(MPM-202)
Optoelectronics and Optical Communication System

UNIT-I (Optical Process in Semiconductors)

Lecture-1

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.

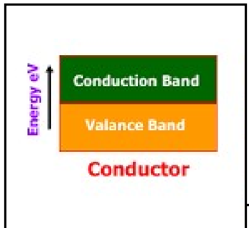
UNIT III: Optical fiber

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

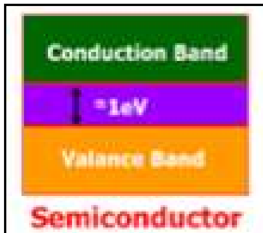
Fiber components: Fibre alignments and joint loss, fiber splices, fiber connectors, optical fiber communication, components of an optical fiber communication system, modulation formats, digital and analog optical communication systems, analysis and performance of optical receivers, optoelectronic modulation.

Types of Material



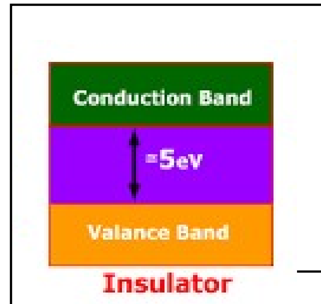
Conductor

- One valance electron
- V.B & C.B. overlapped $E_g \approx 0$ eV)
- Small resistivity
- Good conduction of electrical current
- Eg : Copper, Alluminium etc.



Semiconductor

- Four valance electron
- V.B & C.B. is separated by $E_g \approx$ 1.1 eV)
- High resistivity
- Moderate conduction of electrical current
- Eg : Silicon, Germanium etc.



Insulator

- Eight valance electron
- V.B & C.B. separated by $E_g \approx$ 6-10 eV)
- Very high resitivity
- No any conduction of electrical current
- Eg : Mica, Paper etc.

