Engineering Physics

(PHY1701)

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Optoelectronic Devices & Applications of Optical fibers

Contents

- Introduction to semiconductors
- Sources-LED & Laser Diode,
- Detectors- Photodetectors- PN & PIN(AG 209, 235, 238),
- Applications of fiber optics in communication, &
- Endoscopy*

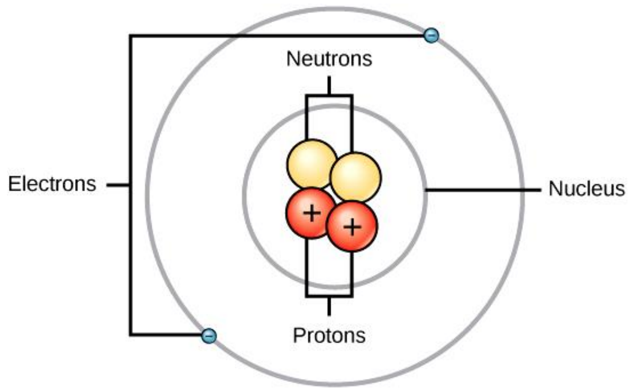
❖ Introduction to Fiber Optics, Ajoy Ghatak and K. Thyagarajan, Cambridge University Press, 2010 (AG)

Prerequisites:

✓ To understand this lecture, the students should have the following prior knowledge:

- About an Atom !
- About the Structure of an Atom !!
- About the Resistivity and Conductivity !!!

$\rho = RA/L;$ $\sigma = 1/\rho$



Learning Concepts:

✓ Know the necessity of semiconductors than metals & insulators

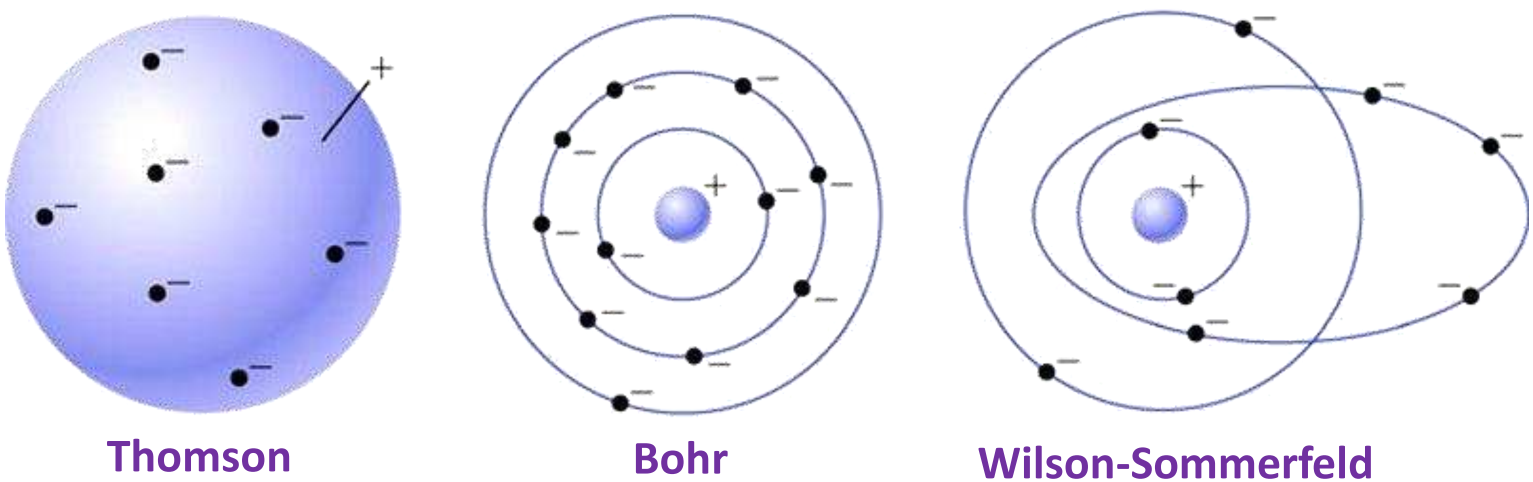
✓ Learn the fundamental physics of how charge carriers behave in matter

✓ Aware of how to control them to create as useful electronic devices

Introduction:

