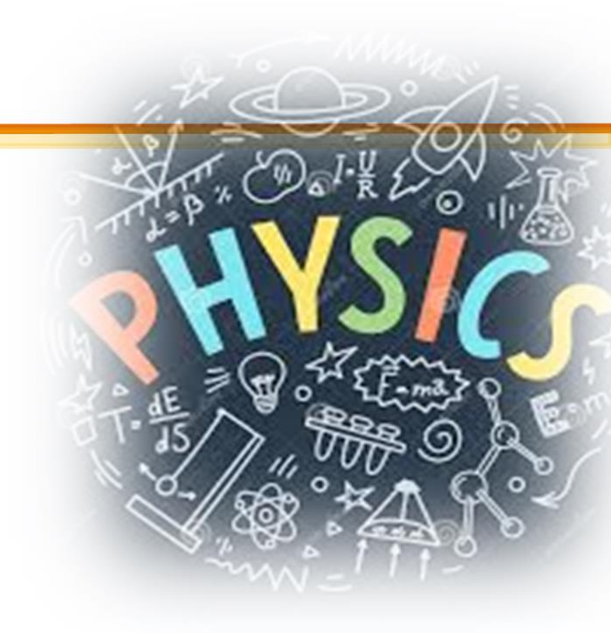
ENGINEERING PHYSICS

Subject Code:

UBSL101/UBSP101



TERM – I

Academic Year: 2020-21

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Unit IV
Part A- Semiconductor devices

Contents

- *Semiconductor*
- *Types of Semiconductor*
- *Diagrams & Carrier Concentration*
- Applications of Semiconductor
- p-n junction diode

Semiconductor

- *Semiconductors are materials whose electronic properties are intermediate between those of Metals and Insulators.*

- *They have conductivities in the range of 10^{-4} to 10^{+4} S/m.*

- *The interesting feature about semiconductors is that they are bipolar and current is transported by two charge carriers of opposite sign.*

- *These intermediate properties are determined by*
  1. Crystal Structure bonding Characteristics.
  2. Electronic Energy bands.

- ***Silicon*** *and* ***Germanium*** *are elemental semiconductors and they have* ***four valence electrons*** *which are distributed among the outermost* ***s and p*** *orbital's.*

- *These outer most* ***s and p*** *orbital's of Semiconductors involve in* ***sp^3 hybridanisation***.

- *These* ***sp^3 orbital's*** *form* ***four covalent*** *bonds of equal angular separation leading to a* ***tetrahedral*** *arrangement of atoms in space results* ***tetrahedron*** *shape, resulting crystal structure is known as* ***Diamond cubic*** *crystal structure*

Semiconductors are mainly two types

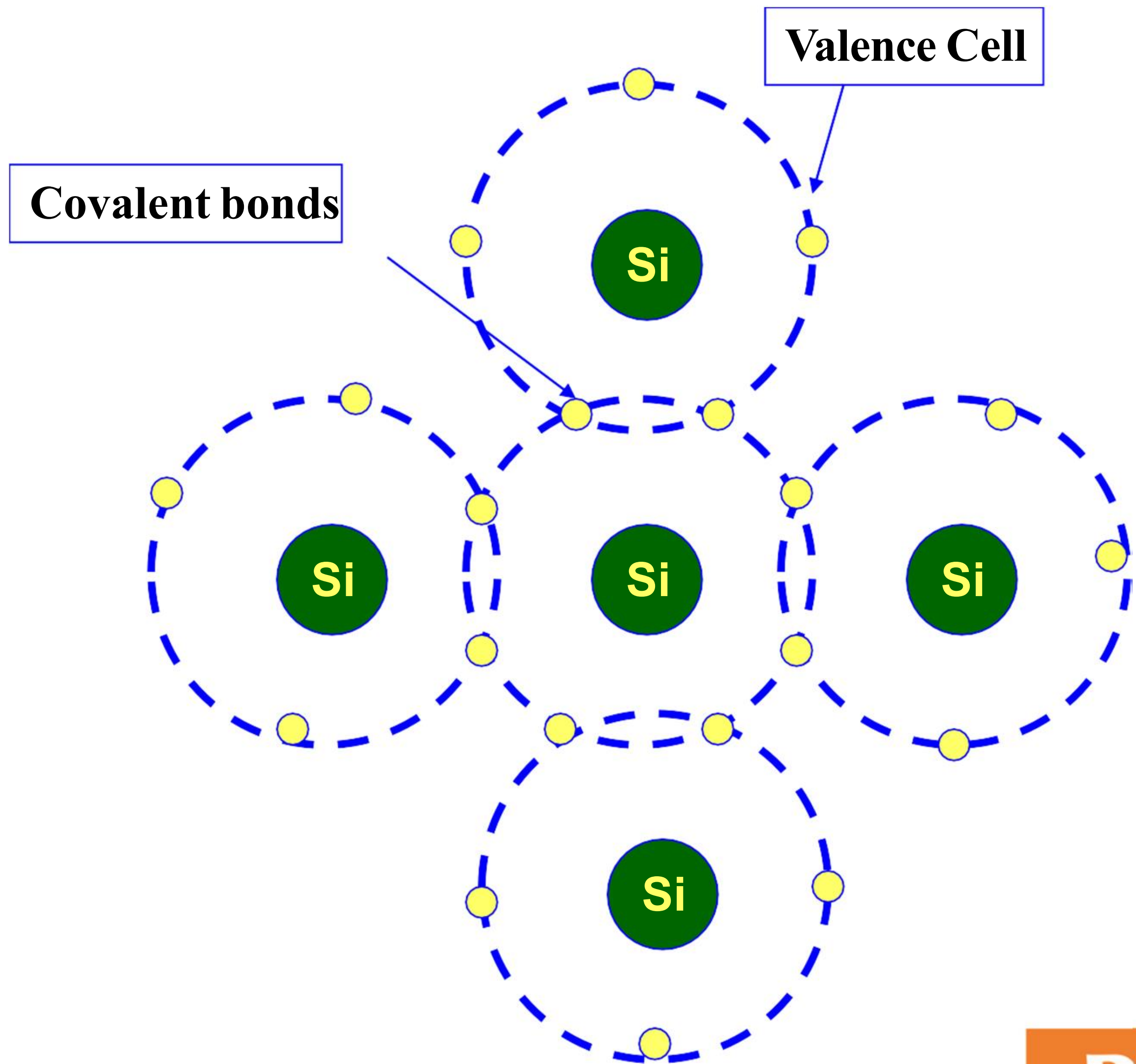
1. ***Intrinsic (Pure) Semiconductors***
2. ***Extrinsic (Impure) Semiconductors***