Semiconductors

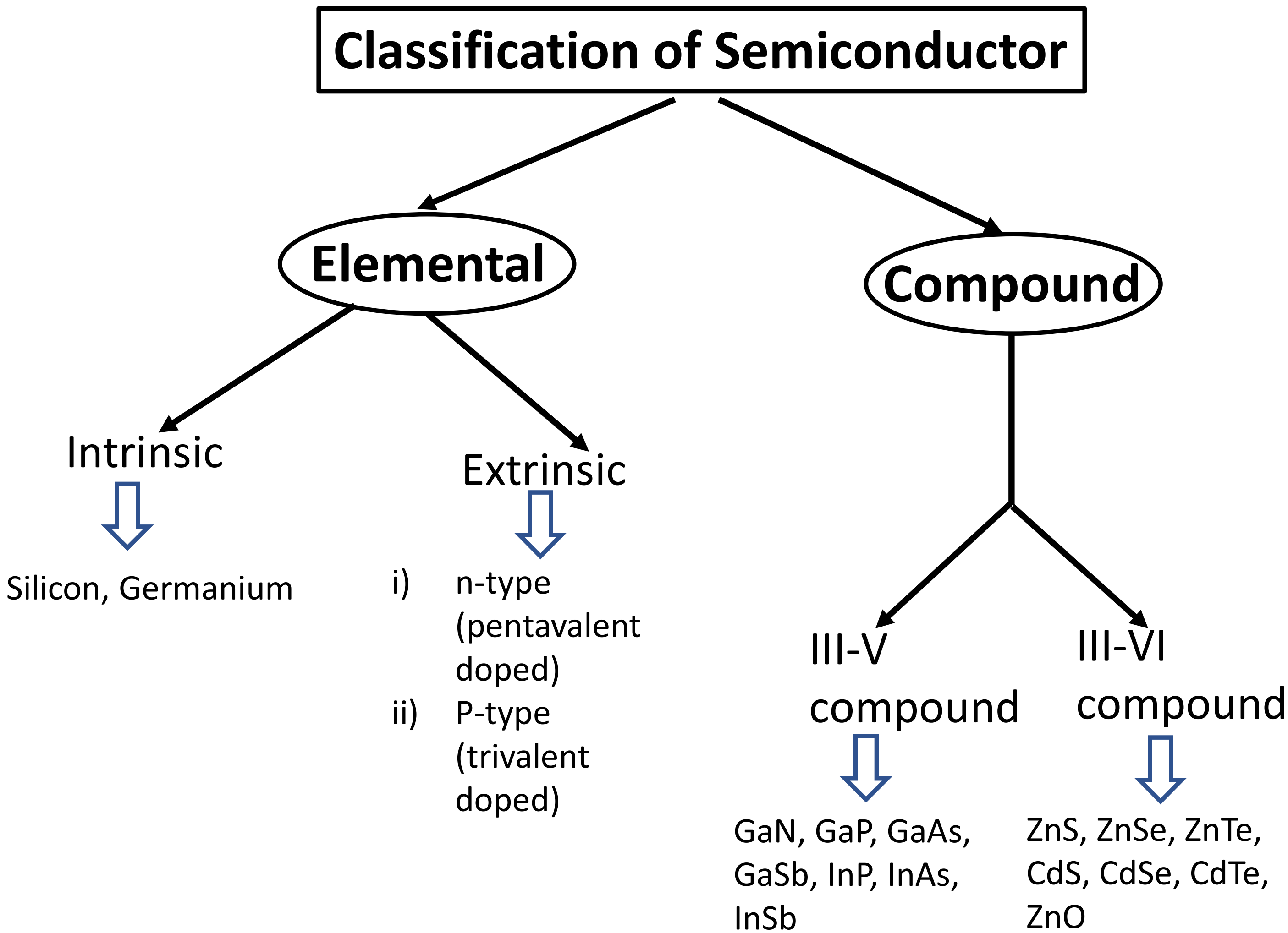
Advantages

- Tunable conductivity
- Miniaturization of electrical components
- Low power consumption
- Longer life
- Used in 3D printing machines
- Tunable bandgap
- Sensing ability

Applications

- Electrical switch
- Amplifier
- Logic device (CMOS logic)
- Memory devices
- LEDs
- Laser diode
- Solar Cell
- Photodetector
- Op-Amp
- ICs
- Diodes
- Capacitor
- Transistors
- Resistor

Classification of Semiconductor



Why Compound Semiconductors?

- ✓ The elemental semiconductors, in particular Si, have been very useful for the development of microelectronics but they have some important drawbacks as follows-

- The fundamental band gap of these semiconductors is indirect.

- They emit light very poorly and their absorption coefficient are low.

- Silicon is technologically good but because of its small energy gap the conversion efficiency is low

- It became clear that Si, considered by many as a universal semiconductor material , cannot perform many important functions.

- For optoelectronic applications, in particular, it was natural to turn to other material.

Compound Semiconductors

- ✓ The compound semiconductor materials offers many of the desired properties and could be synthesized without much difficulty.
- ✓ Compound semiconductors as the name suggest are made of elements of different columns of the periodic table. Examples are III-V, II-VI, IV-VI or IV-IV compounds.
- ✓ The compound semiconductor, represented by $A_{III}B_{V}$ or $C_{II}D_{VI}$, has the same average number of valance electrons per atom as Si.
- ✓ Si has four valance electrons and in III-V or II-VI compounds, the sum of outer electrons is eight.