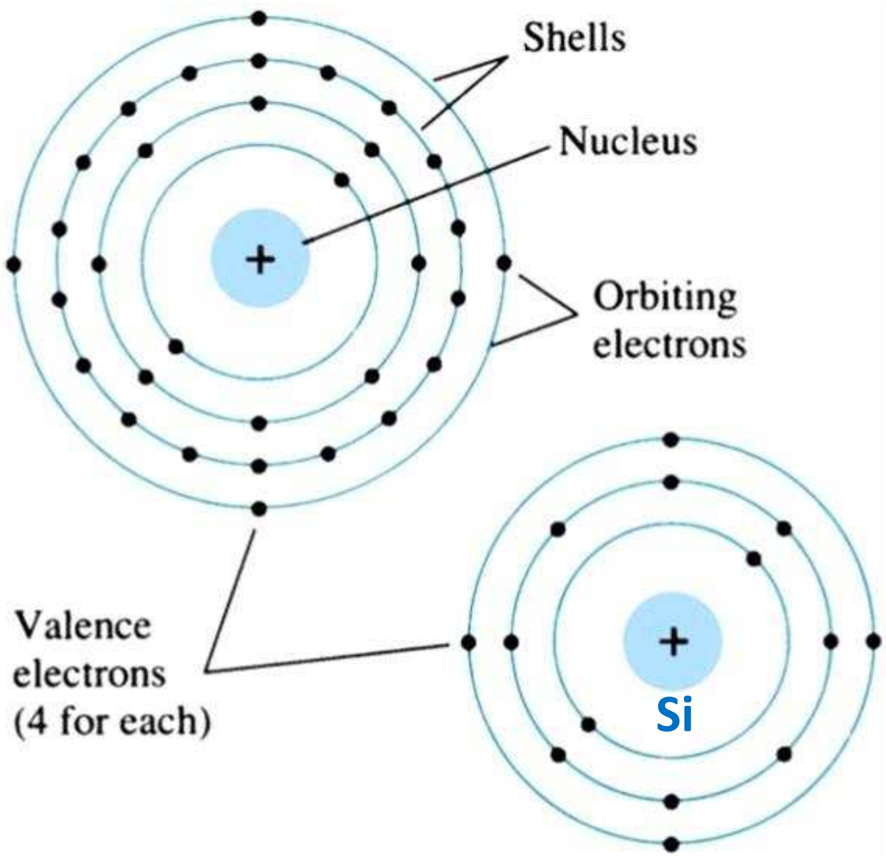
- ✓ Matter is created by atoms, so start with the atom:
- ✓ Thousands of matter in the universe, but all of them made with a single type or more than one type of atoms.
- ✓ Only 92 types of atoms are found in nature & few more of atoms invented in laboratories.

The Atom



- ✓ ***Thomson*** says that **atoms are uniform spheres** of +ly charged matter in which **electrons are embedded** (*plum-pudding model*: Electrons describe orbits about a tiny + nucleus)
- ✓ ***Bohr* model** assumes that the electron **orbits are circular**
- ✓ ***Wilson-Sommerfeld* model** describes that the electron **orbits to be elliptical**

- ✓ **Bohr model of the atom:** An atom is composed of a nucleus, which contains +ly charged protons and neutral neutrons, and -ly charged electrons that orbit the nucleus.
- ✓ These electrons are distribute themselves in shells (*Quantized energy levels*).
- ✓ Electrons in the outermost shell/orbit are called as valence electrons.



- ✓ In case of Si atom:

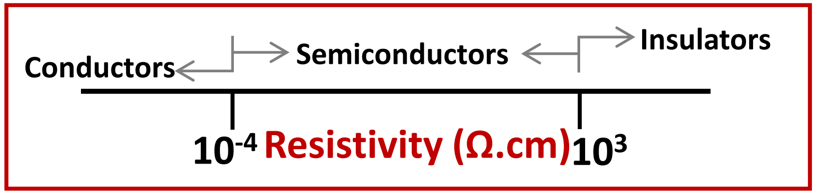
  Atomic no: **Z= 14**

  Electronic configuration:

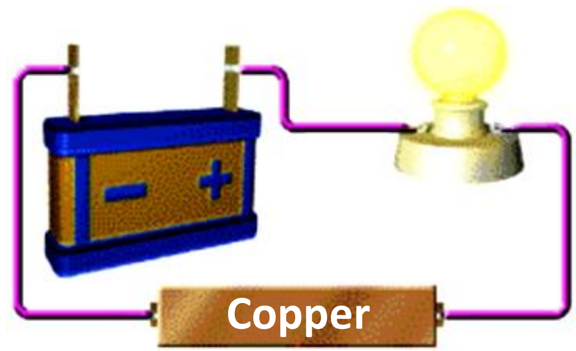
$$\underbrace{\mathbf{1S^2\ 2S^22P^6}}_{\text{Inner Shell/ Orbit}}\ \underbrace{\mathbf{3S^23P^2}}_{\text{Outer Shell/ Valance } e^-}$$

Electronic Materials:

- ✓ The purpose of electronic materials: Generate & control the flow of an electrical current
- ✓ Electronic materials include: Conductors, Insulators & Semiconductors