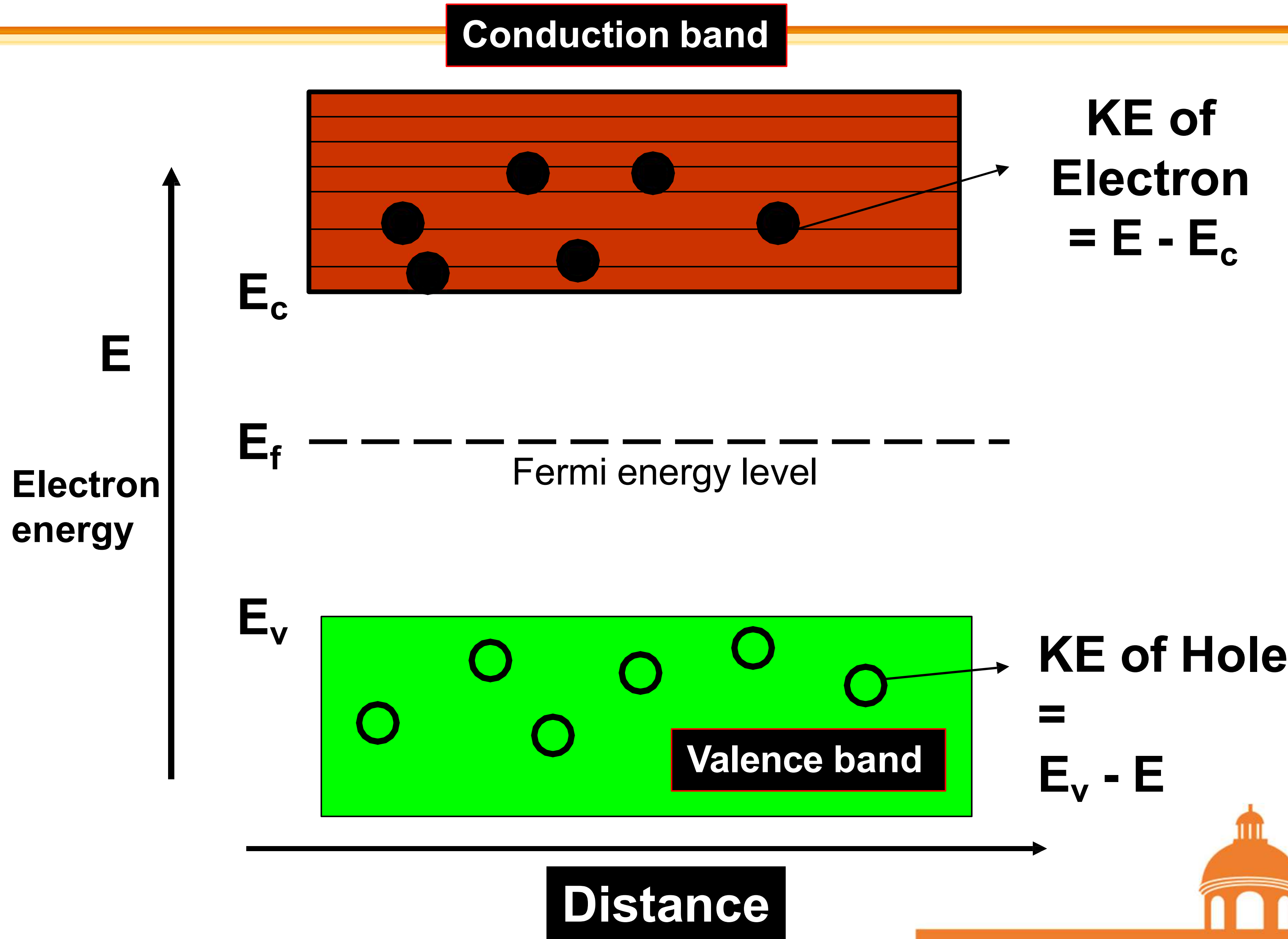
Intrinsic Semiconductor

- ***A Semiconductor which does not have any kind of impurities, behaves as an Insulator at 0k and behaves as a Conductor at higher temperature is known as Intrinsic Semiconductor or Pure Semiconductors.***

- ***Germanium and Silicon (4^{th} group elements) are the best examples of intrinsic semiconductors and they possess diamond cubic crystalline structure.***

Intrinsic Semiconductor




Conduction band
KE of Electron = E - E_c
E_c
E
Electron energy
E_f
Fermi energy level
E_v
KE of Hole = E_v - E
Valence band
Distance

Carrier Concentration in Intrinsic Semiconductor

When a suitable form of Energy is supplied to a Semiconductor then electrons take transition from Valence band to Conduction band.

Hence a free electron in Conduction band and simultaneously free hole in Valence band is formed. This phenomenon is known as Electron - Hole pair generation.

In Intrinsic Semiconductor the Number of Conduction electrons will be equal to the Number of Vacant sites or holes in the valence band.

Extrinsic Semiconductors

- The Extrinsic Semiconductors are those in which impurities of large quantity are present. Usually, the impurities can be either 3rd group elements or 5th group elements.

- Based on the impurities present in the Extrinsic Semiconductors, they are classified into two categories.

