General Secince

Second Stage

Chapter five

Semiconductor

Optical Properties of Semiconductor : 2023- 2024

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The optical properties of semiconductors.

These phenomena are also used in the development of optical devices widely used in research and industry.

First we may divide the optical properties into *electronic* and *lattice* properties. Electronic properties, involving the electronic states of a solid, while lattice properties involve the vibration of the lattice (creation and absorption of phonons).

Lattice properties are of considerable current interest, but it is electronic properties which receive most attention in semiconductors, particularly so far as practical applications are concerned.

The important optical lattice properties: in which that ionic crystals exhibit strong absorption and reflection in th infrared region as a result of the interaction of light with optical phonons.

1- Fundamental Absorption Process

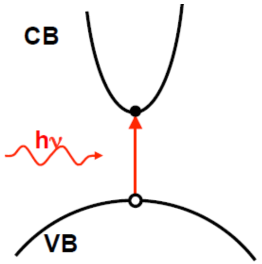
The fundamental absorption process takes place when photons with energies greater than the band gap energy of the semiconductor (i.e., $h\nu \geq E$g) incident on semiconductor are absorbed in a semiconductor. This process usually results in the generation of electron–hole pairs in the semiconductor.

In fundamental absorption, an electron absorbs a photon (from the incident beam), and jumps from the valence band into the conduction band.

For most semiconductors, the fundamental absorption process may occur in the UV, visible, and IR wavelength regimes. The most important optical absorption process involves the transition of electrons from the valence to the conduction band (Fig.

$$f \geq \frac{E_g}{h}$$

There are two types of optical transition associated with the fundamental absorption process, namely, direct and indirect band-to-band transitions, as shown in Figures (2) a and b. In a direct transition only one photon is involved, while in an indirect transition additional energy is supplied or released in the form of phonons.



Direct bandgap materials
- CB minimum and VB maximum occur at the same k
- Examples
  - GaAs, InP, InGaAsP
  - $(Al_xGa_{1-x})As$, x < 0.45

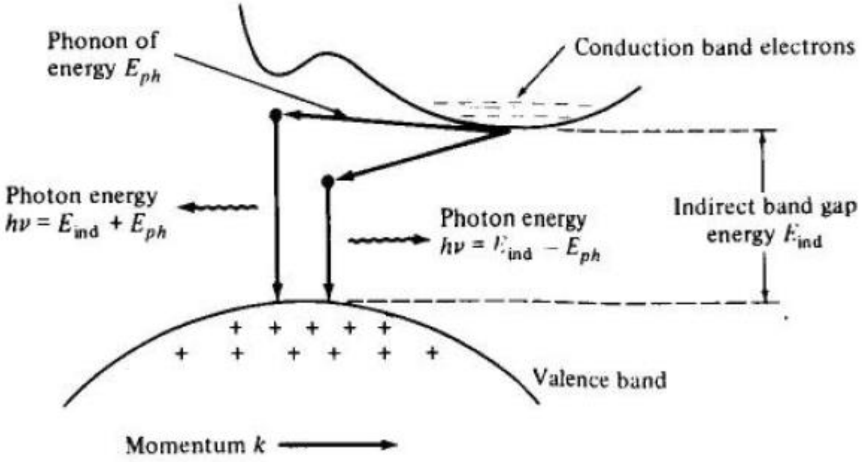


Fig. (1): The fundamental absorption process in semiconductors

Direct and Indirect Semiconductors

The type of band gap in semiconductors is important for the selection of material for many electronic devices including thermoelectric devices, solar cells and lasers.

The energy E of a particle is always associated with a wave vector k (or momentum), which implies that, for any transition between bands, both energy and momentum must be conserved. When an electron absorbs enough energy to exceed the energy gap E_g, the electron can jump from the valence band into the conduction band. The source of the energy could be photons, phonons, or electric field.

The band gap represents the minimum energy difference between the top of the valence band and the bottom of the conduction band . the top of the valence band and the bottom of the conduction band are not generally at the same value of the electron momentum The band gap can be **classified as direct or indirect a band gap**

in a direct" when the energy minimum (the bottom) of the conduction band lies directly above the energy maximum (the top) of the valence band occur at the same value of momentum or (have the same wave vector), as in the schematic below.