1. Conductors: Have lowest resistivity (<0), which allows electrical current flow

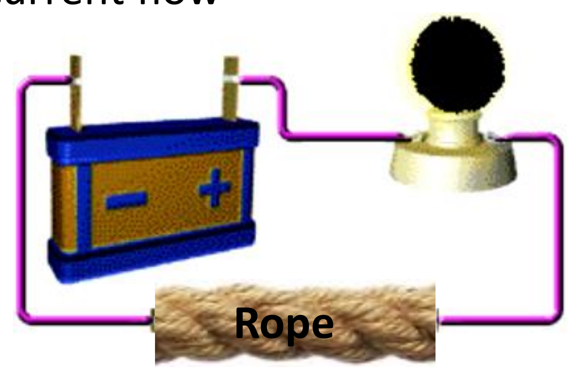


Ex: Cu, Ag, Au, Al, & Ni (Metals)

Brass & Steel (Alloys) &

Salt water (Liquids)

2. Insulators: Have high resistivity, which suppresses electrical current flow here, the atoms are tightly bound to one another



Ex: Wood, Rope

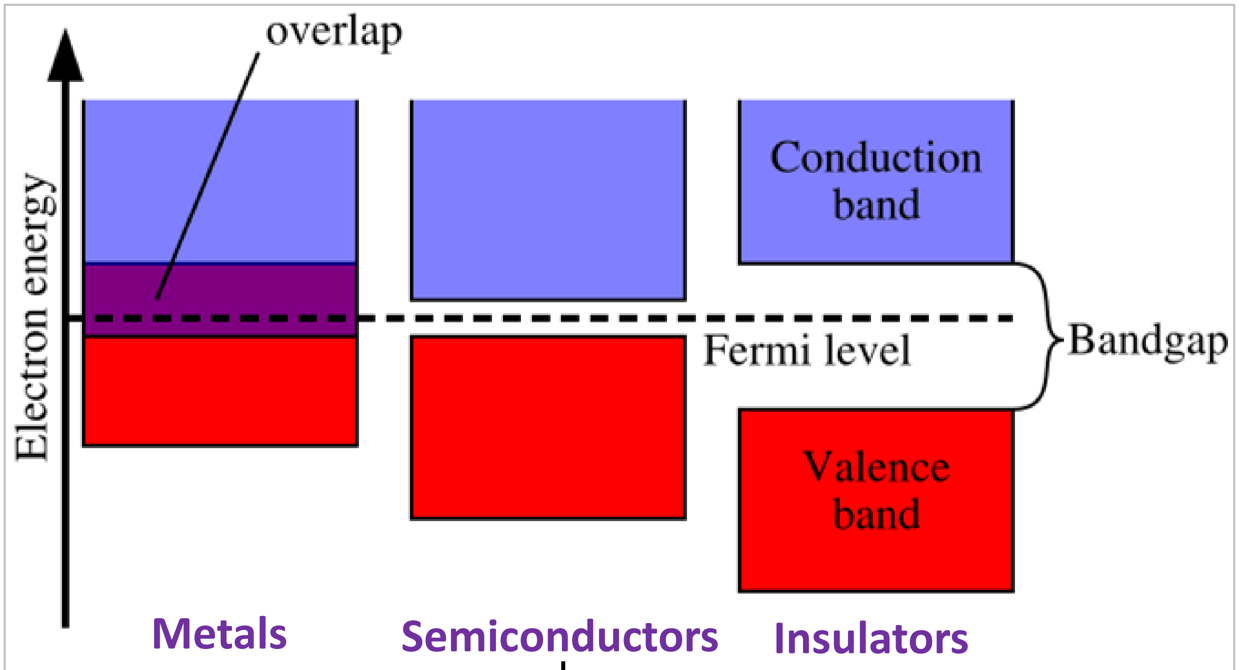
Glass &

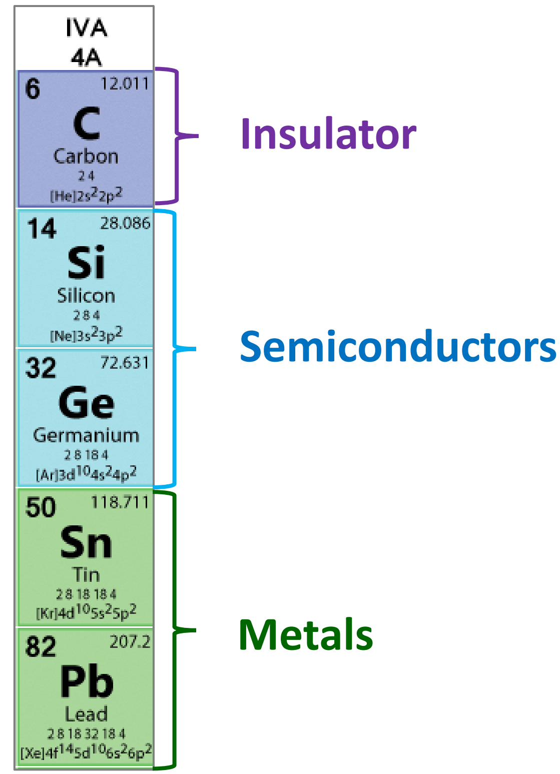
Plastics (compounds of several elements)

3. Semiconductors: Can allow or suppress the electrical current flow,

i.e., these can be to act as good conductors, or good insulators, or anything in between.

