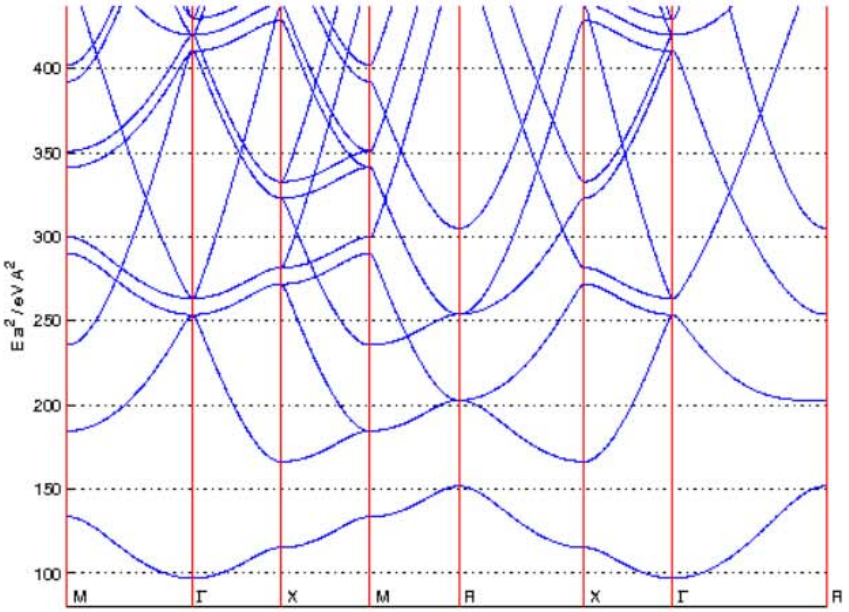
Semiconductor devices

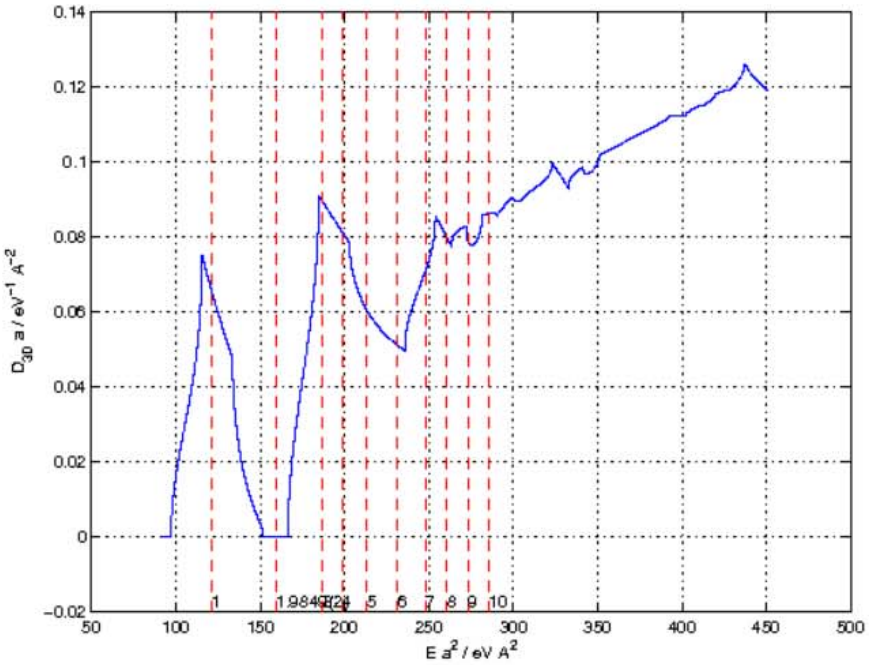
metals, semiconductors, and insulators

v = 17.024, b = 0.4951, n = 2

v - - | v++ | b - - | b++ | n - - | n++



Dispersion relation



Density of states

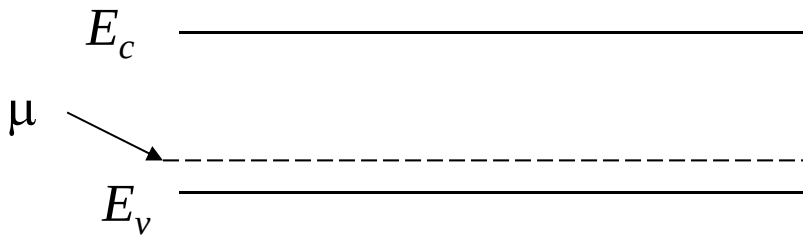
http://lampx.tugraz.at/~hadley/ss1/separablecrystals/thermo.html

