Conduction (1A)

- Drift Current
- Diffusion Current

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The Density of Energy States (1)

$$E - E_c = \frac{h^2}{8\pi^2 m^*} k^2$$

$$E - E_v = -\frac{h^2}{8\pi^2 m_v} k^2$$

$$E_c - E_v = E_g$$

The Density of States

To determine
the number of allowed states
per unit volume
as a function of energy

$$N(E) = 4\pi \left(\frac{2m}{h^2}\right)^{3/2} E^{(1/2)}$$

$$N(E)dE = 4\pi \left(\frac{2m}{h^2}\right)^{3/2} E^{(1/2)} dE$$

The Density of Energy States (2)

$$E - E_c = \frac{h^2}{8\pi^2 m^*} k^2$$

$$E_v - E = \frac{h^2}{8\pi^2 m_v} k^2$$

$$E_c - E_v = E_g$$

$$4\pi \left(\frac{2m^*}{h^2}\right)^{3/2} (E - E_c)^{(1/2)} dE$$

$$4\pi \left(\frac{2m_v}{h^2}\right)^{3/2} (E_v - E)^{(1/2)} dE$$

The Density of Energy States

To determine

the number of allowed *<u>states</u>*

per unit *<u>volume</u>*

as a function of energy

$$N(E) = 4\pi \left(\frac{2m}{h^2}\right)^{3/2} E^{(1/2)}$$

$$N(E)dE = 4\pi \left(\frac{2m}{h^2}\right)^{3/2} E^{(1/2)} dE$$

The Density of Occupied States

$$E - E_c = \frac{h^2}{8\pi^2 m^*} k^2$$

$$E_v - E = \frac{h^2}{8\pi^2 m_v} k^2$$

$$E_c - E_v = E_g$$

$$4\pi \left(\frac{2m^*}{h^2}\right)^{3/2} (E - E_c)^{(1/2)} dE$$

$$4\pi \left(\frac{2m_v}{h^2}\right)^{3/2} (E_v - E)^{(1/2)} dE$$

The density of occupied state

The product of
the density of allowed states and the
probability of occupation

$$N_e dE = N(E) f(E) dE$$

$$N_p dE = N(E) f_p(E) dE$$

The concentration of electrons

$$n = \int_0^\infty N(E) f(E) dE$$

The concentration of holes

$$p = \int_0^\infty N(E) f_p(E) dE$$

Fermi-Dirac Distribution Function (1)

$$f(E) = \frac{1}{1 + e^{(E - E_f)/kT}}$$

$$f_p(E) = 1 - f(E)$$

$$= 1 - \frac{1}{1 + e^{(E - E_f)/kT}}$$

$$= \frac{1 + e^{(E - E_f)/kT} - 1}{1 + e^{(E - E_f)/kT}}$$

$$= \frac{e^{(E - E_f)/kT}}{1 + e^{(E - E_f)/kT}}$$

$$= \frac{1}{e^{-(E - E_f)/kT} + 1}$$

$$= \frac{1}{e^{(E_f - E)/kT} + 1}$$

$$f(E) = \frac{1}{1 + e^{(E - E_f)/kT}}$$

$$f_p(E) = \frac{1}{1 + e^{(E_f - E)/kT}}$$

Fermi-Dirac Distribution Function (2)

$$f(E) = \frac{1}{1 + e^{(E - E_f)/kT}}$$

$$f(E) = \frac{1}{1 + e^{(E - E_f)/kT}}$$

$$f_p(E) = 1 - f(E)$$

$$f_p(E) = \frac{1}{1 + e^{(E_f - E)/kT}}$$

For electrons $e^{(E - E_f)/kT} \gg 1$

$$f(E) = \frac{1}{1 + e^{(E - E_f)/kT}} \simeq \frac{1}{e^{(E - E_f)/kT}}$$

$$f(E) \simeq e^{-(E - E_f)/kT}$$

For holes $e^{(E_f - E)/kT} \gg 1$

$$f_p(E) = \frac{1}{1 + e^{(E_f - E)/kT}} \simeq \frac{1}{e^{(E_f - E)/kT}}$$

$$f_p(E) \simeq e^{-(E_f - E)/kT}$$

Electron Concentration

$$n = \int_0^\infty N(E) e^{-(E-E_f)/kT} f(E)\, dE$$

$$f(E) \simeq e^{-(E-E_f)/kT}$$

$$= \int_0^\infty 4\pi \left(\frac{2m^*}{h^2}\right)^{3/2} (E-E_c)^{1/2} e^{-(E-E_f)/kT} dE$$