Ex: Si & Ge (Si is the best & most widely used semiconductor)



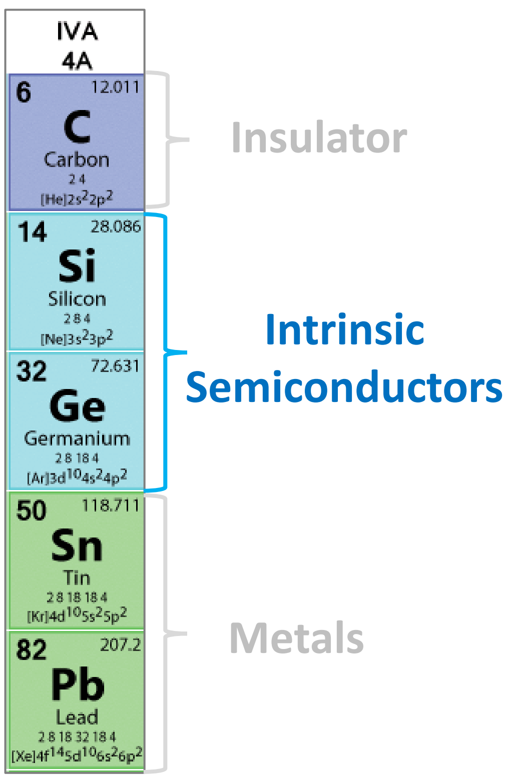


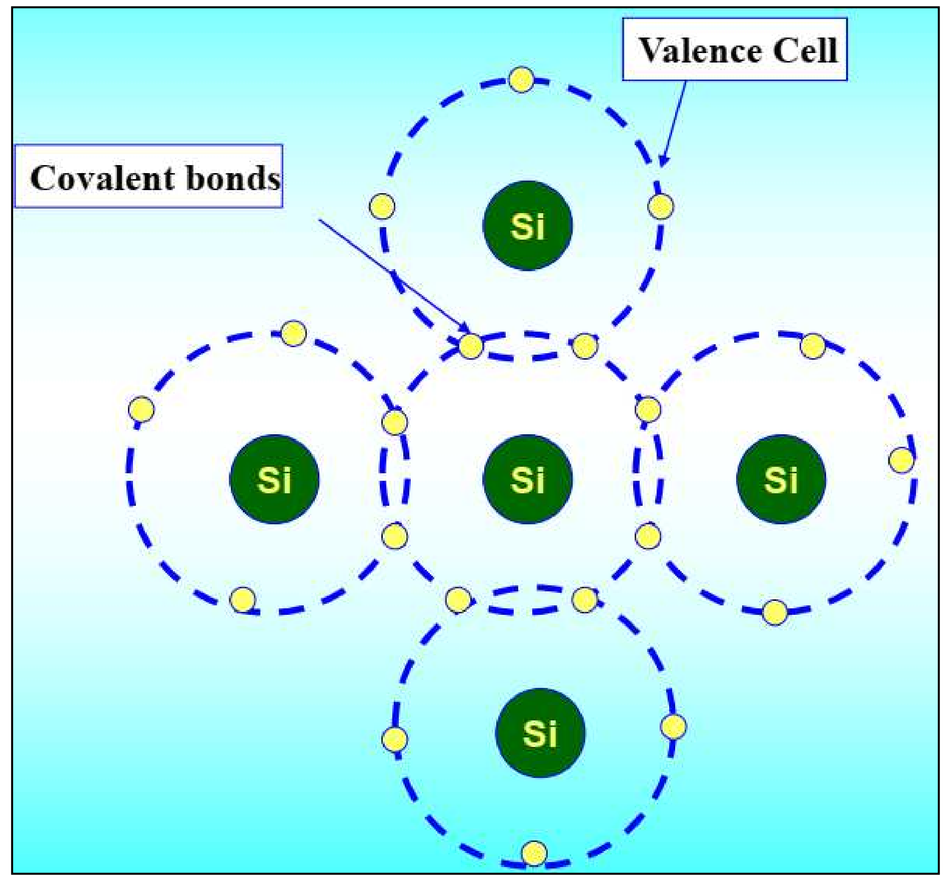
Intrinsic SCs

Extrinsic SCs

Intrinsic Semiconductors:

- ✓ A semiconductor which does not have any kind of impurities is known as Intrinsic or Pure Semiconductor.
- ✓ *Germanium* & *Silicon* (4th group elements) are the best examples.