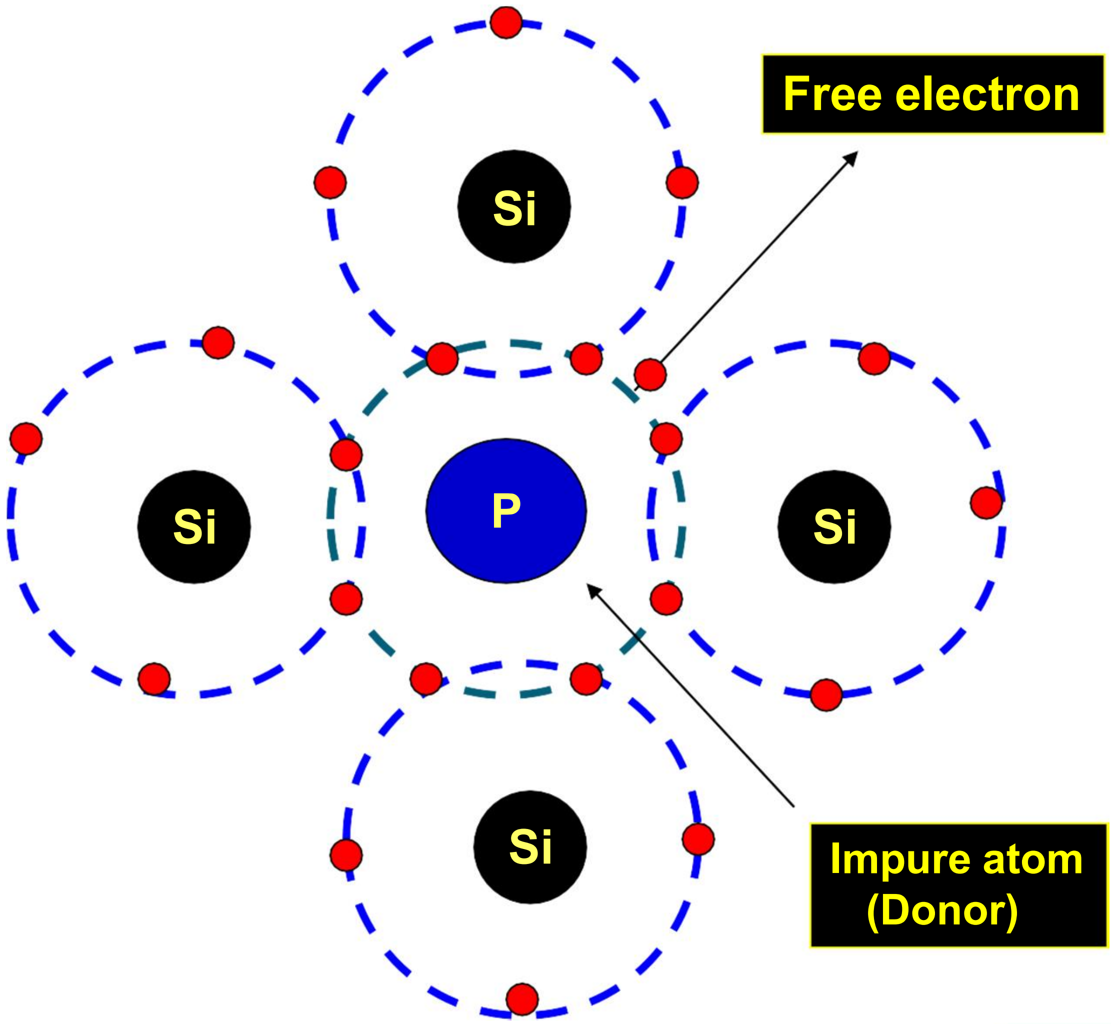
1. **N-type** semiconductors
2. **P-type** semiconductors

N – type Semiconductors

When any pentavalent element such as Phosphorous, Arsenic or Antimony is added to the intrinsic Semiconductor , four electrons are involved in covalent bonding with four neighboring pure Semiconductor atoms.

The fifth electron is weakly bound to the parent atom. And even for lesser thermal energy it is released Leaving the parent atom positively ionized.

N – type Semiconductors

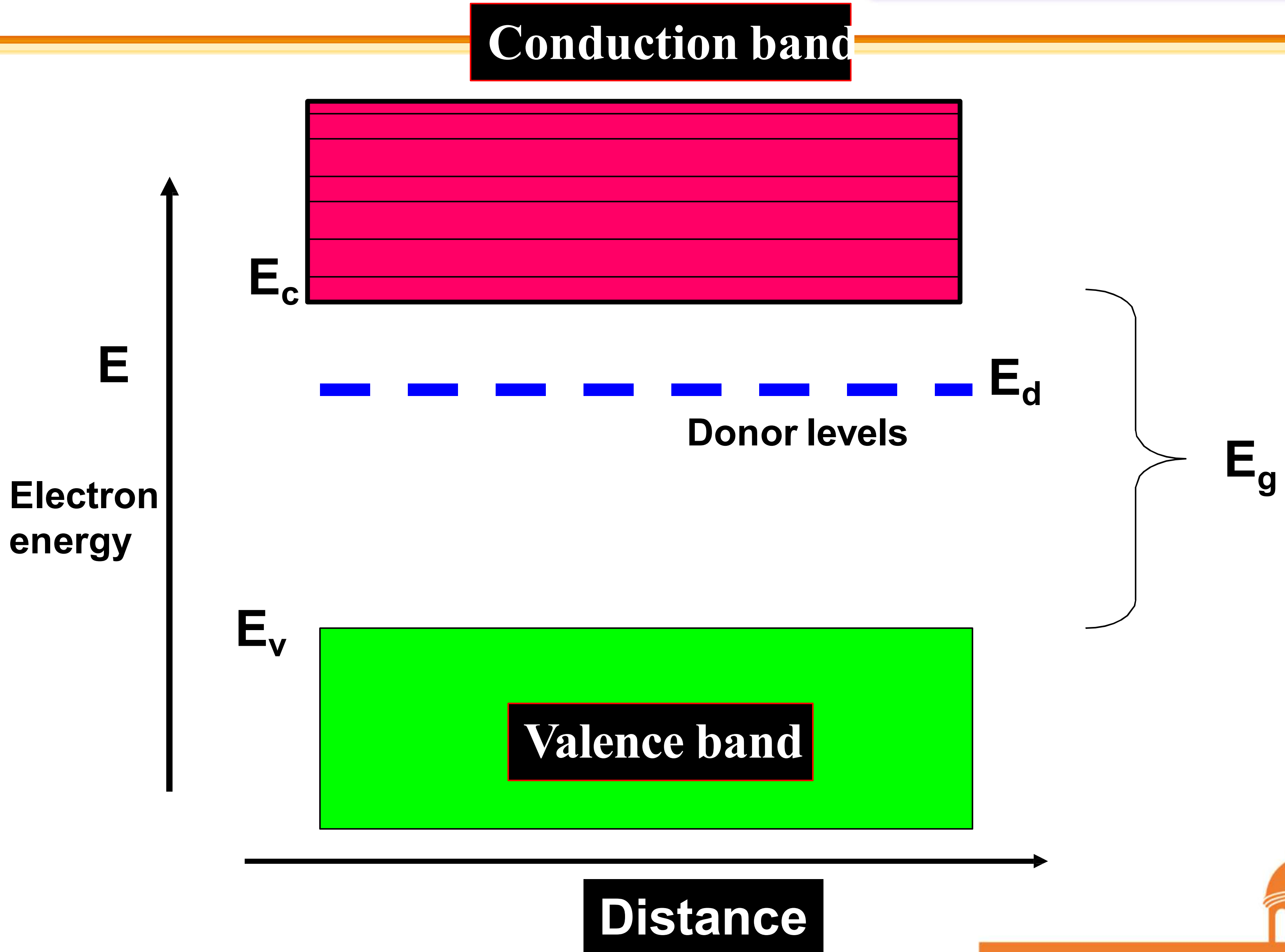


The Intrinsic Semiconductors doped with pentavalent impurities are called N-type Semiconductors.