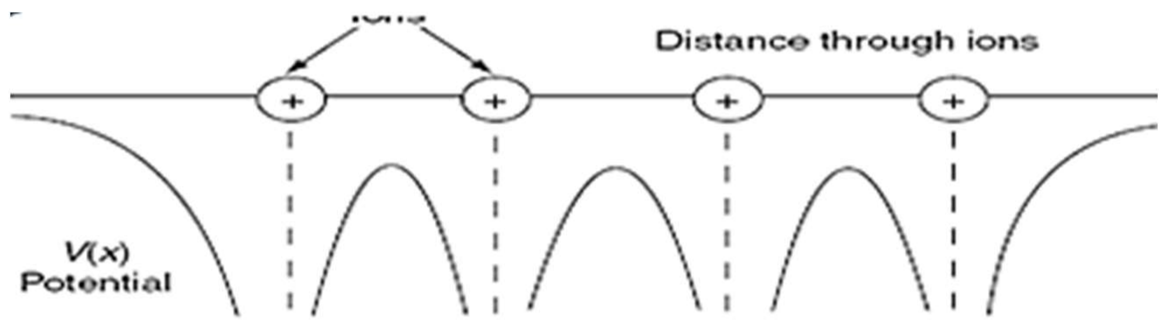
Electronic Properties of Semiconductors

The models that are used to study the electronic properties of solids are-

Free-electron Model	One-electron Model	Kronig-Penney Model
• Explains conduction and related phenomena in metals. • In this model, the nearly free valance electrons are shared by all the atoms in the solid. Thus, there is a "sea" of free electrons swimming around and these electron see a nearly constant smeared-out potential. • It can't explain phenomena in covalently bonded solids such as semiconductors.	• More successful in explaining the electronic properties of semiconductors. • In this model, it is assumed that the conduction electron obeying Pauli exclusion principle is not entirely free and does not see a constant potential.	• It overcomes the limitations of the free electron model. • It is the quantum-mechanical interaction of an electron with the periodic potential of the lattice that gives rise to the band theory of solids. • The formation of allowed energy bands in which electron can exist, satisfying Pauli's exclusive principle, separated by forbidden energy regions. • The concept of a hole, effective mass of carriers and conduction properties also arise from the band theory.

Origin of E-k Diagram

- Most of the semiconductors are crystalline and in the crystalline semiconductors the atoms are periodically arranged in the lattice.



- The periodical arrangement leads to the periodical potential energy variation.

- But the motion of electron in a system is governed by the laws of quantum mechanics.

- For the one electron one proton system like hydrogen it is very easy to solve Schrodinger wave equation but for many electron system it is quite complicated.

Origin of E-k diagram

- **F. Bloch** observed that since the potential vary periodically so the probability of finding the electron ($|\Psi|^2$) should also vary periodically.

- Which implies wave function (Ψ) should vary periodically where 'Ψ' is wave function.

- So the wave function is given by a product of plane wave ($e^{i\vec{k}.\vec{r}}$) multiplied by a periodic function ($\mathrm{u}_k(r)$) which is called the cell function.

$$\Psi_k(r) = \mathrm{u}_k(r)e^{i\vec{k}.\vec{r}}$$

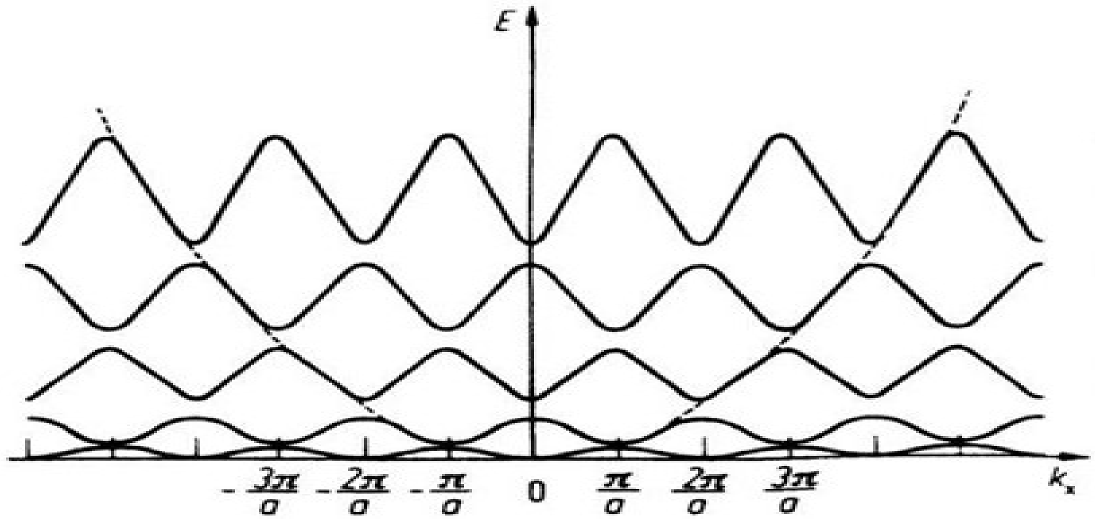
$$\text{where } \mathrm{u}_k(r+a) = \mathrm{u}_k(r)$$

- Substituting the value of above wave function (Ψ) in

$$\nabla^2(\Psi) + \frac{2m}{\hbar^2}(E-V)\Psi = 0$$

Origin of E-k diagram

- After solving we get that that the energy Eigen value E is also periodic in wave vector k.