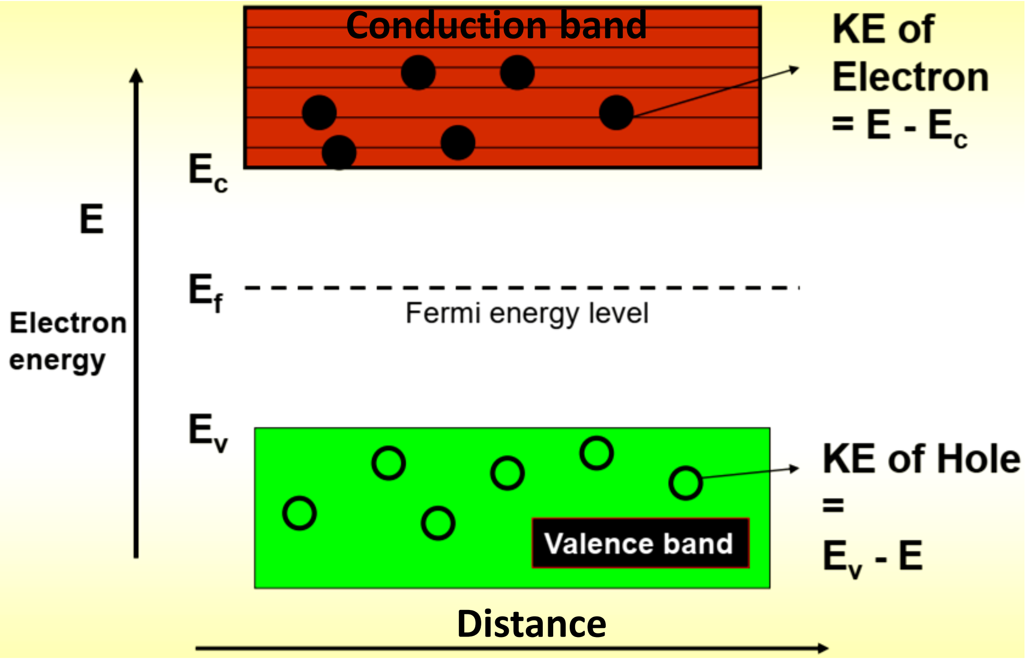




Electron Conduction in Intrinsic SCs:

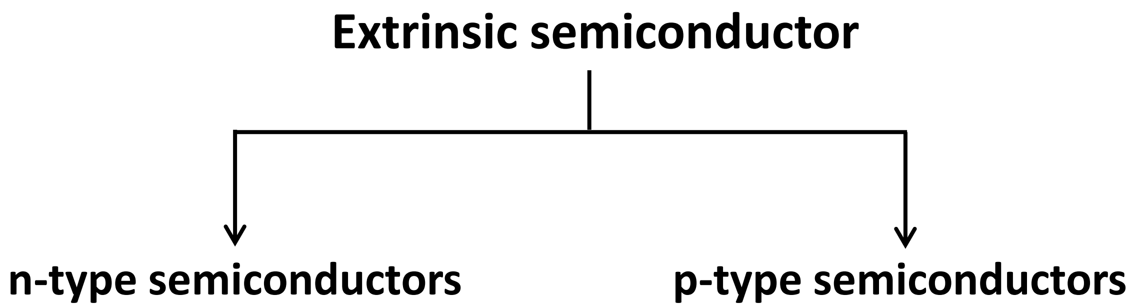
- ✓ When a suitable form of energy is supplied to a Semiconductor then electrons take transition from Valence Band to Conduction Band.
- ✓ Here, a **free electron** in CB and simultaneously **free hole** in VB is formed.
- ✓ This phenomenon is known as Electron - Hole pair generation.
- ✓ In intrinsic SC, the *no of electrons in CB* will be equal to *no of holes in the VB*.

$$n_e = n_h \Rightarrow n = p$$



Extrinsic Semiconductors:

- ✓ The extrinsic semiconductors are those in which impurities of large quantity are present.
- ✓ Usually, the impurities can be either 3rd group or 5th group elements.
- ✓ Based on the impurities present in the extrinsic semiconductors, they are classified into two categories.