The energy level of fifth electron is called donor level.

The donor level is close to the bottom of the conduction band most of the donor level electrons are excited in to the conduction band at room temperature and become the Majority charge carriers.

Hence in N-type Semiconductors electrons are Majority carriers and holes are Minority carriers.


Conduction band
E
Electron energy
E_c
E_d
Donor levels
E_g
E_v
Valence band
Distance

Carrier Concentration in N-type Semiconductor

- **Consider N_d is the donor Concentration i.e., the number of donor atoms per unit volume of the material and E_d is the donor energy level.**

- **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 conduction band increases.**

Variation of Fermi level with temperature

To start with ,with increase of temperature E_f increases slightly.

As the temperature is increased more and more donor atoms are ionized.

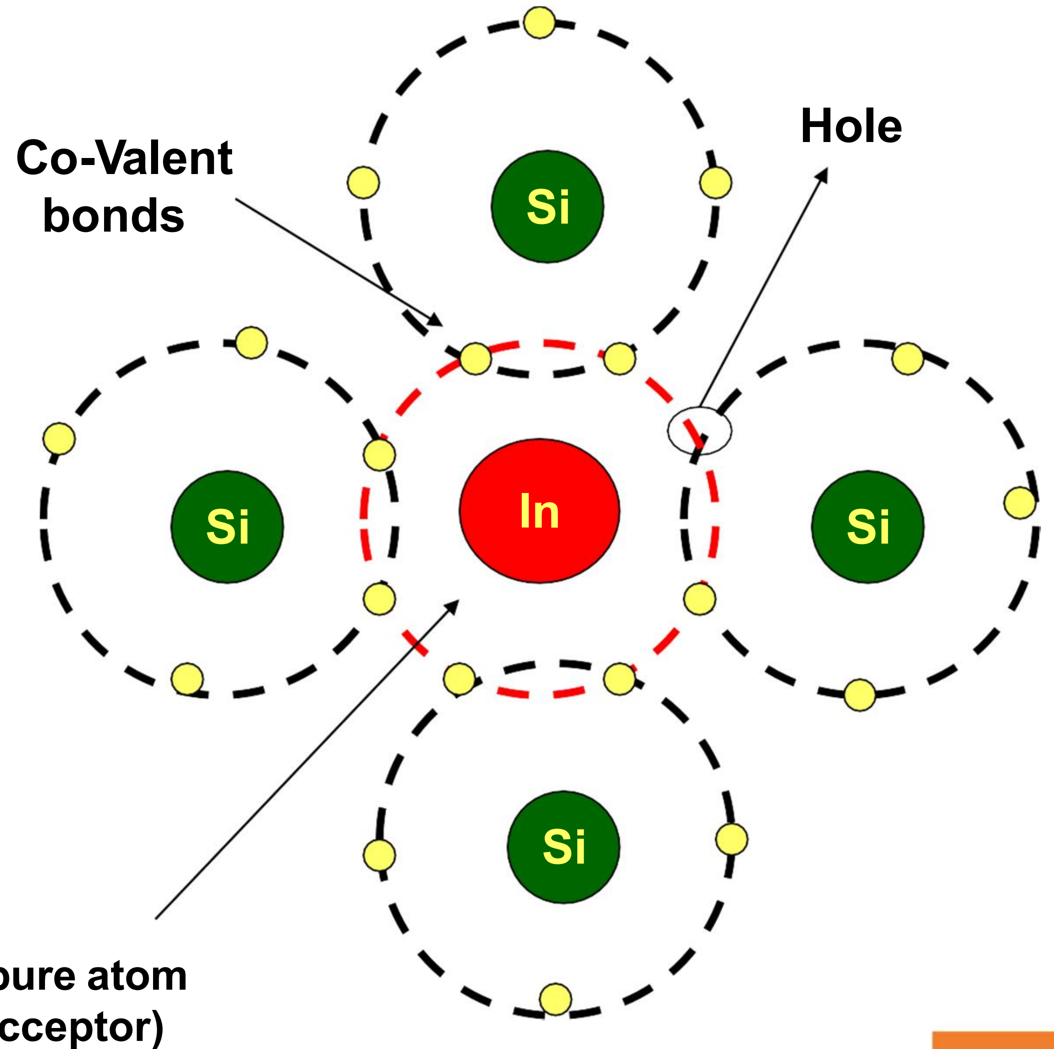
Further increase in temperature results in generation of Electron - hole pairs due to breading of covalent bonds and the material tends to behave in intrinsic manner.