In an **indirect band gap semiconductor**, the maximum energy (the top) of the valence band occurs at a different value of momentum to the minimum (the bottom) of the conduction band .

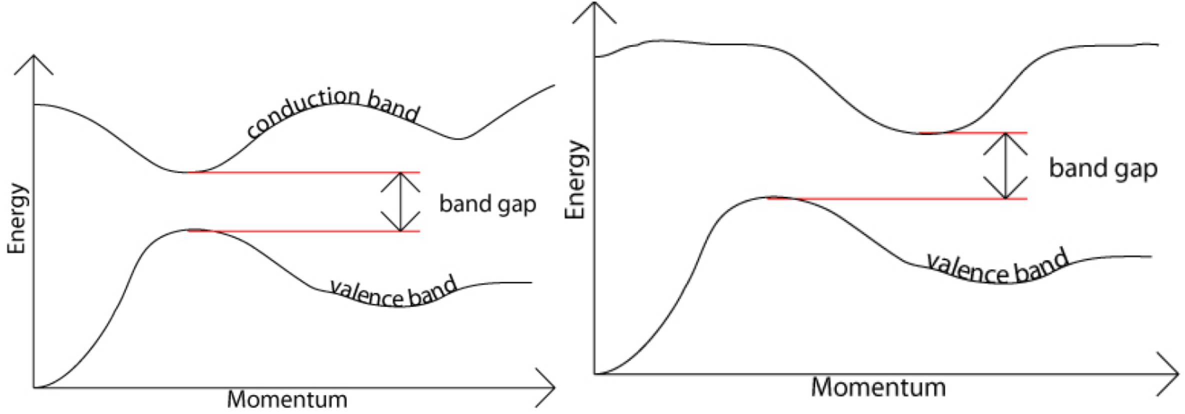


Figure (3) Energy verse momentum (a) direct band gap (b) indirect band gap

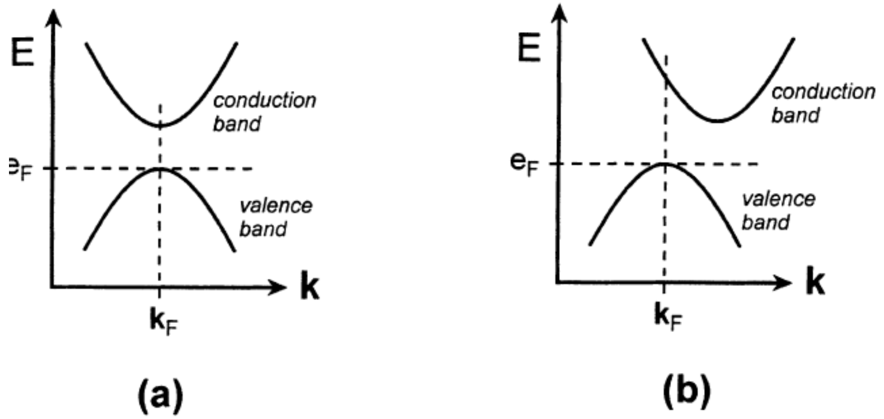
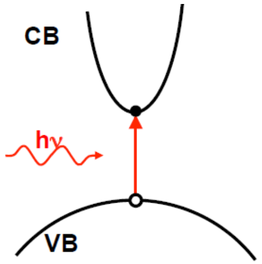


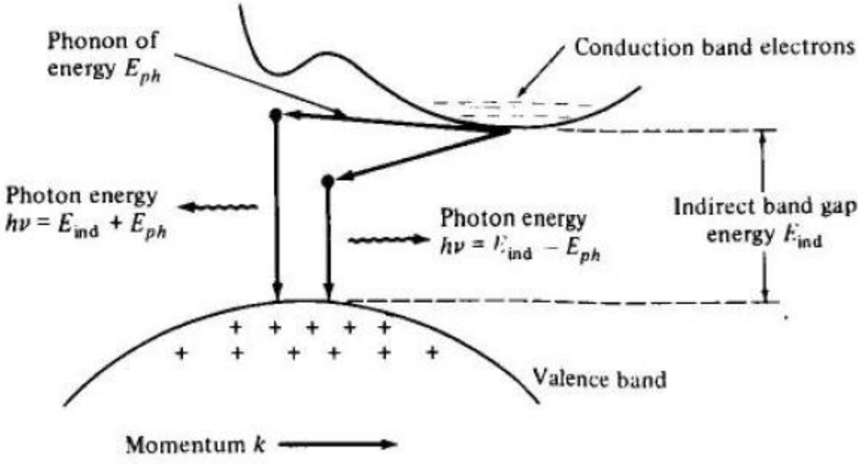
Figure (4) Schematic representations of electronic band structures near the Fermi level for a a solid with a direct band gap and b a solid with an indirect band gap. E_F is the Fermi level having the Fermi wave vector K_F

