



Lecture 10

Reading Material



Reading:

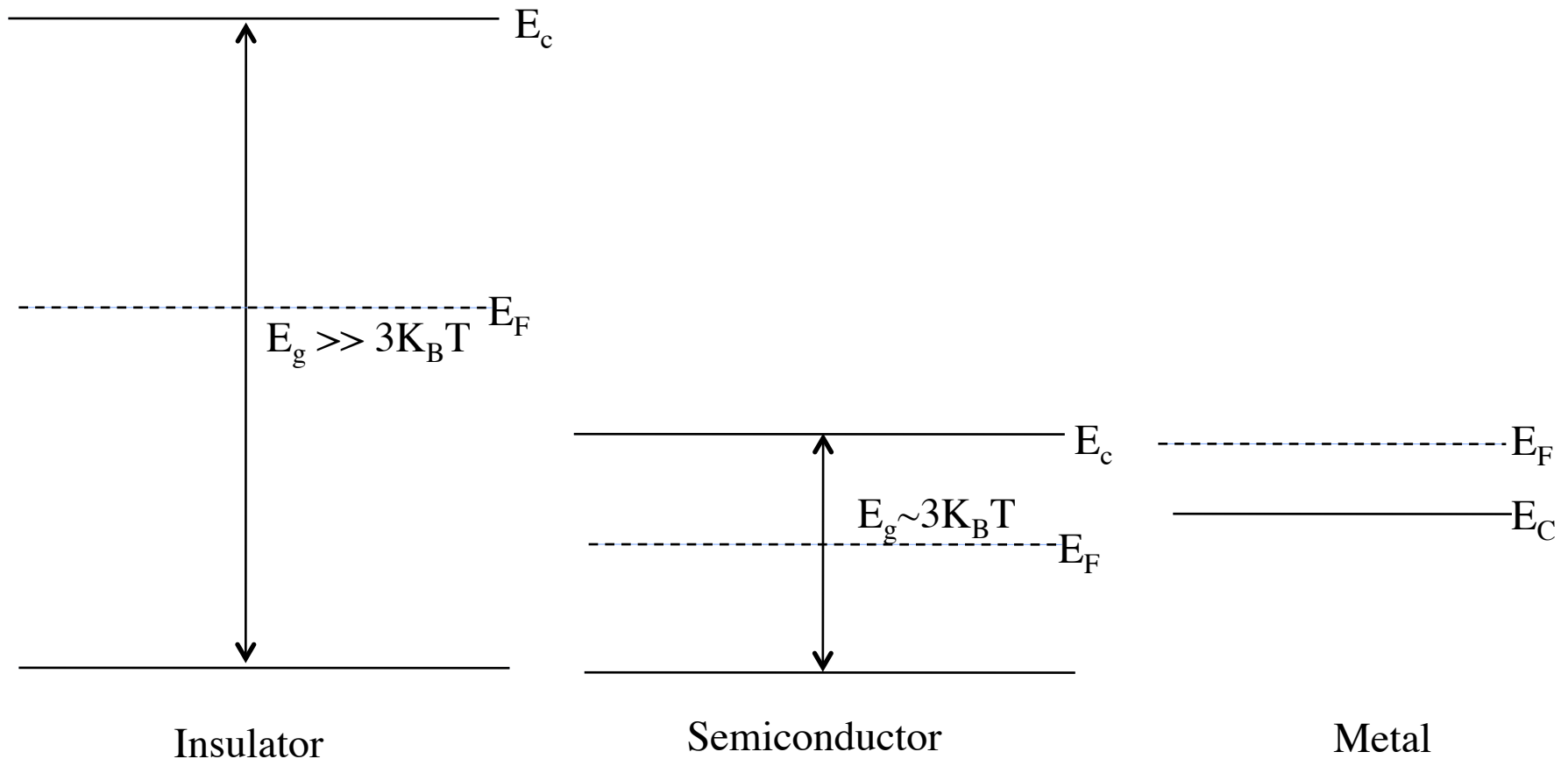
Chapter 8 Solymar and Walsh

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)

$$k_x a, k_y b, k_z c \ll 1$$

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

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

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

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

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

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

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

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

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

Intrinsic Semiconductors



- Now let's take $E_0 = 0$ and assume the effective masses are equal

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

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

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

Fermi-Dirac Statistics

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

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

- ⇒ 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}

