(MPM-202)
Optoelectronics and Optical Communication System

UNIT-I (Optical Process in Semiconductors)

Lecture-2

by

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SYLLABUS

MPC-202 OPTOELECTRONICS AND OPTICAL COMMUNICATION SYSTEM Credits 4 (3-1-0)

UNIT I: Optical process in semiconductors

Optoelectronic properties of semiconductor: effect of temperature and pressure on bandgap, carrier scattering phenomena, conductance processes in semiconductor, bulk and surface recombination phenomena, optical properties of semiconductor, EHP formation and recombination, absorption in semiconductors, effect of electric field on absorption.

UNIT II: Optical sources and detectors

An overview of optical sources (Semiconductor Laser and LEDs), Optical Detectors: Type of photo detectors, characteristics of photo detectors, noise in photo detectors, photo transistors and photo conductors.

UNIT III: Optical fiber

Structure of optical wave guide, light propagation in optical fiber, ray and wave theory, modes of optical fiber, step and graded index fibers, transmission characteristics of optical fibers, signal degradation in optical fibers; attenuation, dispersion and pulse broadening in different types of optical fibres.

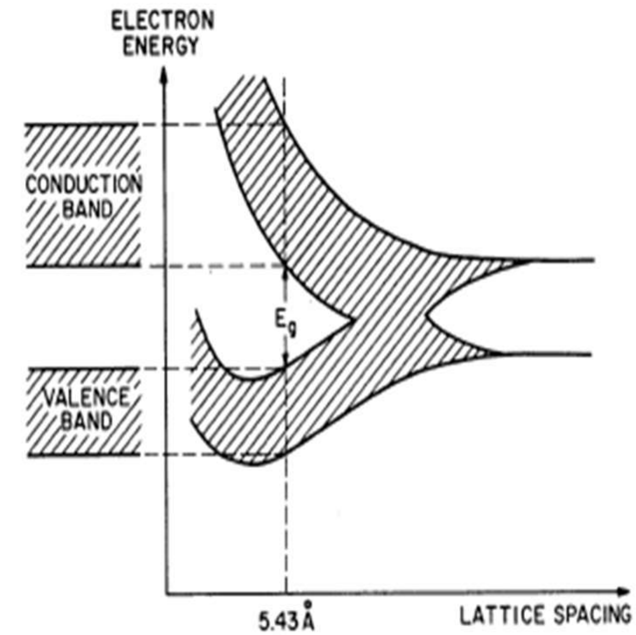
UNIT IV: Fiber components and optoelectronic modulation

Fiber components: Fibre alignments and joint loss, fiber splices, fiber connectors, optical fiber communication, components of an optical fiber communication system, modulation formats, digital and analog optical communication systems, analysis and performance of optical receivers, optoelectronic modulation.

Bandgaps in Semiconductor

- The band is formed because of the interaction and overlapping of a large number of electronic levels in a material.
- When number of atoms come closer the electronic levels which are farther away from nucleus overlaps and these electronic levels splits into a large number of energy levels.
- Because of splitting of energy levels bands are formed.

How band is formed in semiconductor ?



Formation of energy bands as a diamond lattice crystal by bringing together isolated silicon atoms.

E-k Diagram

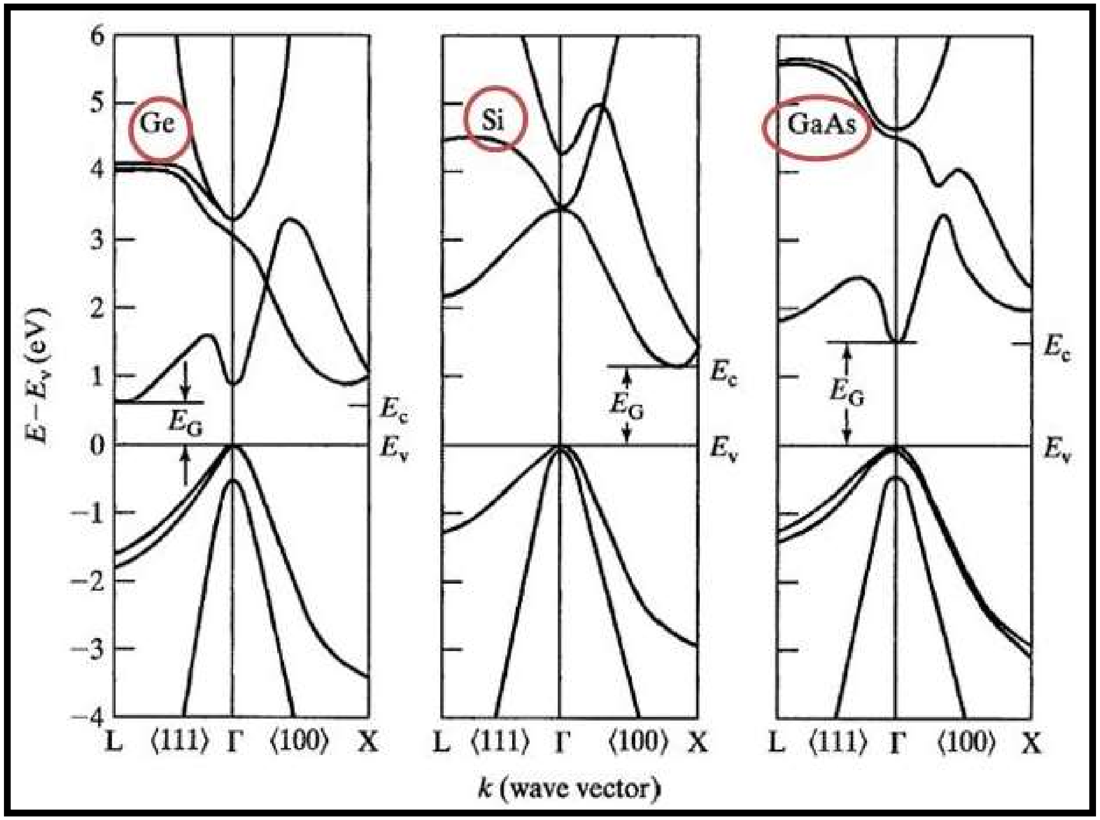
➢ From the E-k diagram of the given semiconductors we observe that-