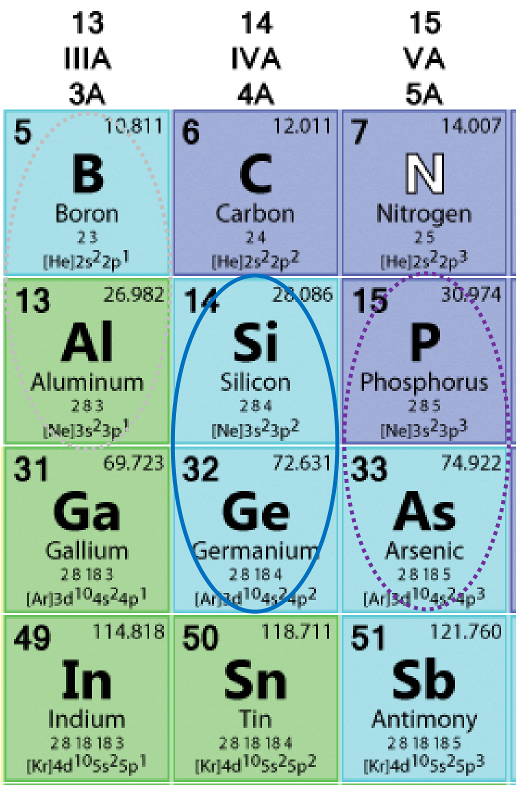


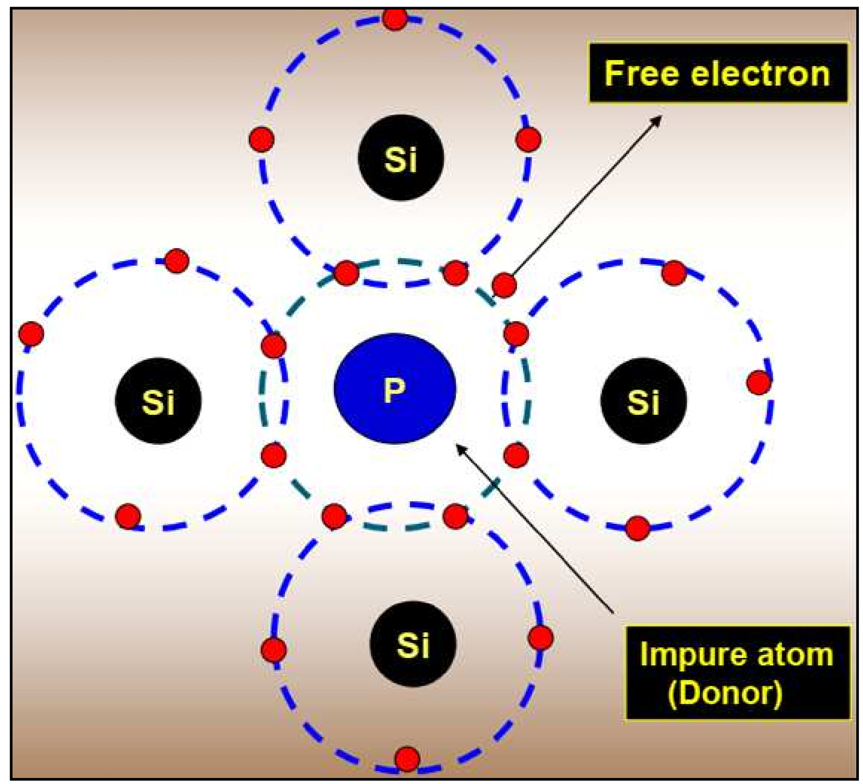
1. n-type Semiconductors:

- ✓ When any pentavalent element such as *P/As* is added to the intrinsic SC, *four electrons* are involved in *covalent bonding* with four neighboring pure SC atoms.
- ✓ The *fifth electron* is weakly bound to the parent atom.
- ✓ Even for lesser thermal energy it is released to leaving the parent atom & positively ionized.

1. n-type Semiconductors:

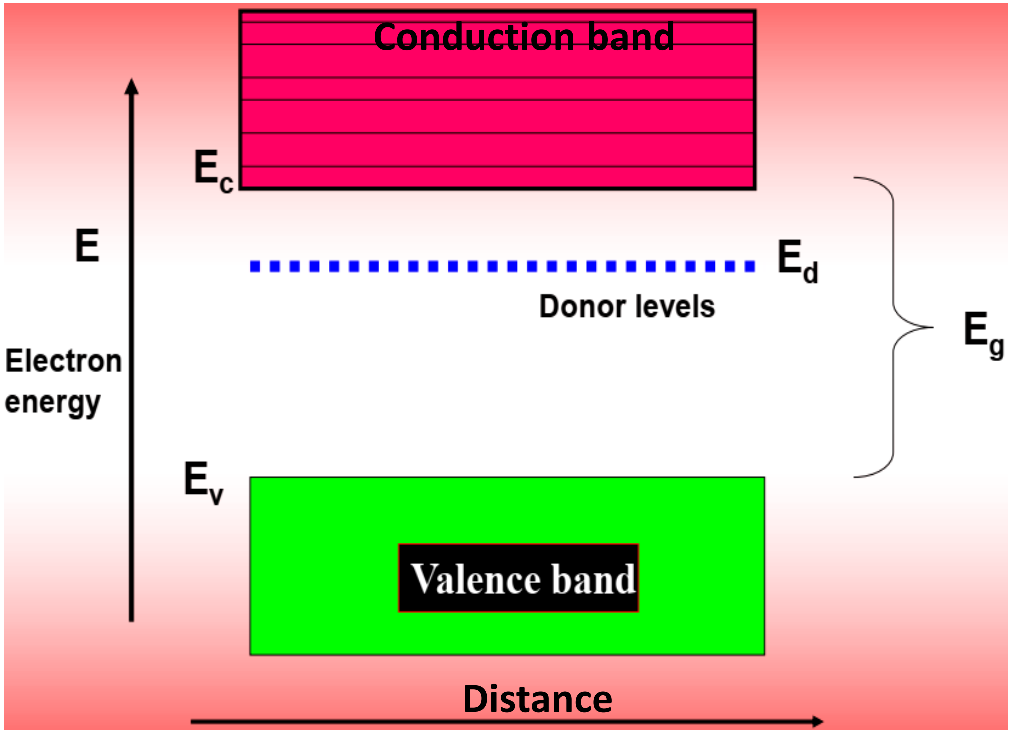
- ✓ When Intrinsic semiconductor was doped with pentavalent impurities (P/As) then n-type semiconductor can be created.
- ✓ The energy level of fifth electron is called **donor level**.
- ✓ Most of the donor level electrons are excited into the CB & become the majority charge carriers.





