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 <u>states</u> per unit <u>volume</u> as a function of energy

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

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

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The Density of Energy States (2)

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

The Density of Energy States

To determine the number of allowed <u>states</u> per unit <u>volume</u> as a function of energy

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

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

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

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

The Density of Occupied States

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

The density of occupied state

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

The concentration of electrons

The concentration of holes

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

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

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

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

$$n = \int_{0}^{\infty} N(E)f(E)dE$$
$$p = \int_{0}^{\infty} N(E)f_{p}(E)dE$$

Fermi-Dirac Distribution Function (1)

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

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

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

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

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

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

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

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

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

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

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

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

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

Electron Concentration

$$\begin{split} n &= \int_{0}^{\infty} N(E) e^{-(E-E_{f})/kT} f(E) dE & f(E) \simeq e^{-(E-E_{f})/kT} \\ &= \int_{0}^{\infty} 4\pi \left(\frac{2m^{*}}{h^{2}}\right)^{3/2} (E-E_{c})^{1/2} e^{-(E-E_{f})/kT} dE & (E-E_{f}) = (E-E_{c}) + (E_{c}-E_{f}) \\ &= \int_{0}^{\infty} 4\pi \left(\frac{2m^{*}}{h^{2}}\right)^{3/2} (E-E_{c})^{1/2} e^{-(E-E_{c})/kT} e^{-(E_{c}-E_{f})/kT} dE \\ &= 4\pi \left(\frac{2m^{*}}{h^{2}}\right)^{3/2} e^{(E_{f}-E_{c})/kT} \int_{0}^{\infty} (E-E_{c})^{1/2} e^{-(E-E_{c})/kT} dE \\ &= 4\pi \left(\frac{2m^{*}}{h^{2}}\right)^{3/2} e^{(E_{f}-E_{c})/kT} \int_{0}^{\infty} (E-E_{c})^{1/2} e^{-(E-E_{c})/kT} dE \\ &= 4\pi \left(\frac{2m^{*}}{h^{2}}\right)^{3/2} e^{(E_{f}-E_{c})/kT} \left(\frac{\pi^{1/2}}{\frac{2}{(kT)^{3/2}}}\right) \\ &= 2 \left(\frac{2\pi m^{*} kT}{h^{2}}\right)^{3/2} e^{(E_{f}-E_{c})/kT} = N_{c} \cdot e^{(E_{f}-E_{c})/kT} \quad n = N_{c} e^{(E_{f}-E_{c})/kT} \end{split}$$

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Hole Concentration

$$\begin{split} p &= \int_{0}^{\infty} N(E) e^{-(E_{v} - E)/kT} f_{p}(E) dE & f_{p}(E) \simeq e^{-(E_{f} - E)/kT} \\ &= \int_{0}^{\infty} 4\pi \left(\frac{2m_{v}}{h^{2}}\right)^{3/2} (E_{v} - E)^{1/2} e^{-(E_{f} - E)/kT} dE & (E_{f} - E) = (E_{f} - E_{v}) + (E_{v} - E) \\ &= \int_{0}^{\infty} 4\pi \left(\frac{2m_{v}}{h^{2}}\right)^{3/2} (E_{v} - E)^{1/2} e^{-(E_{f} - E_{v})/kT} e^{-(E_{v} - E)/kT} dE \\ &= 4\pi \left(\frac{2m_{v}}{h^{2}}\right)^{3/2} e^{(E_{v} - E_{f})/kT} \int_{0}^{\infty} (E_{v} - E)^{1/2} e^{-(E_{v} - E)/kT} dE \\ &= 4\pi \left(\frac{2m_{v}}{h^{2}}\right)^{3/2} e^{(E_{v} - E_{f})/kT} \left(\frac{\pi^{1/2}}{\frac{2}{(kT)^{3/2}}}\right) \\ &= 2\left(\frac{2\pi m_{v}kT}{h^{2}}\right)^{3/2} e^{(E_{v} - E_{f})/kT} = N_{v} \cdot e^{(E_{v} - E_{f})/kT} \qquad p = N_{v} e^{(E_{v} - E_{f})/kT} \end{split}$$

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Intrinsic Type Concentration

$$n = N_{c} e^{(E_{f} - E_{c})/kT} \qquad np = N_{c} N_{v} e^{(E_{r} - E_{c})/kT} e^{(E_{v} - E_{f})/kT}$$
$$p = N_{v} e^{(E_{v} - E_{f})/kT} \qquad = N_{c} N_{v} e^{(E_{v} - E_{c})/kT} = N_{c} N_{v} e^{-E_{g}/kT}$$

$$n_{i} = N_{c} e^{(E_{fo} - E_{c})/kT}$$

$$n_{i} p_{i} = N_{c} N_{v} e^{(E_{v} - E_{c})/kT} e^{(E_{v} - E_{c})/kT}$$

$$= N_{c} N_{v} e^{(E_{v} - E_{c})/kT} = N_{c} N_{v} e^{-E_{s}/kT}$$

$$n_{i}^{2} = N_{c} N_{v} e^{-E_{g}/kT}$$
$$n_{i} = p_{i} = (N_{c} N_{v})^{1/2} e^{\frac{-E_{g}}{2kT}}$$

References

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