$$(E-E_f) = (E-E_c) + (E_c - E_f)$$

$$= \int_0^\infty 4\pi \left(\frac{2m^*}{h^2}\right)^{3/2} (E-E_c)^{1/2} e^{-(E-E_c)/kT} e^{-(E_c-E_f)/kT} dE$$

$$= 4\pi \left(\frac{2m^*}{h^2}\right)^{3/2} e^{(E_f-E_c)/kT} \int_0^\infty (E-E_c)^{1/2} e^{-(E-E_c)/kT} dE$$

$$\int_0^\infty x^{1/2} e^{-ax} dx = \frac{1}{2a}\sqrt{\frac{\pi}{a}} = \frac{\pi^{1/2}}{2a^{3/2}}$$

$$= 4\pi \left(\frac{2m^*}{h^2}\right)^{3/2} e^{(E_f-E_c)/kT} \left(\frac{\frac{\pi^{1/2}}{2}}{(kT)^{3/2}}\right)$$

$$= 2\left(\frac{2\pi m^* kT}{h^2}\right)^{3/2} e^{(E_f-E_c)/kT} = N_c \cdot e^{(E_f-E_c)/kT}$$

$$n = N_c\, e^{(E_f-E_c)/kT}$$

Hole Concentration

$$p = \int_0^\infty N(E) e^{-(E_v - E)/kT} f_p(E) dE$$

$$f_p(E) \simeq e^{-(E_f - E)/kT}$$

$$= \int_0^\infty 4\pi \left(\frac{2m_v}{h^2}\right)^{3/2} (E_v - E)^{1/2} e^{-(E_f - E)/kT} dE$$

$$(E_f - E) = (E_f - E_v) + (E_v - E)$$

$$= \int_0^\infty 4\pi \left(\frac{2m_v}{h^2}\right)^{3/2} (E_v - E)^{1/2} e^{-(E_f - E_v)/kT} e^{-(E_v - E)/kT} dE$$

$$= 4\pi \left(\frac{2m_v}{h^2}\right)^{3/2} e^{(E_v - E_f)/kT} \int_0^\infty (E_v - E)^{1/2} e^{-(E_v - E)/kT} dE$$

$$\int_0^\infty x^{1/2} e^{-ax} dx = \frac{1}{2a}\sqrt{\frac{\pi}{a}} = \frac{\pi^{1/2}}{2a^{3/2}}$$

$$= 4\pi \left(\frac{2m_v}{h^2}\right)^{3/2} e^{(E_v - E_f)/kT} \left(\frac{\frac{\pi^{1/2}}{2}}{(kT)^{3/2}}\right)$$

$$= 2\left(\frac{2\pi m_v kT}{h^2}\right)^{3/2} e^{(E_v - E_f)/kT} = N_v \cdot e^{(E_v - E_f)/kT}$$

$$p = N_v e^{(E_v - E_f)/kT}$$

Intrinsic Type Concentration

$$n = N_c \, e^{(E_f - E_c)/kT}$$

$$p = N_v \, e^{(E_v - E_f)/kT}$$

$$n_i = N_c \, e^{(E_{fo} - E_c)/kT}$$

$$p_i = N_v \, e^{(E_v - E_{fo})/kT}$$

$$n\,p = N_c N_v \, e^{(E_f - E_c)/kT} \, e^{(E_v - E_f)/kT}$$

$$= N_c N_v \, e^{(E_v - E_c)/kT} = N_c N_v \, e^{-E_g/kT}$$

$$n_i\,p_i = N_c N_v \, e^{(E_{fo} - E_c)/kT} \, e^{(E_v - E_{fo})/kT}$$

$$= N_c N_v \, e^{(E_v - E_c)/kT} = N_c N_v \, e^{-E_g/kT}$$

$$n_i^2 = N_c N_v \, e^{-E_g/kT}$$

$$n_i = p_i = (N_c N_v)^{1/2} \, e^{\frac{-E_g}{2kT}}$$

References

[1] http://en.wikipedia.org/