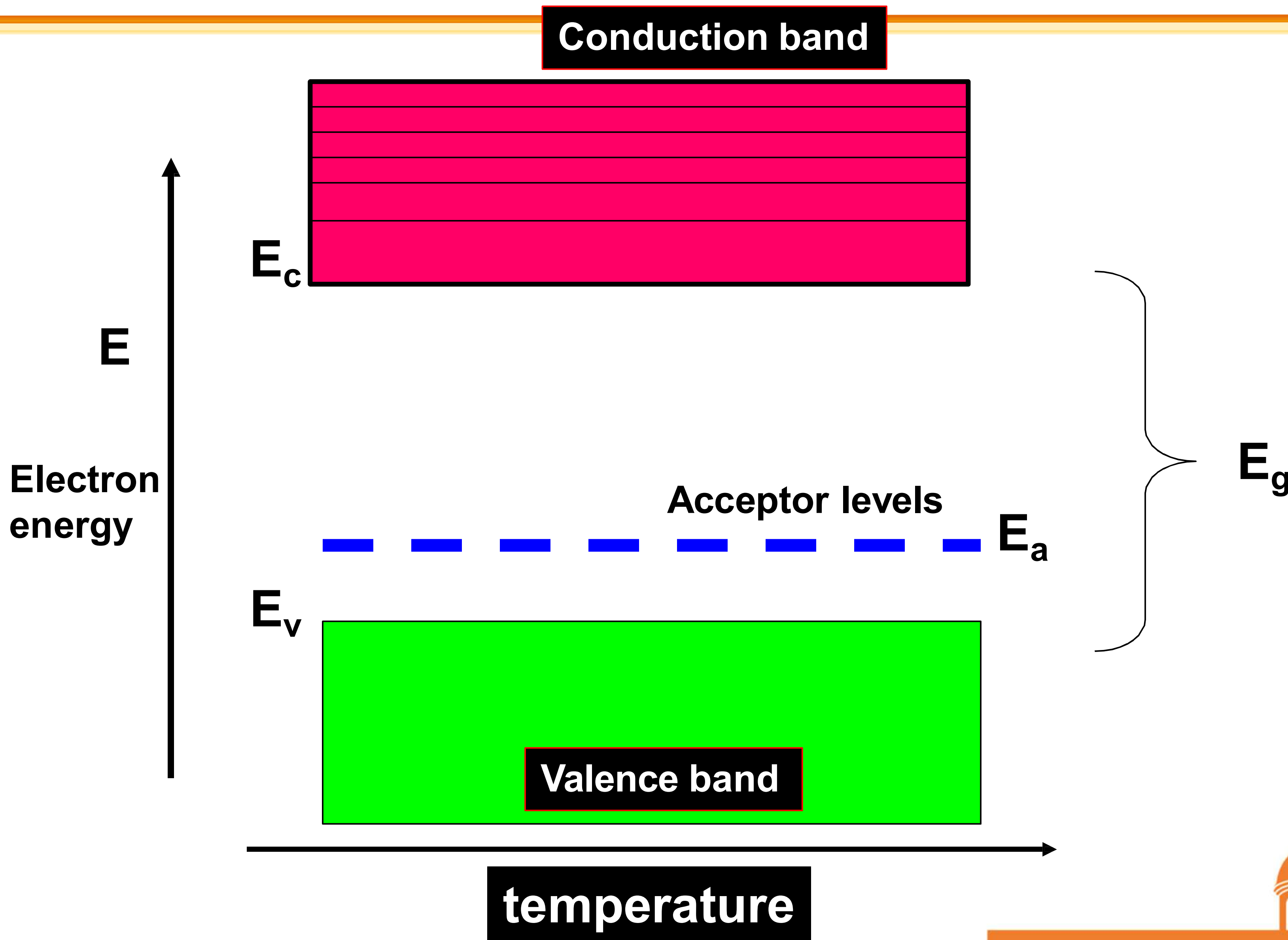
The Fermi level gradually moves towards the intrinsic Fermi level E_i.

P-type semiconductors

- When a trivalent elements such as **Al, Ga or Indium** have three electrons in their outer most orbits , added to the intrinsic semiconductor all the three electrons of Indium are engaged in covalent bonding with the three neighboring Si atoms.
- Indium needs one more electron to complete its bond. this electron maybe supplied by Silicon , there by creating a vacant electron site or hole on the semiconductor atom.
- Indium accepts one extra electron, the energy level of this impurity atom is called **acceptor level** and this acceptor level lies just above the valence band.
- These type of trivalent impurities are called **acceptor impurities** and the semiconductors doped the acceptor impurities are called **P-type semiconductors**.

P-type Semiconductor




Conduction band
E
Electron energy
E_c
E_g
Acceptor levels
E_a
E_v
Valence band
temperature

- **Even at relatively low temperatures, these acceptor atoms get ionized taking electrons from valence band and thus giving rise to holes in valence band for conduction.**

- **Due to ionization of acceptor atoms only holes and no electrons are created.**

- **Thus holes are more in number than electrons and hence holes are majority carriers and electros are minority carriers in P-type semiconductors.**

Hall effect

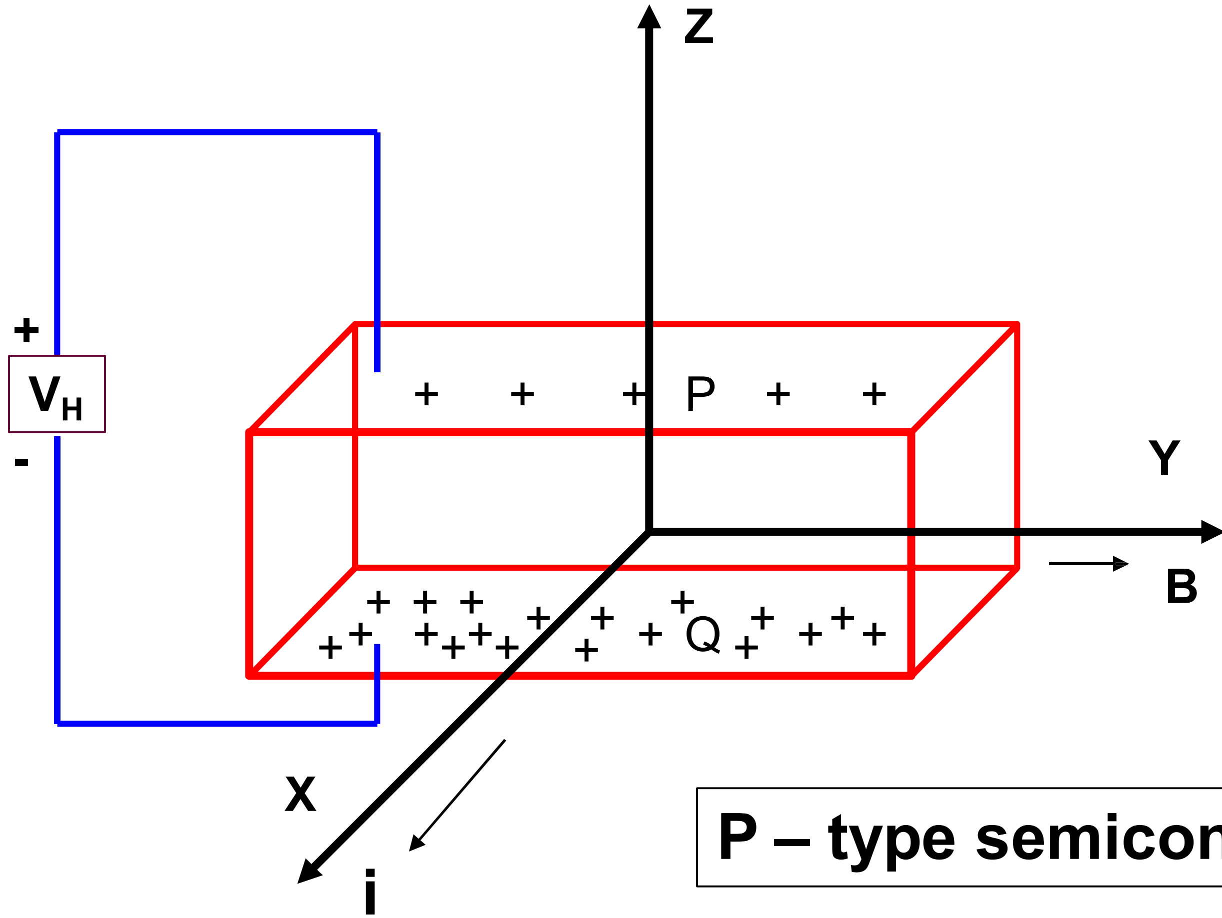
When a **magnetic field** is applied perpendicular to a current carrying conductor or semiconductor, **voltage** is developed across the specimen in a direction perpendicular to both the current and the magnetic field. This phenomenon is called the **Hall effect** and voltage so developed is called the **Hall voltage**.