pn junction

under normal operation conditions

p-type

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

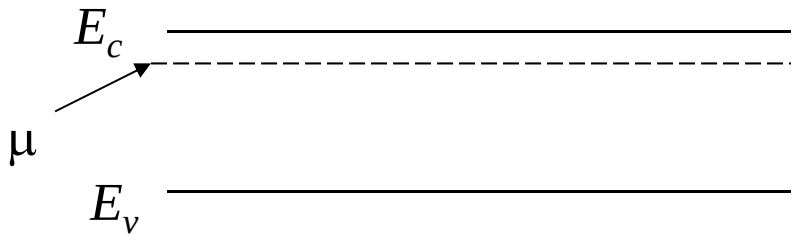


$$p = N_v \exp\left(\frac{E_v - \mu}{k_B T}\right)$$

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

n-type

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

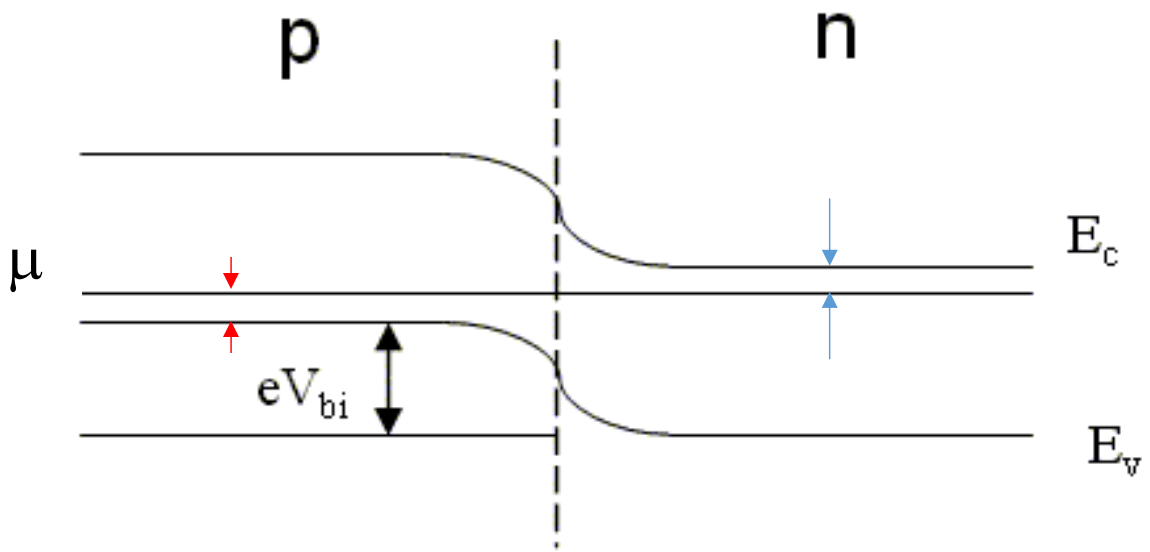


$$n = N_c \exp\left(\frac{\mu - E_c}{k_B T}\right)$$

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

Semiconductor devices Kittel p. 503 - 512

V_{bi} built-in voltage



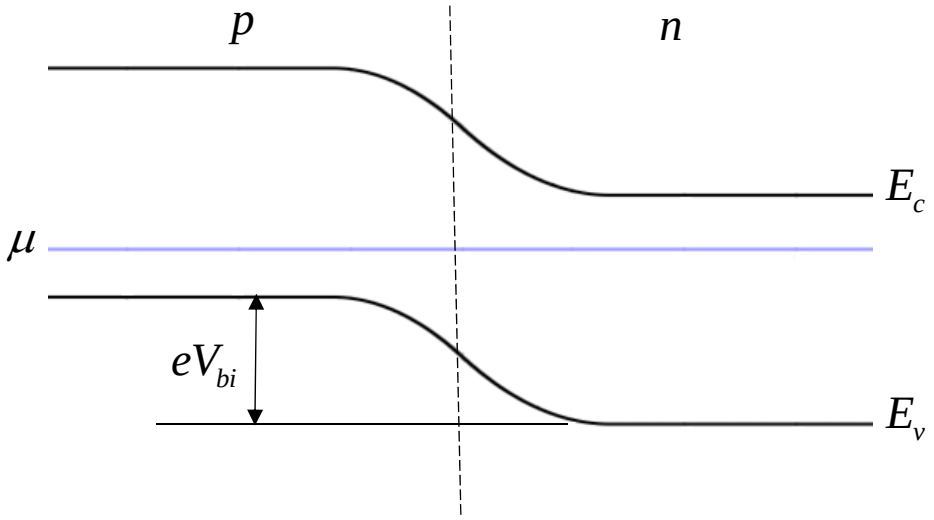