- The valance band maxima in all the semiconductors lie on the $\Gamma-$ point.

- In Si and Ge the VB maxima and CB minima lie at different k-values while in GaAs they lie on same k-value.

- In all the semiconductors the valance band consists three overlapping bands.

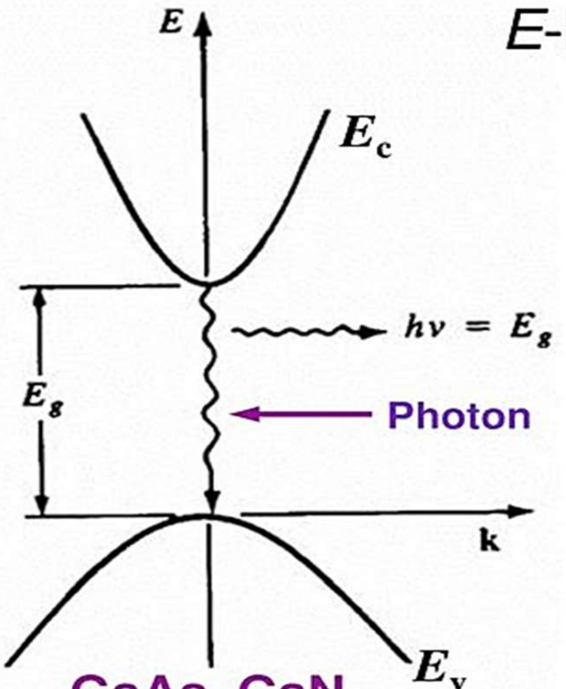
I. Heavy hole (HH)
II. Light hole (LH)
III. Split off (SO)



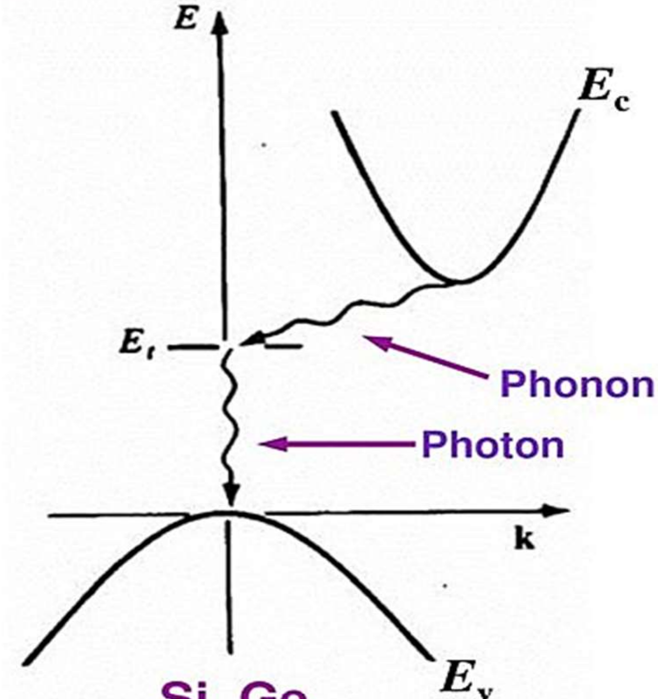
E-k diagram of Ge , Se and GaAs

Direct and Indirect Band gap Semiconductors

E-**k** Diagrams



GaAs, GaN
(direct semiconductors)