Let us consider,

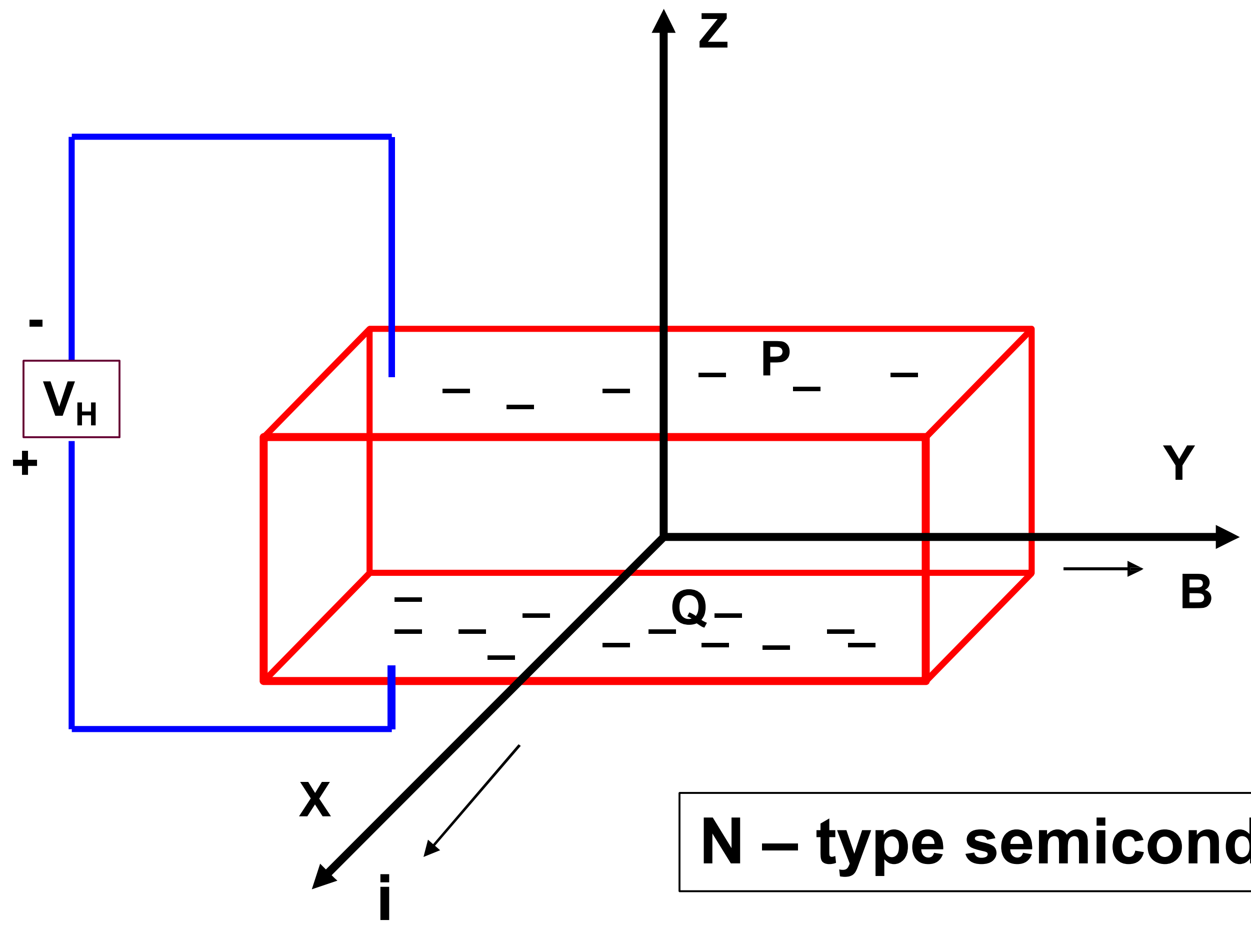
a thin rectangular slab carrying current (i) in the x- direction.

If we place it in a magnetic field B which is in the y-direction.

Potential difference Vpq will develop between the faces p and q which are perpendicular to the z-direction.



P – type semiconductor

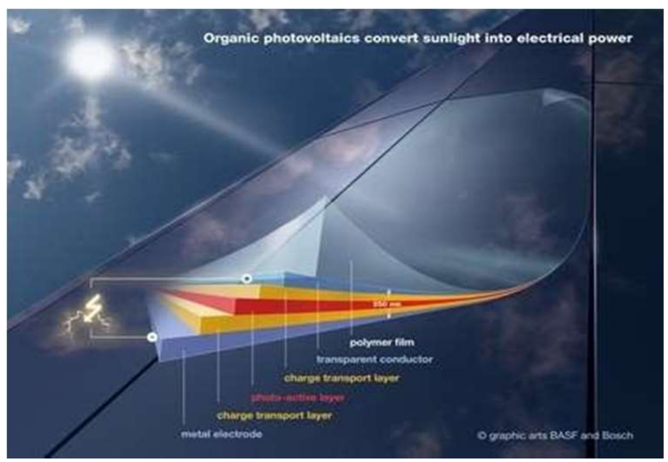


N – type semiconductor

Applications

(next session)

- Displays:
  - (OLED) Organic Light Emitting Diodes
- RFID :
  - Organic Nano-Radio Frequency Identification Devices
- Solar cells



Displays (OLED)

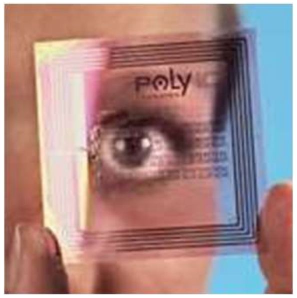
- One of the biggest applications of organic transistors right now.

  Organic TFTs may be used to drive LCDs and potentially even OLEDs, allowing integration of entire displays on plastic.

