Density of states: spread out of energy (valance electrons) with energy distributed.

N_c - effective DOS of conduction band
N_v - " " " " valence band.

No two electrons can have the same overall energy

\[ f(E) = \frac{1}{1 + e^{\frac{E - E_F}{kT}}} \quad E_F = 0 \text{ to } 1 \]

The concentration of electrons in the conduction band:

\[ n = N_c \exp\left(\frac{E_F - E_c}{kT}\right) \]

\[ p = N_v \exp\left(\frac{E_v - E_F}{kT}\right) \]

Rearranging the two equations and looking at an intrinsic semiconductor

\[ N_c = n_i \exp\left(\frac{E_F - E_{c_i}}{kT}\right) \]

\[ N_v = n_i \exp\left(\frac{E_{v_i} - E_F}{kT}\right) \]
Carrier concentration in non-intrinsic material.

\[ n = n_i \exp \left( \frac{E_F - E_F^0}{kT} \right) \]

\[ \rho = n_i \exp \left( \frac{E_F^0 - E_F}{kT} \right) \]

It turns out that from above

\[ n \cdot \rho = n_i^2 \]

\[ n \cdot \rho = n_i^2 \exp \left( \frac{E_F - E_F^0}{kT} \right) \exp \left( \frac{E_F^0 - E_F}{kT} \right) \]

\[ \exp \left( \frac{E_F - E_F^0 + E_F^0 - E_F}{kT} \right) \]

\[ \exp \frac{0}{kT} = 1 \]

\[ \therefore n \cdot \rho = n_i^2 \]

Overall neutrality of charge must be conserved.

So that

\[ n - \rho = N_D - N_A \]

\[ \rho - n = N_A - N_D \]

# of holes

# of electrons

acceptor atom (has a hole)

donor atom (has an electron)

\[ \text{positive ion} \]

\[ \text{negative ion} \]
For an intrinsic semiconductor

\[ p - n = N_A - N_D \]

\[ np = n_i^2 \]

\[ \frac{n_i^2}{n} = \frac{p}{n} \]

\[ \frac{n_i^2}{n} - n = N_A - N_D \]

\[ n_i^2 - n^2 = n(N_A - N_D) \]

\[ n_i^2 - n^2 - n(N_A - N_D) = 0 \]

complete ionization of dopants. (intrinsic behavior of both Si and \( n \))

No dopants leads to \( N_A = N_D = 0 \)

so \( n = n_i \)

Singly charged vacancies in doped silicon.

related to intrinsic silicon.

\[ \frac{n}{n_i} = \exp \left( \frac{E_F - E_F^i}{kT} \right) \]

Diffusion is proportional to doping concentration

Deal-Grove balance between reaction and diffusion

\[ k_s (C_r - C_e) = D \frac{C_r - C_i}{l} \]

slow

fast