law of mass action

$$n_i^2 = N_c N_v \exp\left(\frac{-E_g}{k_B T}\right)$$

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

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

p and n profiles



$V_{bi} \sim 1$ V

$W \sim 1$ μm

$E_{max} \sim 10^4$ V/cm

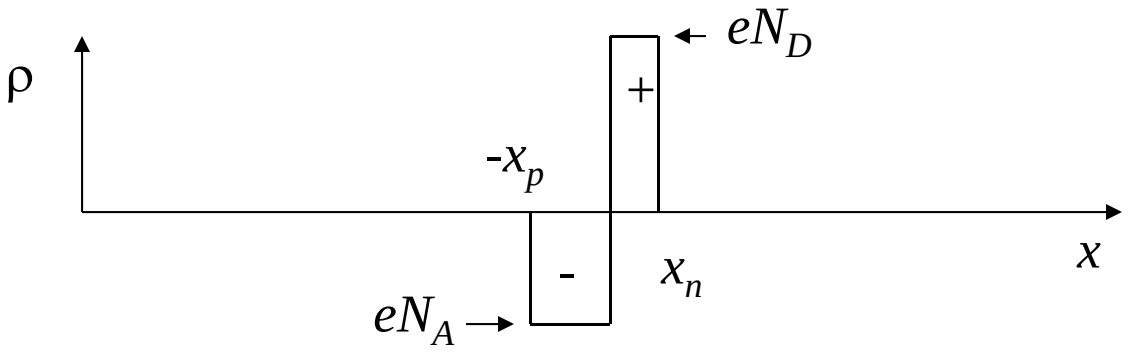
$$p = N_v \exp\left(\frac{E_v - \mu}{k_B T}\right)$$

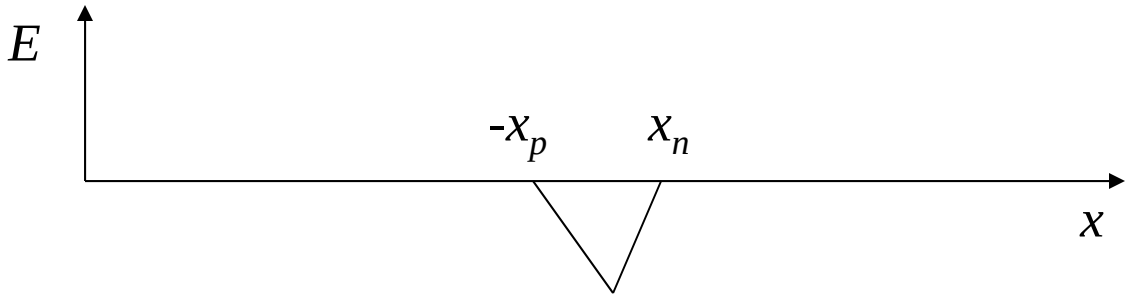
$$n = N_c \exp\left(\frac{\mu - E_c}{k_B T}\right)$$

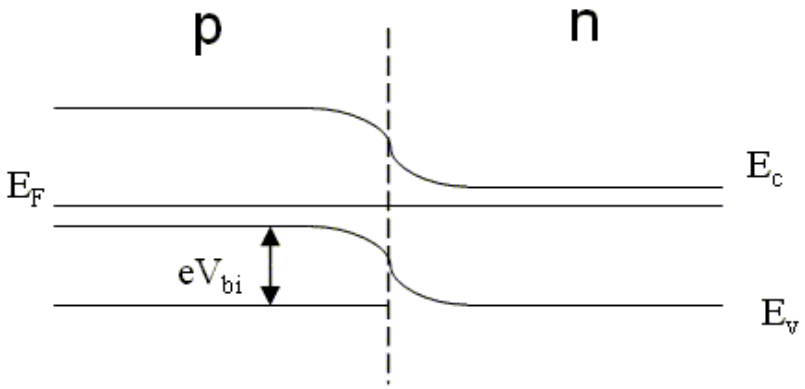
The electric field pushes the electrons towards the n-region and the holes towards the p-region.