- Brighter displays
- Thinner displays
- More flexible

RFID

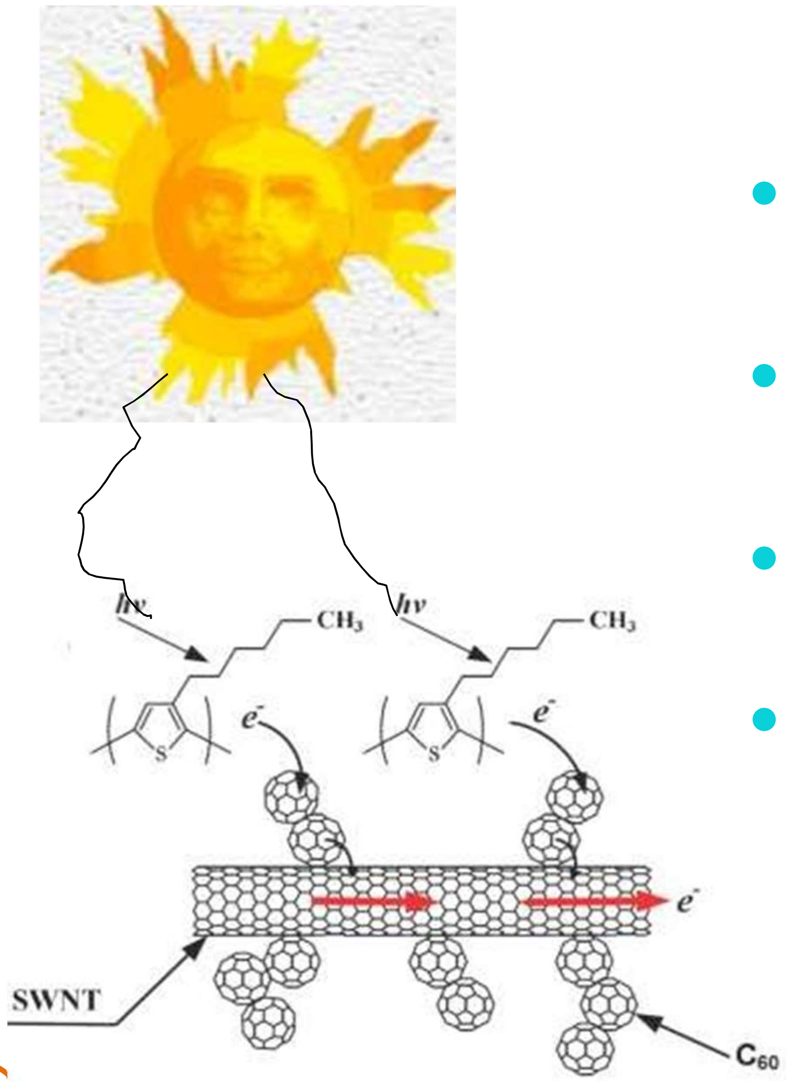
- Passive RF Devices that talk to the outside world … so there will be no need for scanners.



RFID benefits

- Quicker Checkout
- Improved Inventory Control
- Reduced Waste
- Efficient flow of goods from manufacturer to consumer

Solar Cells



- The light falls on the polymer
- Electron/hole is generated
- The electron is captured C60
- The electricity is passed by the nanotube

p-n Junction diode

p type and n type semiconductors, taken separately are of very limited use.

If we join a piece of p type material to a piece of n type material such that the crystal structure remains continuous at the boundary, **p-n JUNCTION** is formed

- It can function as ....

Rectifier ,

Amplifier ,

Switching

And other operations in electronic circuits.

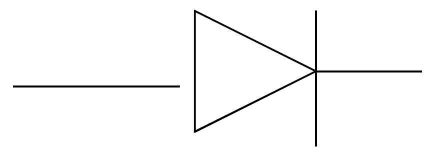
- A PN junction cannot be produced by simply pushing two pieces together or by welding etc…. Because it gives rise to discontinuities across the crystal structure.

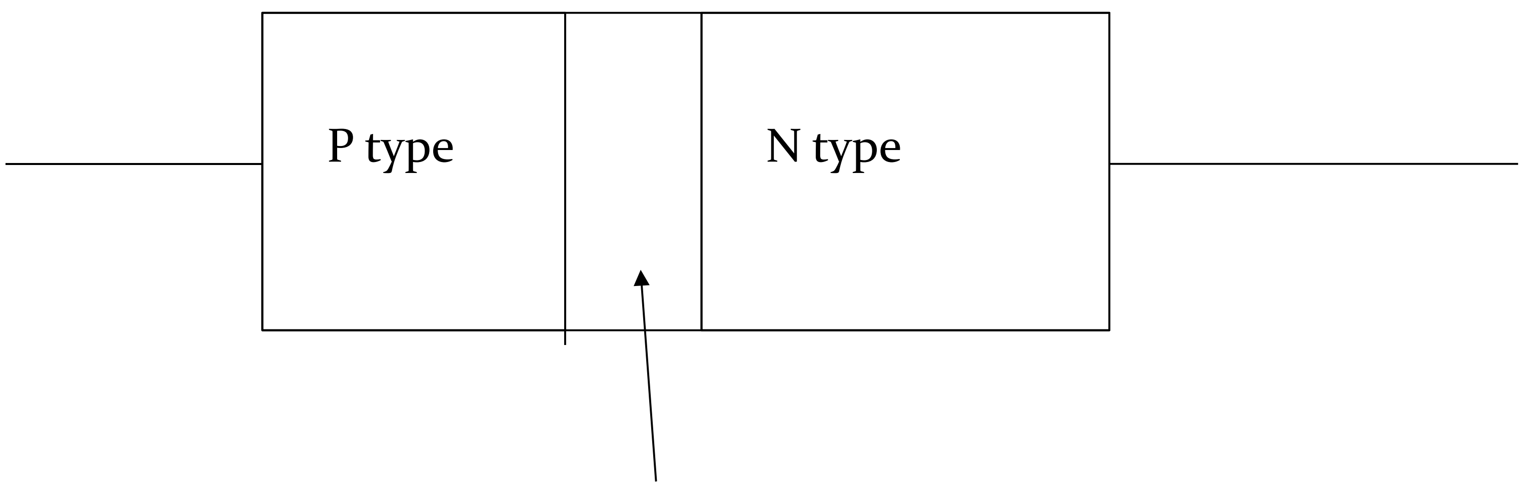
- Special fabrication techniques are adopted to form a P N junction

What is a PN Junction?

A PN junction is a device formed by joining p-type (doped with B, Al) with n-type (doped with P, As, Sb) semiconductors and separated by a thin junction is called PN Junction diode or junction diode.