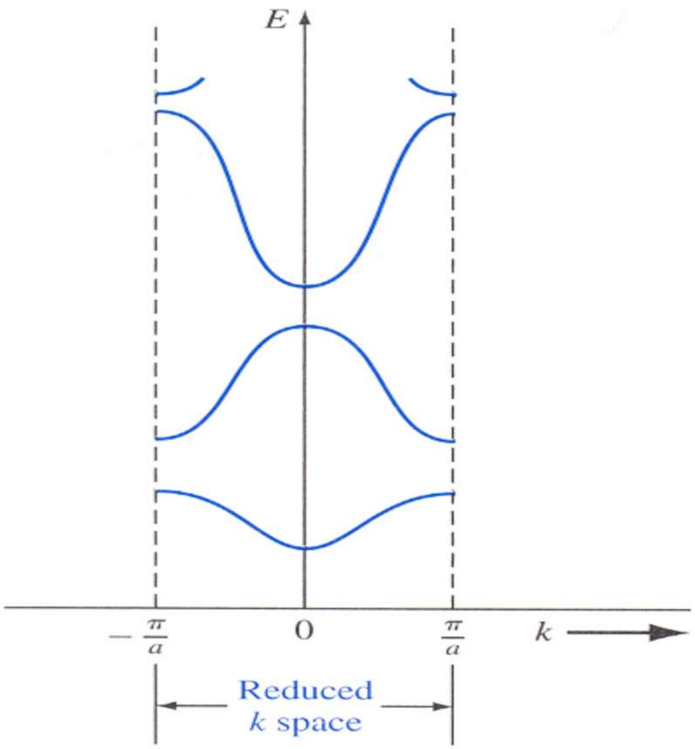
- First Brillouin zone corresponds $\frac{-\pi}{a}$ to $\frac{\pi}{a}$ and k = 0 is $\boldsymbol{\Gamma}$ **– point.**

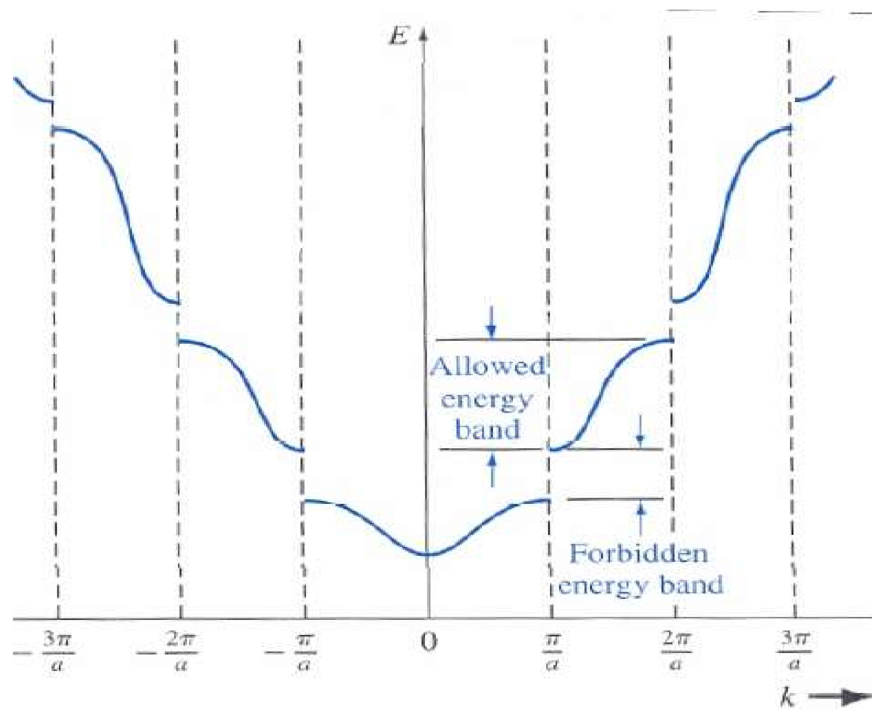
- **There are three pictures of E-k diagram-**