Carrier Concentration in n-type SC:

- ✓ The **donor level** is close to the bottom of the conduction band.
- ✓ At very low temperatures, all donor levels are filled with electrons.
- ✓ With increase of temperature more and more donor atoms get ionized and the **density of electrons** in the CB increases.
- ✓ Further increase in temperature, results in the generation of e-h pairs due to the breaking of covalent bonds.



- ✓ **Electrons** are **majority** charge carriers.

In n-type SC's case:

$$n_e >> n_h$$

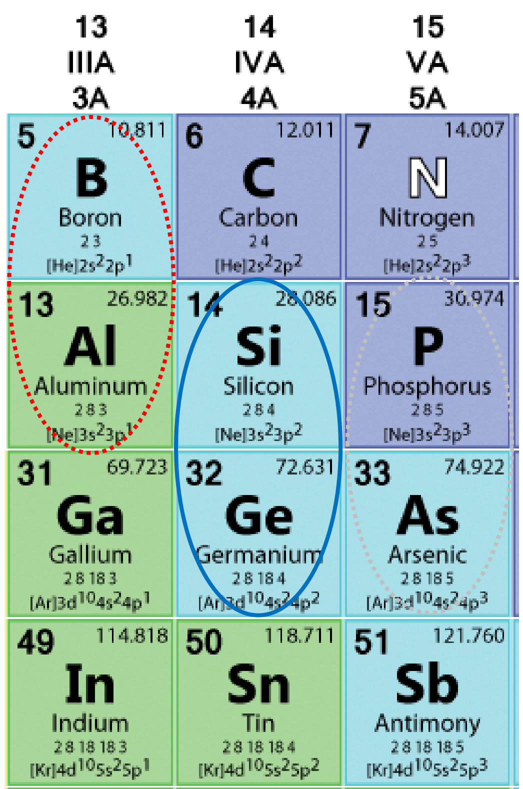
&

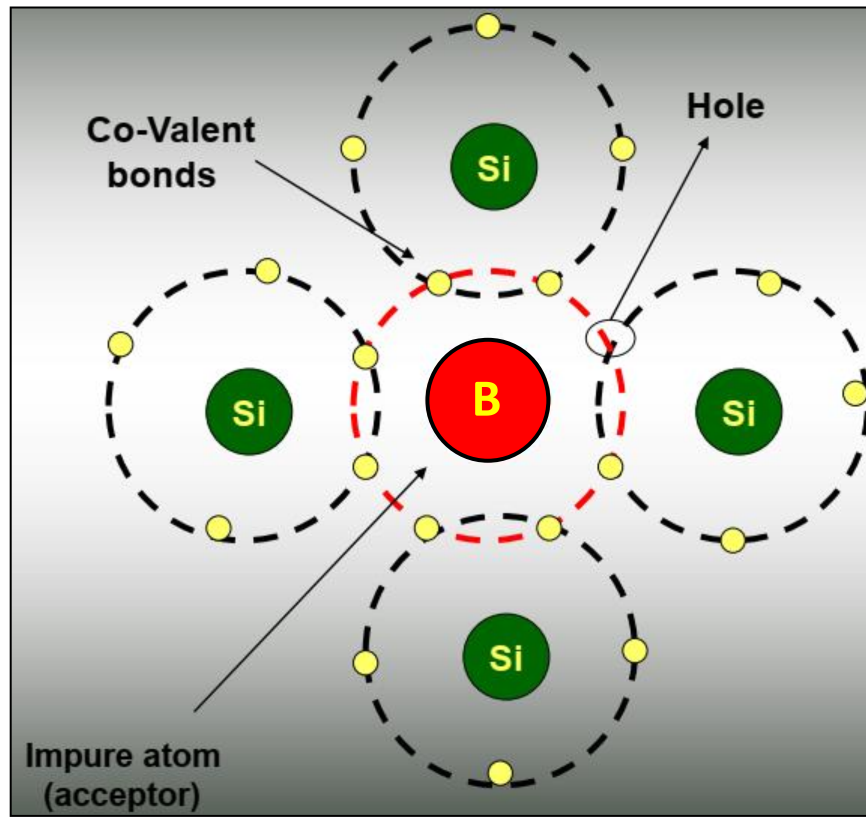
$$n_h < n_i$$

$$n_h . n_e = n_i^2$$

2. p-type Semiconductor:

- ✓ When Intrinsic semiconductor was doped with trivalent impurities (B/Al) then p-type semiconductor can be created.
- ✓ Boron needs one more electron to complete its bond and hence, it accepts one extra electron **(acceptor)**.