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

depletion approximation







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

$$E = -\frac{eN_A}{\varepsilon}\left(x + x_p\right) \qquad -x_p > x > 0$$

$$E = \frac{eN_D}{\varepsilon}\left(x - x_n\right) \qquad 0 > x > x_n$$

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

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

Abrupt pn junctions in the depletion approximation

In an abrupt pn junction, the doping changes abruptly from p to n. It is common to solve for the band bending, the local electric field, the carrier concentration profiles, and the local conductivity in the depletion approximation. In this approximation it is assumed that there is a depletion width W around the transition from p to n where the charge carrier densities are negligible. Outside the depletion width the charge carrier densities are equal to the doping densities so that the semiconductor is electrically neutral outside the depletion width. Using this approximation it is possible to calculate the important properties of the pn junction.

N_A = 1E15 1/cm³ N_D = 1E15 1/cm³ E_g = 1.166-4.73E-4*T*T/(T+636) eV

$N_v(300)$ = 9.84E18 1/cm³ $N_c(300)$ = 2.78E19 1/cm³ ϵ_r = 12 T = 300 K

μ_p = 480 cm²/V s μ_n = 1350 cm²/V s τ_p = 1E-10 s τ_n = 1E-10 s

V = -0.5 V

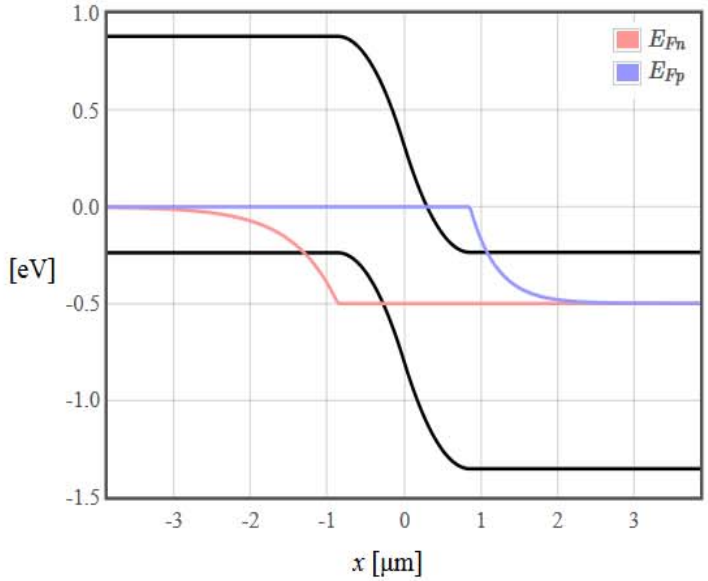
V

Submit

$E_g = 1.12$ eV $W = 1.72$ µm $x_p = -0.861$ µm $x_n = 0.861$ µm $V_{bi} = 0.618$ V $C_j = 6.17$ nF/cm²

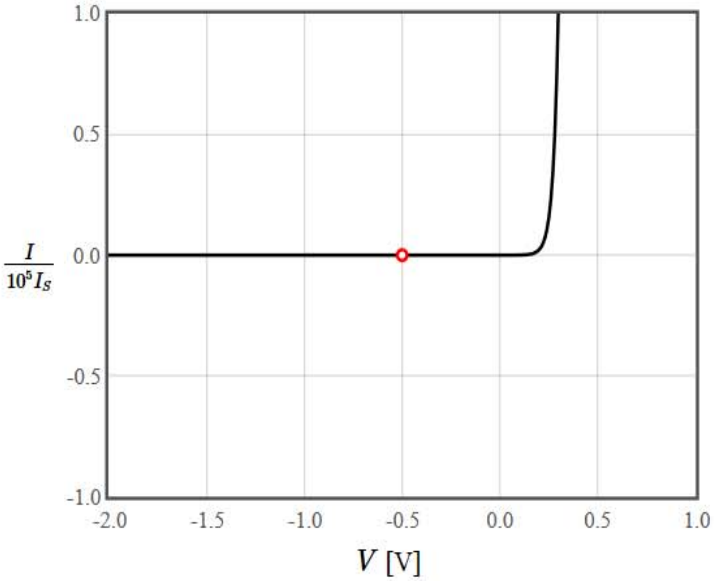
$D_p = 12.4$ cm²/s $D_n = 34.9$ cm²/s $L_p = 0.352$ µm $L_n = 0.591$ µm