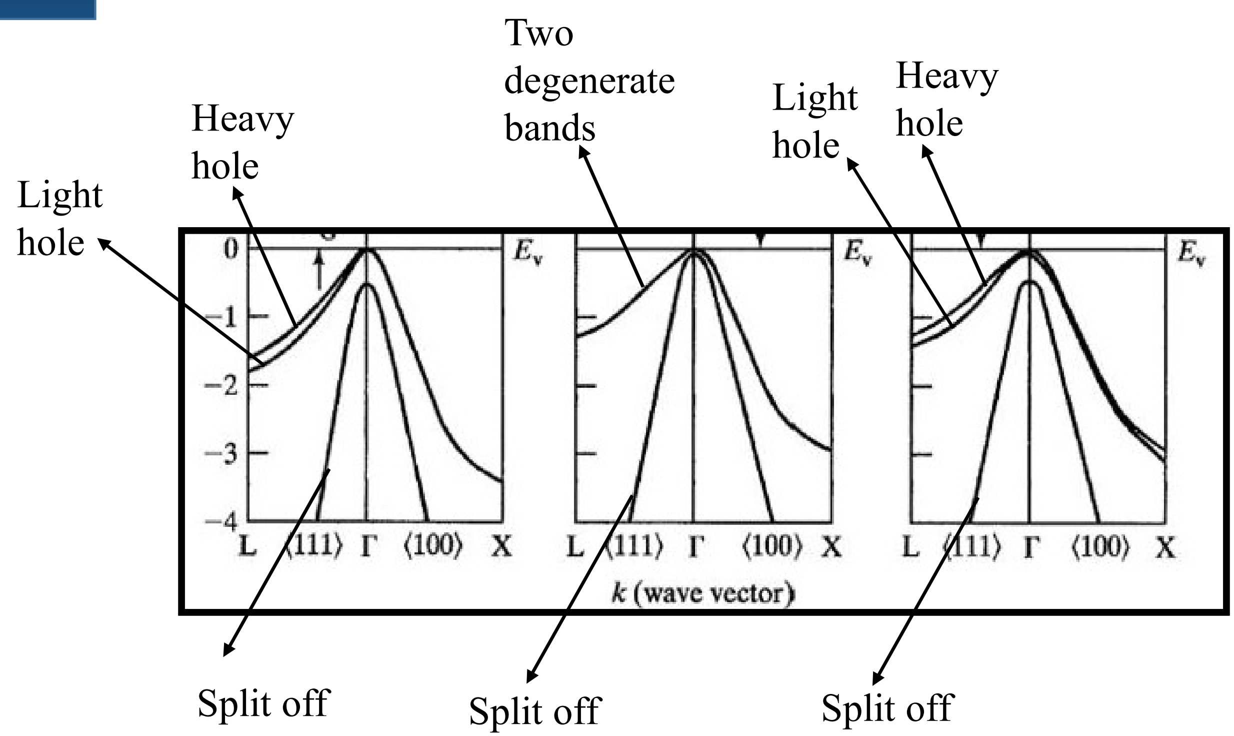
Si, Ge
(indirect semiconductors)

- **Little change in momentum is required for recombination**
- **Momentum is conserved by photon (light) emission**

- **Large change in momentum is required for recombination**
- **Momentum is conserved by mainly phonon (vibration) emission + photon emission**

Valance Band Maxima

- From the Figure, we see that there are always two degenerate bands on the maxima of VB at gamma point.
- In Silicon, two bands fully overlap.
- Split off band is away from the two overlapping band maxims at gamma point hence the name of the band is **'split off'** and it arises due to spin-orbit coupling.



Valance band maxima of Ge , Se and GaAs respectively.

Valance Band Maxima

- The curvature of valance band maxima is concave downward which indicates the positive charge (hole) occupancy.

- **The curvature of heavy hole (HH) band is less which indicates higher effective mass of holes in this band so this band is called 'heavy hole'.**

- **The curvature of light hole(LH) band is larger than that of HH band which indicates lower effective mass of holes in this band than in HH band so this band is called 'light hole'.**

Carrier Effective Mass

- By considering both the forces that is external field and force from periodic potential of the lattice acting on the electron, the equation of motion of electron in a perfect lattice with no scattering is

$$\boldsymbol{F = m_e^* \frac{dv_g}{dt}} \qquad (1)$$

where F is the force acting on the electron

v_g is the group velocity of wave packet describing the electron motion

and $\boldsymbol{m_e^*}$ is the electron *effective mass*, given by

$$\boldsymbol{m_e^*} = \hbar^2 \left(\frac{\boldsymbol{d^2\varepsilon}}{\boldsymbol{dk^2}}\right)^{\boldsymbol{-1}} \qquad (2)$$