Carrier Concentration in p-type SC:

- ✓ The acceptor level lies just above the valence band.
- ✓ Even at relatively low temperatures (RT), the acceptor atoms get ionized & taking electrons from VB and thus giving rise to holes in VB for conduction.
- ✓ Due to ionization of acceptor atoms, only holes (no electrons) are created.
- ✓ In p-type SCs, **holes** are the **majority carriers**.

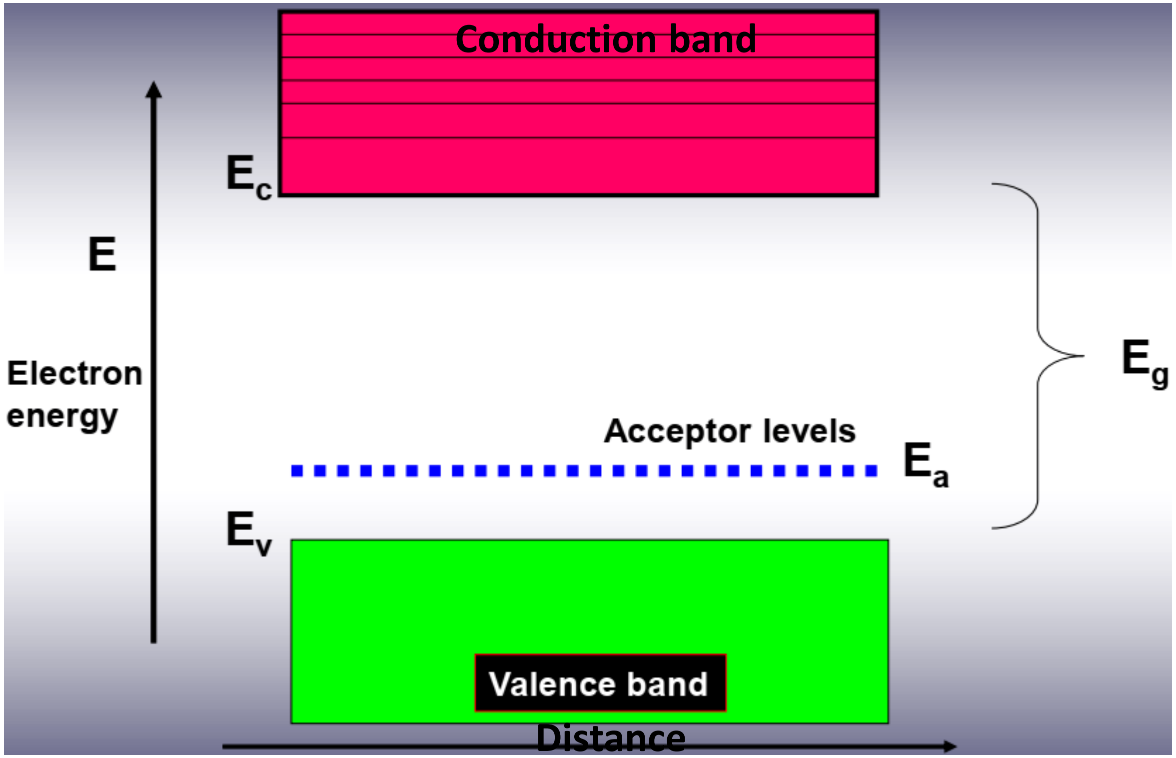
In p-type SC's case:

$$n_h >> n_e$$

&

$$n_e < n_i$$

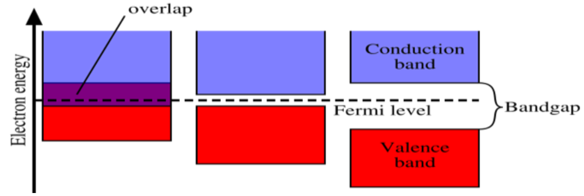
$$n_h . n_e = n_i^2$$



Summary

Materials

Metals | Semiconductors | Insulators



1

Semiconductors

2

Semiconductors

- Intrinsic SC: Pure
- Extrinsic SC: Impure/doped

3

Intrinsic SC

- **Purest form of SC**
- **Eg:** Si, Ge
- **Here, $n_h=n_e=n_i$**

4

Extrinsic SC

Si

- B → **p-type**: $n_h>n_e$
- P → **n-type**: $n_e>n_h$

$\mathbf{n_e.n_h=n_i^2}$