PHYS 5243

Solid State Physics

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Contents

Chapter 8 - Semiconductor Crystals

Semiconductor: 10^{-2} - 10^{9} ohm-cm at RT

Insulator: 10^{14} ohm at T=0K

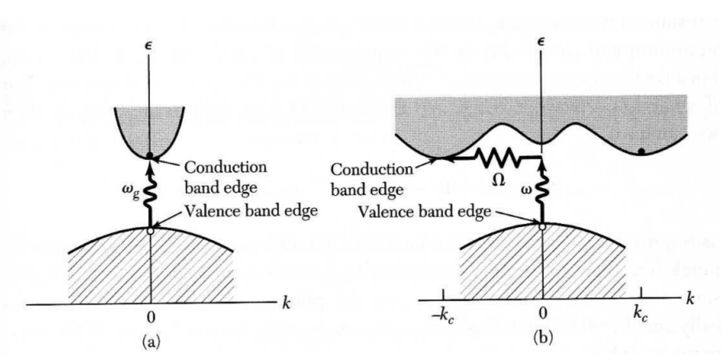
Intrinsic temperature range: Range of temperature where the electrical properties are not affected by impurities in the crystal.

Band Gap

Intrinsic conductivity σ and intrinsic carrier concentration n are controlled by $\frac{E_g}{k_B T}$. $\frac{E_g}{k_B T} >> 1 \Rightarrow n, \sigma << 1$, $\frac{E_g}{k_B T} << 1 \Rightarrow n, \sigma >> 1$.

Direct band gap:
$\mathbf{k}(photon) = \mathbf{k}_c$??
$\Rightarrow E_g = \hbar\omega$

Indirect band gap:
$\mathbf{k}(photon) = \mathbf{k}_c + \mathbf{K} \approx 0$
Emitted phonon: $\mathbf{K} = -\mathbf{k}_g \Rightarrow \hbar\omega = E_g + \hbar\Omega$
Absorbed phonon: $\mathbf{K} = \mathbf{k}_g \Rightarrow \hbar\omega = E_g - \hbar\Omega$



Equations of Motion

The motion of a wavefunction in an applied electric field. Wavepacket made up of wavefunctions assembled near a wavevector k. The group velocity is:

$$v_g = \frac{d\omega}{dk} \tag{1}$$

The frequency associated with a wavefunction of energy $\boldsymbol{\epsilon}$ is $\omega = \frac{\boldsymbol{\epsilon}}{\hbar}$ Therefore:

$$v_g = \frac{1}{\hbar}\frac{d\boldsymbol{\epsilon}}{dk} \tag{2}$$

$$\mathbf{v} = \frac{1}{\hbar}\nabla_{\boldsymbol{k}}\boldsymbol{\epsilon}(\boldsymbol{k}) \tag{3}$$

This can be used to show that an external force on an electron can be related to the change in wave vector:

$$\hbar\frac{d\mathbf{k}}{dt} = \mathbf{F} \tag{4}$$

The force term includes the Lorentz force so:

$$\hbar\frac{d\mathbf{k}}{dt} = -e\mathbf{v}\times\mathbf{B} \tag{5}$$

exchanging for the group velocity we have:

$$\hbar\frac{d\mathbf{k}}{dt} = -e\frac{1}{\hbar^2}\nabla_{\boldsymbol{k}}\boldsymbol{\epsilon}(\boldsymbol{k})\times\mathbf{B} \tag{6}$$

Which shows that electrons move along constant energy surfaces normal to the direction of the **B** field in **k** space.

Holes

1) $\mathbf{k}_h = -\mathbf{k}_e$

2) $\boldsymbol{\epsilon}_h(\mathbf{k}_h) = -\boldsymbol{\epsilon}_e(\mathbf{k}_e)$

3) $\mathbf{v}_h = -\mathbf{v}_e$

4) $m_h = -m_e$

5) $\hbar\frac{d\mathbf{k}_e}{dt} = e(\mathbf{E} + \frac{1}{c}\mathbf{v}_h\times\mathbf{B})$

Effective mass

With the free electron we notice the reciprocal effect mass $\frac{1}{m^*}$ determines the curvature of the band $\frac{d\boldsymbol{\epsilon}}{d\mathbf{k}}$ if we remember that:

$$\boldsymbol{\epsilon} = \frac{\hbar^2\mathbf{k}^2}{2m^*} \tag{7}$$