Band diagram



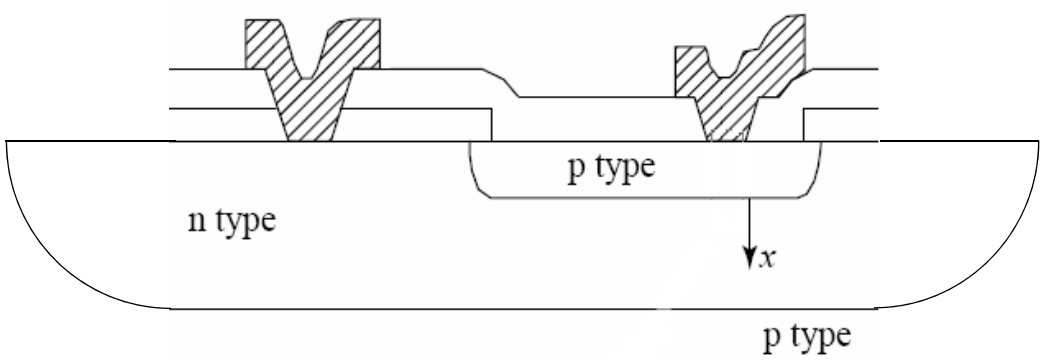
Charge density

Current-Voltage Characteristics

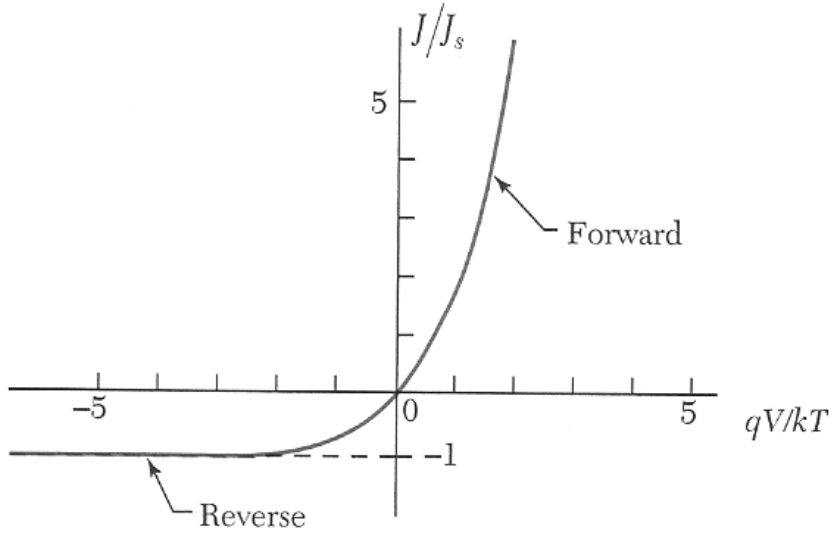


Electric field