1. Periodic Zone Picture (as shown above)
2. Reduced Zone Picture
3. Extended Zone Picture

Origin of E-k diagram

➢ Reduced zone picture is up to first Brillouin zone boundary	➢ In extended zone picture we show discontinuity. (Kronig-Penney Model)



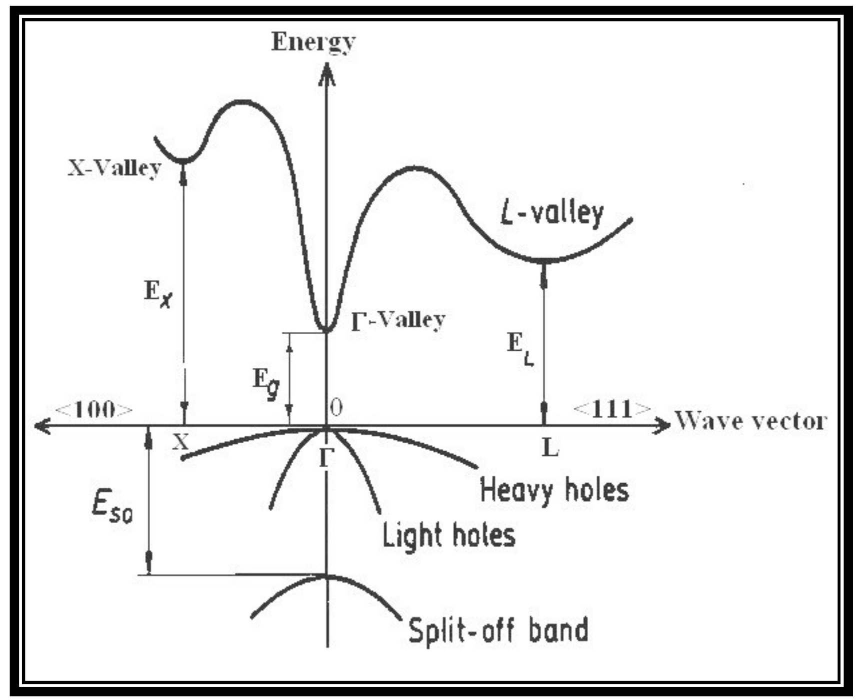


E-k diagram

- In this course we can easily work with the reduced zone picture of E-k diagram.

- More precisely just by focusing the maxima of valance band and minima of conduction band.

- From the figure we observe that



- k=0 corresponds to $\mathbf{\Gamma - point}$ i.e. centre of the Brillouin zone.
- There are two possible directions from $\mathbf{\Gamma - point}$ i.e.

I. $\mathbf{\Gamma}$ to $\mathbf{L}$ which is $< 111 >$ direction

II. $\mathbf{\Gamma}$ to $\mathbf{X}$ which is $< 100 >$ direction

- All the energies below the valance band maxima and above the conduction band minima are allowed energies and in between there is a gap which is known as band gap.

E-k diagram

- The visible energy range (400-800 nm) corresponds to energy range of 1.5-3 eV.
- At room temperature (RT) kT=29 meV so at room temperature and for band gap 1.5-3 eV , 29 meV energy is sufficient enough to cause to jump this band gap.
- The band gap of various semiconductors at RT and atT= 0 K has been tabulated below-

Temperature	Si	Ge	GaAs	CdTe	GaP
RT	1.1 eV	0.67 eV	1.43 eV	1.49 eV	2.26 eV
0 K	1.17 eV	0.74 eV	1.5 eV	1.61 eV	2.32 eV

- In Silicon at 0 K, the conduction band is completely filled and valance band is completely empty so it does not conduct at 0 K.


THANK YOU