Lecture 10

Reading Material

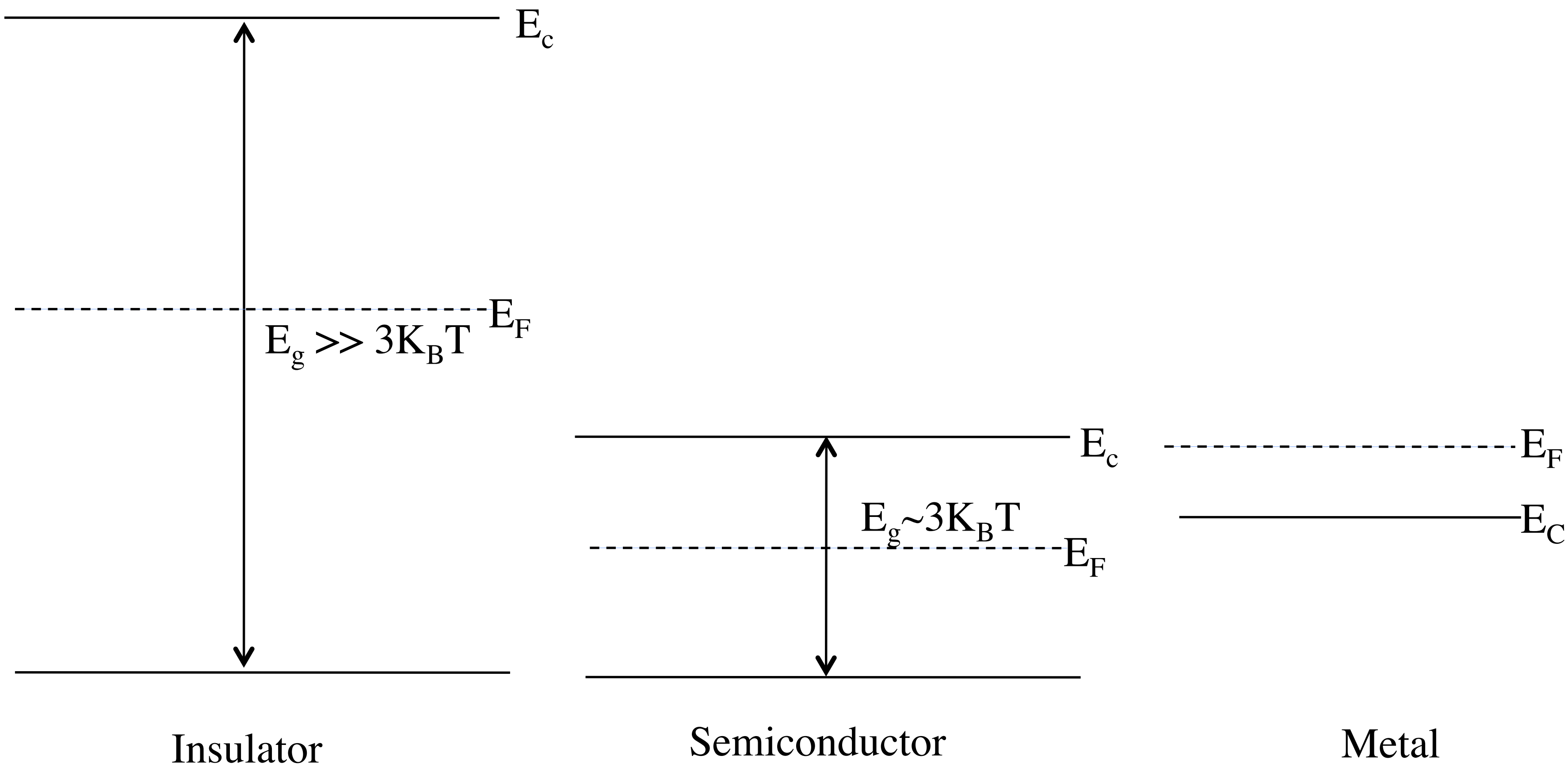
Reading:

Chapter 8 Solymar and Walsh

Intrinsic Semiconductors

- The first step in using semiconductors is to try to purify them as much as possible and then the second step is to introduce a controlled amount of impurities so that the material and electronic/optical properties can be designed and controlled.
- The pure semiconductor is called an "intrinsic" semiconductor
- A semiconductor with impurities introduced is called an "extrinsic" semiconductor
- Most devices are extrinsic semiconductors
- We will start the discussion with intrinsic SCs first to understand the basic behavior.