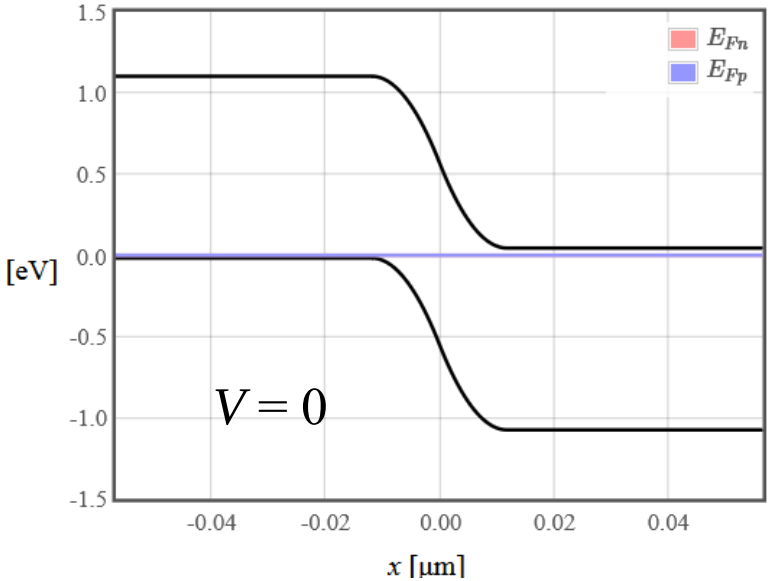
Diode

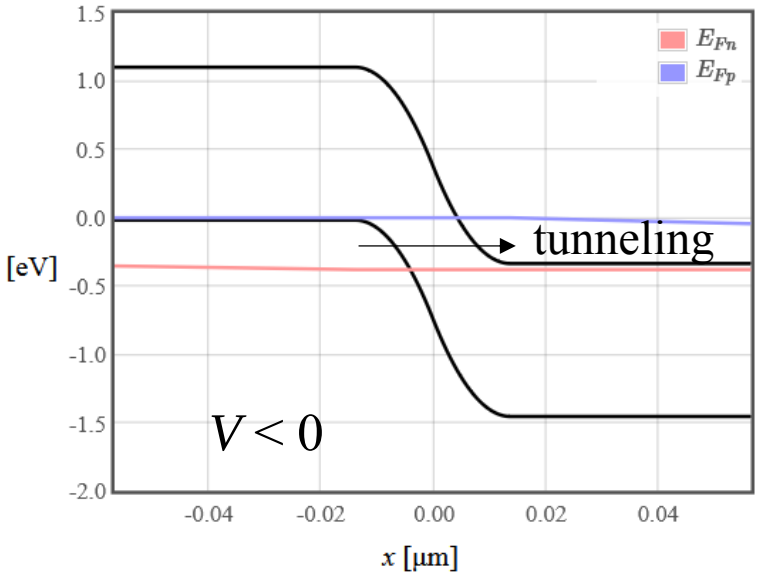


$$I = I_s\left(\exp\left(\frac{eV}{k_BT}\right)-1\right)$$

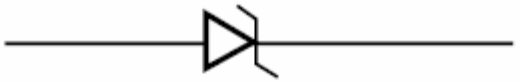