Direct vs Indirect Bandgaps



Direct bandgap materials
- CB minimum and VB maximum occur at the same k
- Examples
  - GaAs, InP, InGaAsP
  - (Al$_x$Ga$_{1-x}$)As, x < 0.45

Indirect bandgap materi
- CB minimum and VE maximum occur at different k
- Example
  - Si, Ge
  - (Al$_x$Ga$_{1-x}$)As, x > 0.
- Not "optically active



The absorption process (*direct-gap semiconductors*)

In **a *direct band gap*** *semiconductors*, such as GaAs, the maximum and minimum of energy versus momentum relationship occur at the same value of the wave vector (Figure (a)).

in a direct" when the energy minimum (the bottom) of the conduction band lies directly above the energy maximum (the top) of the valence band occur at the same value of momentum or (have the same wave vector),.

Electrons near the top of the valence band are able to make transitions to states near the bottom of the conduction band directly , consistent with the selection rule

The absorption process (*indirect-gap semiconductors*

indirect band gap *semiconductors* like Si and Ge, the maximum and minimum of the energy versus momentum relationship occurs at different wave vectors, which is pictured in Figure (b).

The electron cannot directly jump into the conduction band, but once the electron at the valence band edge E_V absorbs energy (photon, phonon, or electric field) and reaches the energy level of the conduction band edge E_c across the energy band E_g, it can indirectly jump into the conduction band with the aid of phonon energy because phonon usually exists anyway. because this would violate the momentum selection rule.

3- Exciton absorption

In discussing fundamental absorption, we assumed that the excited electron becomes a free particle in the conduction band, and similarly, that the hole left in the valence band is also free. The electron and hole attract each other, however, and may possibly form a *bound* state, in which the two particles revolve around each other. (More accurately, they revolve around their center of mass.) Such a state is referred to as an *exciton*

The binding energy of the exciton is small, about 0.01 eV, and hence the excitaton level falls very slightly below the edge of the conduction band, as indicated in Fig. . (The exciton level is in the same neighborhood as the donor level.)

The energy of the photon involved in exciton absorption is given by

$$h\nu = E_g - E_{ex}$$

However, exciton absorption is important in discussion of optical properties of insulators in the ultraviolet region of the spectrum

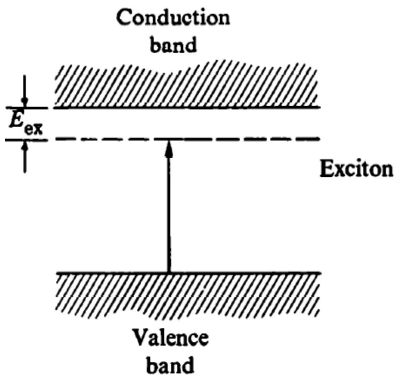


Fig. The exciton level and associated absorption.

4- Free-carrier absorption

Free carriers-both electrons and holes-absorb radiation without becoming excited into the other band. In absorbing a photon, the electron (or hole) in this case makes a transition to another state in the same band, as shown in Fig.. Such a process is usually referred to as an *intr aband transition*

Note that free-carrier absorption takes place even when $hf < E_g$ and frequently this absorption dominates the spectrum below the fundamental edge

For $hf > E_g$ of course, both types of absorption-fundamental and free carrier-occur simultaneously

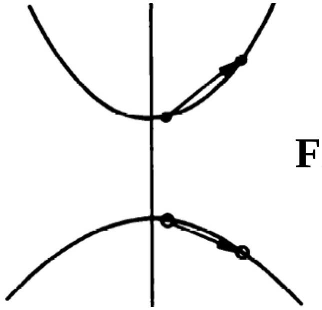


Fig. : Free-carrier absorption