Semiconductor Bandgaps



Carriers

- There are two types of carriers (charge that contributes to current)
  - Electrons – negatively charged particles
  - Holes – Can be treated as positively charged particles even though really the absence of an electronic bond
- Holes contribute to current in the valence band and electrons contribute to current in the conduction band
- By convention we take the direction of current to be opposite the direction of flow of electrons
- The direction convention is so that both electron and hole flow mathematically contribute to the total current flow

Intrinsic Semiconductors

- First assume that only electrons at the bottom of the conduction band and holes at the top of the valence band are of current importance (we will modify this later)

$k_x a,\ k_y b,\ k_x c << 1$

$$E = E_1 - 2A_x \cos(k_x a) - 2A_y \cos(k_y b) - 2A_z \cos(k_z c), \text{ expanding in Taylor Series}$$

$$= E_1 - 2A_x\left(1 - \frac{1}{2}k_x^2 a^2\right) - 2A_y\left(1 - \frac{1}{2}k_y^2 b^2\right) - 2A_z\left(1 - \frac{1}{2}k_z^2 c^2\right)$$

$$m^* = \hbar^2\left(\frac{\partial^2 E}{\partial k^2}\right) = \hbar\left(\frac{\partial^2\left[E_1 - 2A_x\left(1 - \frac{1}{2}k_x^2 a^2\right) - 2A_y\left(1 - \frac{1}{2}k_y^2 b^2\right) - 2A_z\left(1 - \frac{1}{2}k_z^2 c^2\right)\right]}{\partial k^2}\right)$$

$$m_x^* = \frac{\hbar^2}{2A_x a^2},\ m_y^* = \frac{\hbar^2}{2A_y b^2},\ m_x^* = \frac{\hbar^2}{2A_z c^2}$$

$$A_x a^2 = \frac{\hbar^2}{2m_x^*},\ A_y b^2 = \frac{\hbar^2}{2m_y^*},\ A_z c^2 = \frac{\hbar^2}{2m_z^*}$$

$$E = E_1 - \left(2A_x - k_x^2 A_x a^2\right) - \left(2A_y - k_y^2 A_y b^2\right) - \left(2A_z - k_z^2 A_z c^2\right)$$

$$= E_1 - 2A_x - 2A_y - 2A_z + \left[k_x^2 A_x a^2 + k_y^2 A_y b^2 + k_z^2 A_z c^2\right]$$

$$= E_1 - 2A_x - 2A_y - 2A_z + \left[k_x^2\frac{\hbar^2}{2m_x^*} + k_y^2\frac{\hbar^2}{2m_y^*} + k_z^2\frac{\hbar^2}{2m_z^*}\right]$$

$$= E_0 + \frac{\hbar^2}{2}\left[\frac{k_x^2}{m_x^*} + \frac{k_y^2}{m_y^*} + \frac{k_z^2}{m_z^*}\right], \text{ where } E_0 = E_1 - 2A_x - 2A_y - 2A_z$$

Intrinsic Semiconductors

- Now lets take E_0 =0 and assume the effective masses are equal

$$m_x^* = m_y^* = m_z^* = m^*$$

$$A_x a^2 = \frac{\hbar^2}{2m_x^*},\ A_y b^2 = \frac{\hbar^2}{2m_y^*},\ A_z c^2 = \frac{\hbar^2}{2m_z^*}$$

$$E = \frac{\hbar^2}{2m^*}\left[k_x^2 + k_y^2 + k_z^2\right]$$

Fermi-Dirac Statistics

- The probability that a state at energy (E) is occupied by an electron is given by

$$f(E) = \frac{1}{e^{(E-E_F)/\kappa_B T} + 1}$$

- ⇨ Doping the semiconductor can move the Fermi level into the conduction or valance bands depending on the doping concentration

- ⇨ Disturbing the SC from TE, for example with current injection, will create Quasi-Fermi levels E_{Fc} and E_{Fv}