Zener tunneling

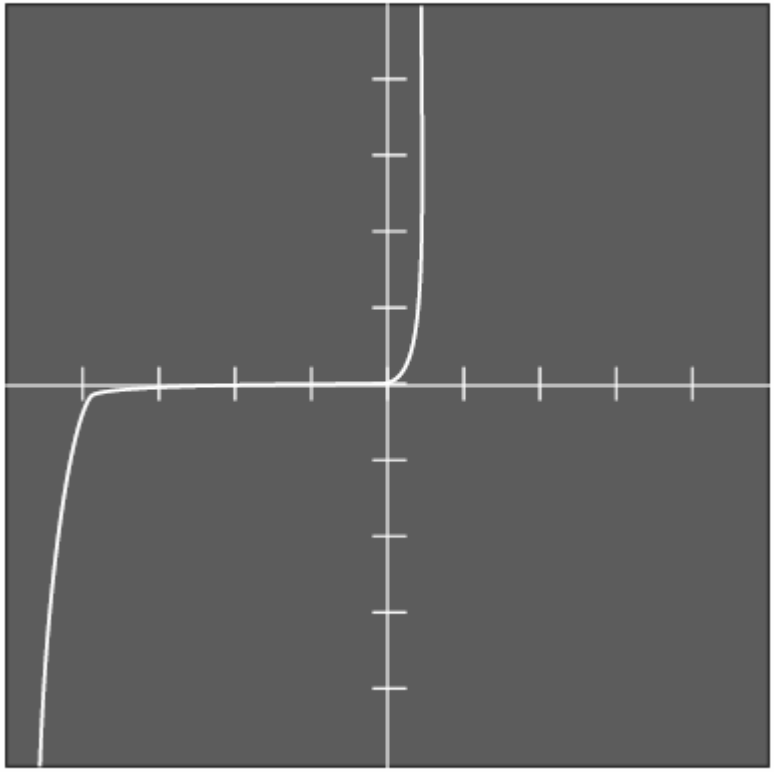




Occurs at high doping

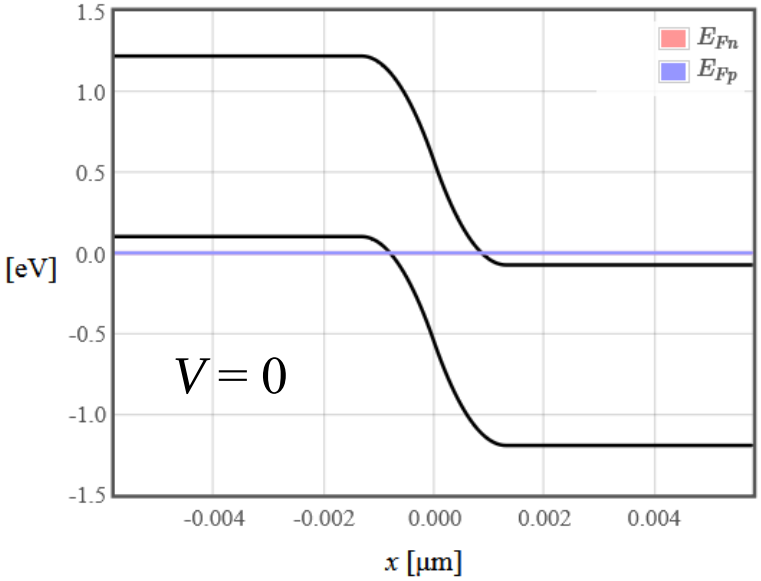


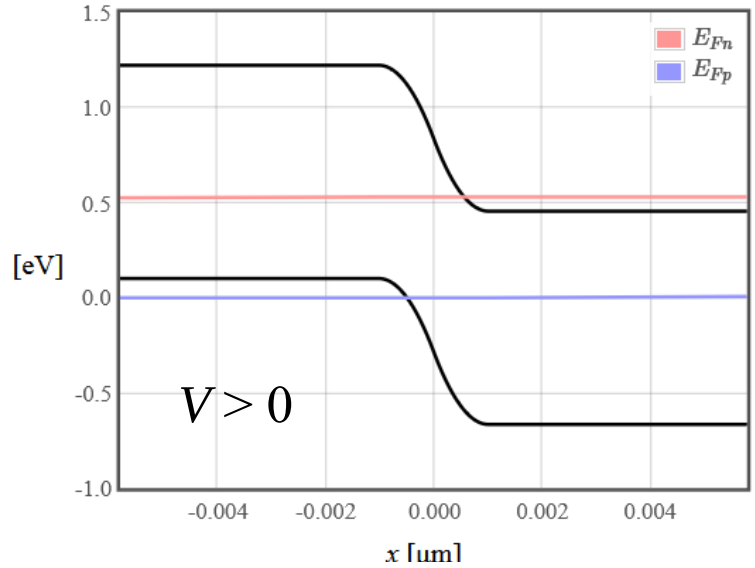
(Zener diode)



