VE320
Intro to Semiconductor Devices

HOMEWORK 2

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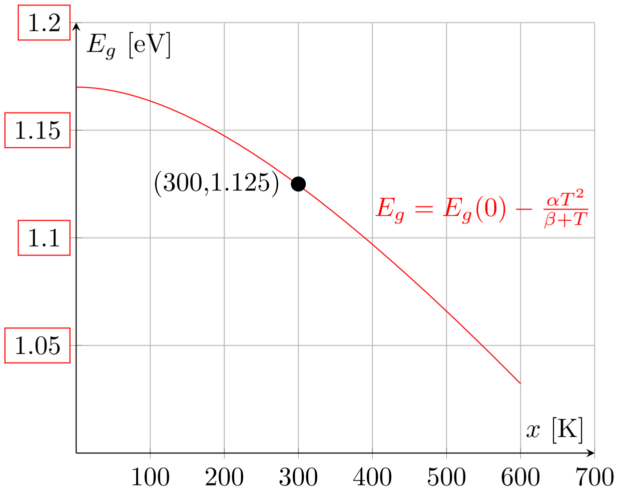
1. The graph of E_g versus T over the range $0 \le T \le 600K$ is shown in Figure 1.

`The graph of` E_g `versus T over the range` $0 \le T \le 600K$



The value at $T = 300$ K is

$$E_g = 1.170 - \frac{4.73 \times 10^{-4} T^2}{636 + T} = 1.170 - \frac{4.73 \times 10^{-4} \times (300)^2}{636 + 300} = 1.125 \text{ eV}.$$

2. (a) Using

$$\frac{1}{\hbar^2}\frac{\mathrm{d}^2E}{\mathrm{d}k^2} = \frac{2C_1}{\hbar^2} = \frac{1}{m^*},$$

at position A and D,

$$\frac{\mathrm{d}^2E}{\mathrm{d}k^2} < 0,$$

the sign of the effective mass is negative;

at position B and C,

$$\frac{\mathrm{d}^2E}{\mathrm{d}k^2} > 0,$$

the sign of the effective mass is positive.

(b) Using

$$\frac{1}{\hbar^2}\frac{\mathrm{d}E}{\mathrm{d}k} = \frac{p}{m} = v,$$

at position A and B,

$$\frac{\mathrm{d}E}{\mathrm{d}k} < 0,$$

the direction of velocity for a particle is -x;

at position C and D,

$$\frac{\mathrm{d}E}{\mathrm{d}k} > 0,$$

the direction of velocity for a particle is $+x$.

3. Using

$$\frac{1}{\hbar^2}\frac{\mathrm{d}^2E}{\mathrm{d}k^2} = \frac{2C_1}{\hbar^2} = \frac{1}{m^*},$$

we have

$$C_1 = \frac{E}{k^2}.$$

Thus,

$$C_1 = \frac{0.05 \text{ eV}}{(0.08 \times 10^{10} \text{ m}^{-1})^2}$$
$$= 1.252 \times 10^{-38} \text{ kg} \cdot \text{m}^4 \cdot \text{s}^{-2}.$$

The effective mass of the electron in material A is

$$m^* = \frac{\hbar^2}{2C_1} = \frac{\hbar^2 k^2}{2E} = 4.442 \times 10^{-31} \text{ kg}.$$

Denote the free electron mass as m_e. The effective mass in units of the free electron mass of the electron in material A is

$$m^* = \frac{m^* m_e}{m_e} = \frac{\hbar^2 k^2 m_f}{2E m_e} = 0.488 m_e.$$

Similarly, the effective mass of the electron in material B is

$$m^* = \frac{\hbar^2}{2C_2} = \frac{\hbar^2 k^2}{2E} = 4.442 \times 10^{-32} \text{ kg}.$$

The effective mass in units of the free electron mass of the electron in material B is

$$m^* = \frac{m^* m_e}{m_e} = \frac{\hbar^2 k^2 m_f}{2E m_e} = 0.0488 m_e.$$

4. (a) (i) The frequency

$$\nu = \frac{E}{h} = \frac{1.42 \times e}{h} = 3.434 \times 10^{14} \text{ Hz}.$$

Thus, the minimum frequency of an incident photon that can interact with a valence electron and elevate the electron to the conduction band is 3.434×10^{14} Hz.

(ii) The wavelength

$$\lambda = \frac{c}{\nu} = \frac{hc}{E} = \frac{hc}{1.42 \times e} = 8.731 \times 10^{-7} \text{ m}.$$

Thus, the corresponding wavelength is 8.731×10^{-7} m.

(b) (i) The frequency

$$\nu = \frac{E}{h} = \frac{1.12 \times e}{h} = 2.708 \times 10^{14} \text{ Hz}.$$

Thus, the minimum frequency of an incident photon that can interact with a valence electron and elevate the electron to the conduction band is 2.708×10^{14} Hz.

(ii) The wavelength

$$\lambda = \frac{c}{\nu} = \frac{hc}{E} = \frac{hc}{1.42 \times e} = 1.107 \times 10^{-6} \text{ m}.$$

Thus, the corresponding wavelength is 1.107×10^{-6} m.

5. The effective mass at $k = k_0$ can be calculated by

$$\frac{1}{\hbar^2} \frac{\mathrm{d}^2 E}{\mathrm{d}k^2}\bigg|_{k=k_0} = \frac{1}{m^*}. \tag{1}$$

Given $E = E_0 - E_1 \cos \alpha (k - k_0)$, the first derivative of the energy is

$$\frac{\mathrm{d}E}{\mathrm{d}k} = \alpha E_1 \sin \alpha (k - k_0).$$

The second derivative of the energy is

$$\frac{\mathrm{d}^2 E}{\mathrm{d}k^2} = \alpha^2 E_1 \cos \alpha (k - k_0).$$

At $k = k_0$,

$$\frac{\mathrm{d}^2 E}{\mathrm{d}k^2} = \alpha^2 E_1.$$

Substituting $\frac{\mathrm{d}^2 E}{\mathrm{d}k^2}$ in Eq. (1),

$$m^* = \frac{\hbar^2}{\alpha^2 E_1}.$$

Therefore, the effective mass of the particle at $k = k_0$ in terms of the equation parameters is $\frac{\hbar^2}{\alpha^2 E_1}$.