- **This relation indicates the higher the curvature the lower would be the effective mass.**

Carrier Effective Mass and Band Structure

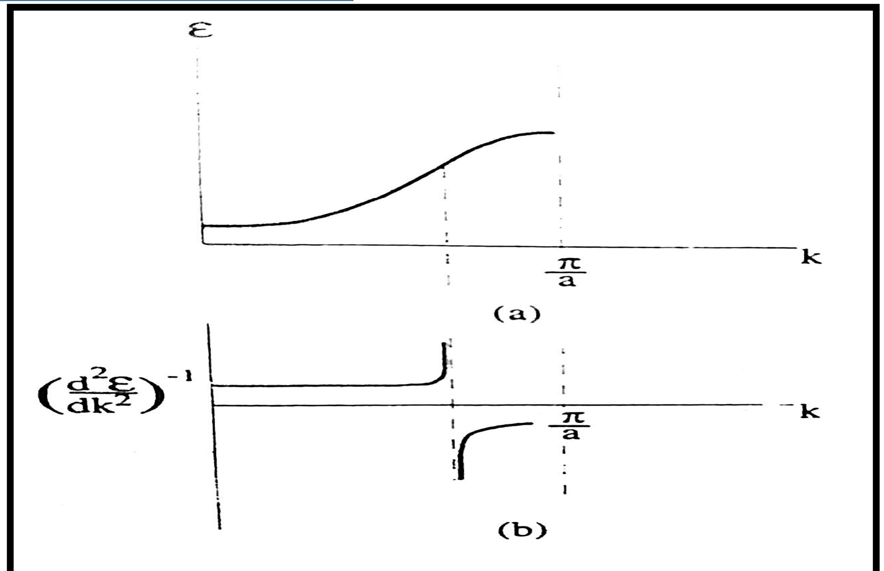
- For small electron energies, the value of $\left(\frac{d^2\varepsilon}{dk^2}\right)^{-1}$ is *positive*.

- As electron energy increases the value becomes indeterminate and then becomes *negative*.
- In this region $\boldsymbol{\varepsilon}$-$\boldsymbol{k}$ curve is *concave downward*.

- **Quantum mechanically, a carrier with a negative mass and negative charge is interpreted as an equivalent charge particle with a positive mass and positive charge, and this is the *hole*.**

- **Concave downward surfaces are hole like surfaces**.

- The conduction band is concave upward, and the valance band is concave downward.



Plot of (a) $\boldsymbol{\varepsilon}$ and (b) $\left(\frac{d^2\varepsilon}{dk^2}\right)^{-1}$ vs wave vector k as obtained from the solution of the Schrodinger equation for a one dimensional lattice , $k = {}^{\pi}/_{a}$ denotes the boundary of the first Brillouin zone. The value of k at which $\left(\frac{d^2\varepsilon}{dk^2}\right)^{-1}$ and the effective mass attain negative values corresponds to the point of maximum slope of the $\boldsymbol{\varepsilon}(k)$ curve

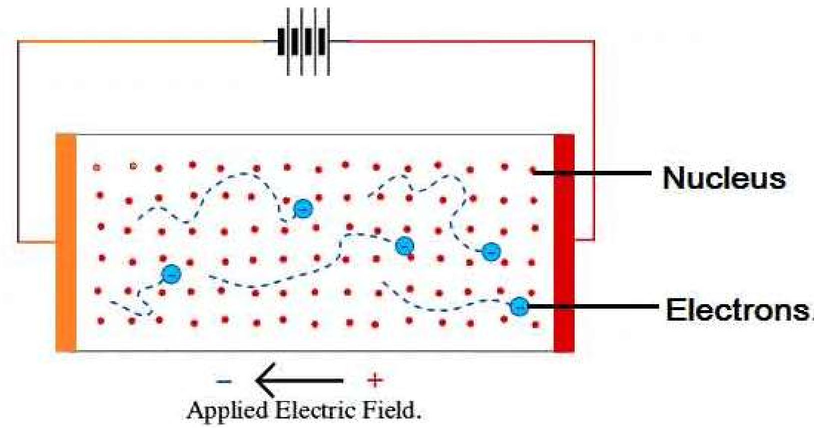
Carrier Effective Mass

- If the momentum in a semiconductor is given by-

$$p = \hbar k$$

where p and k are vector quantities

then this momentum is known as 'crystal momentum'.



- The electron moves in a material not freely but in the influence of its internal electrostatic field with mass m_e and applied external electric field (-eE).

- But it directly responds to the external electric field as a free particle of mass m_e^* i.e. effective mass.

- Thus an electron with mass equal to effective mass can be treated as a free electron of mass m_e^* without considering the influence of the internal field.


THANK YOU