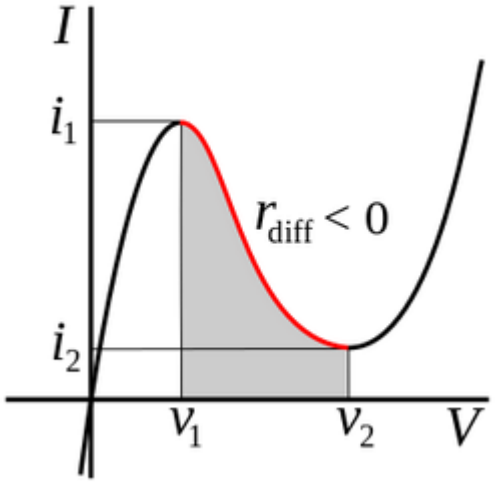
Vertical: 5 mA/div
Horizontal: 5 V/div

Esaki diode / tunnel diode



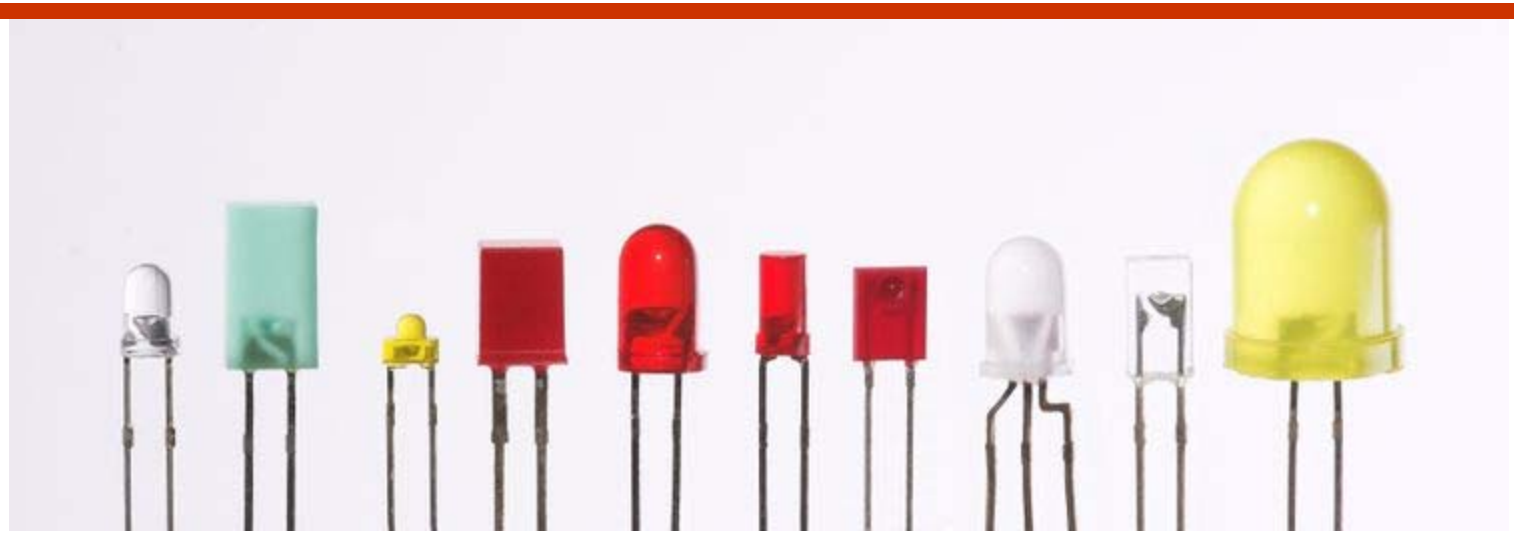


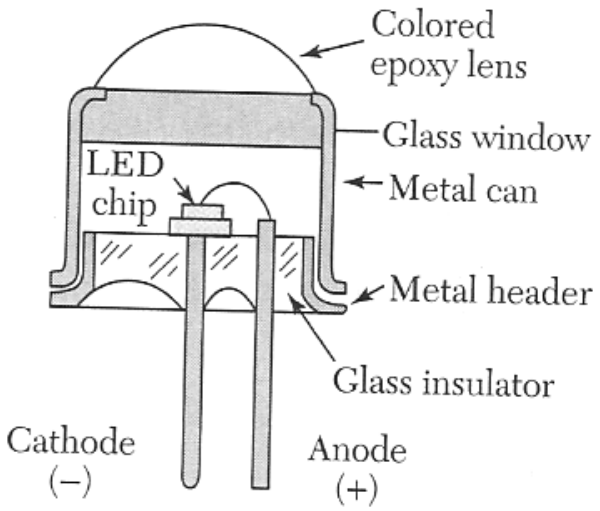
Degenerate doping

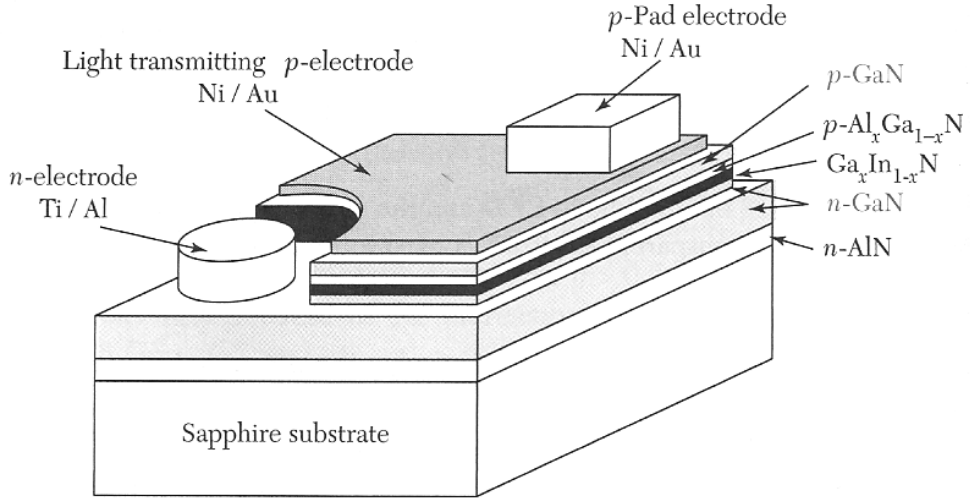


https://en.wikipedia.org/wiki/Tunnel_diode#/media/File:Voltage_controlled_negative_resistance.svg

Light emitting diodes







Solid state lighting is efficient.