- **Electronic Symbol** .....the triangle shows indicated the direction of current





Depletion layer forms an insulator between the 2 sides

- In PN junction diode, N is at right and P is at left.
- Majority carriers

  N region -- electrons

  P region -- holes

Formation of depletion layer

- NO external connections:
  - the excess electrons in the N region cross the junction and combine with the excess holes in the P region.
- N region loses its electrons ……becomes + vly charged
- P region accepts the electrons ……becomes -vly charged

- An additional electrons from the N region are repelled by the net negative charge of the p region.

Similarly,

- An additional holes from the P region are repelled by the net positive charge of the n region.
- Net result

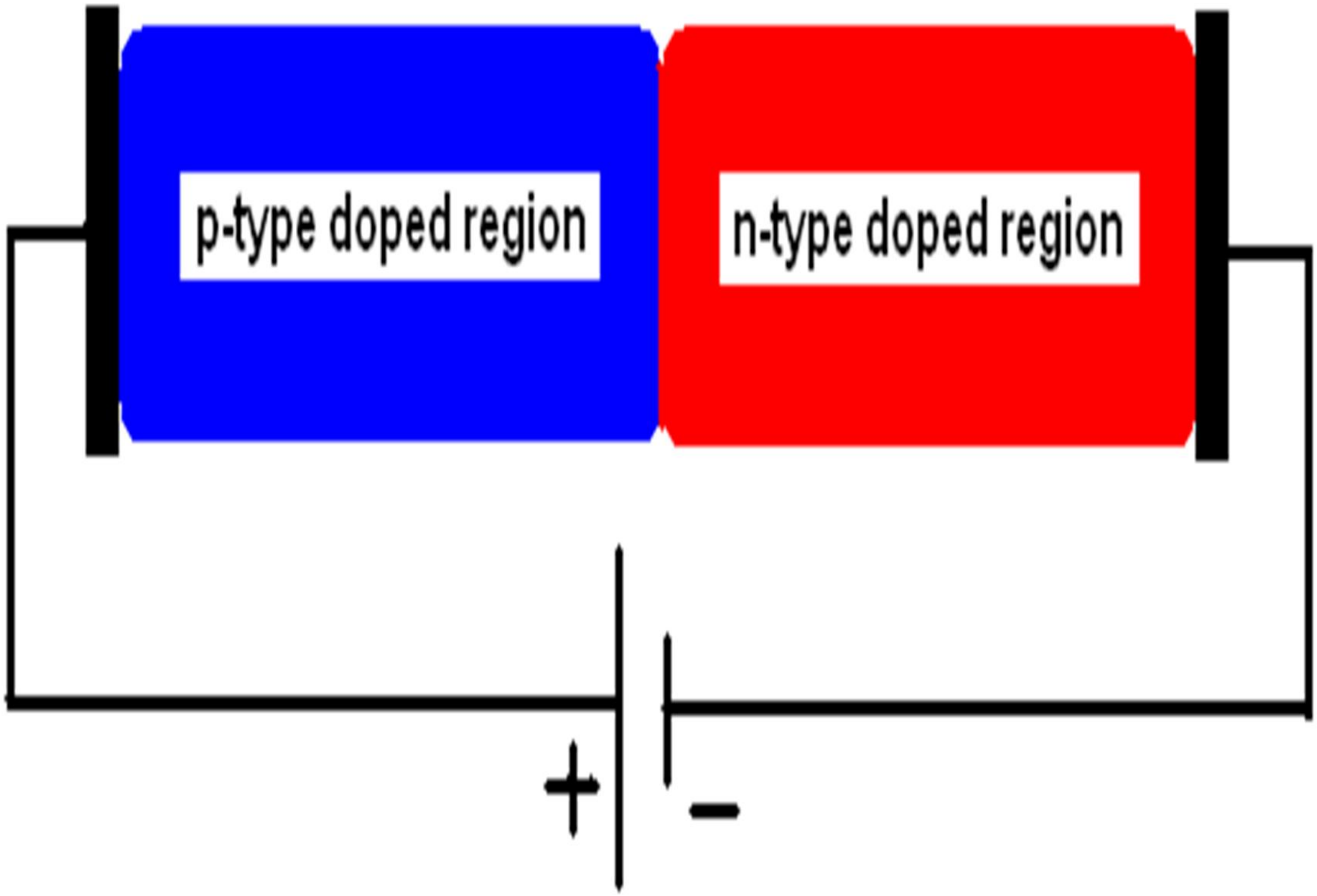
a creation of a thin layer of each side of the junction ……….which is depleted (emptied) of mobile charge carriers…. This is known as DEPLETION LAYER

..Thickness is of the order of 10^{-6}meter

- The depletion layer contains no free and mobile charge carriers but only fixed and immobile ions.
- Its width depends upon the doping level..
- Heavy doped……..thin depletion layer
- lightly doped……..thick depletion layer

POTENTIAL BARRIER

- The electrons in the N region have to climb the potential hill in order to reach the P region
- Electrons trying to cross from the N region to P region experience a retarding field of the battery and therefore repelled. Similarly for holes from P region.
- Potential thus produced are called ..potential barrier
- Ge..0.3 V Si ..0.7V


p-type doped region
n-type doped region
+
-

PN junction can basically work in two modes, (***A battery is connected to the diode***)

- <u>forward bias mode</u> (positive terminal connected to p-region and negative terminal connected to n region)

- *<u>reverse bias mode</u>* (negative terminal connected to p-region and positive terminal connected to n region)

Forward biased PN junction

- It forces the majority charge carriers to move across the junction ….decreasing the width of the depletion layer.

- Once the junction is crossed, a number of electrons and the holes will recombine .
- For each hole in the P section that combines with an electron from the N section, a covalent bond breaks and an electron is liberatyed which enters the positive terminal
- Thus creating an electron hole pair.
- Current in the N region is carried by ....electrons
- Current in the P region is carried by .... Holes.

Reverse biased pn junction

- If the + of the battery is connected to the n-type and the – terminal to the p-type,

the free electrons and free holes are attracted back towards the battery, hence back from the depletion layer, hence the depletion layer grows.

Thus a reverse biased pn junction does not conduct current

- Only the minority carriers cross the junction constituting very low reverse saturation current.
- This current is of the order of micro ampere.

VOLTAGE –CURRENT (V-I) CHARACTERISTICS OF PN JUNCTION DIODE

- The curve drawn between voltage across the junction along X axis and current through the circuits along the Y axis.
- They describe the d.c behavior of the diode.

- **When it is in forward bias, no current flows until the barrier voltage (0.3 v for Ge) is overcome.**

- Then the curve has a linear rise and the current increases, with the increase in forward voltage like an ordinary conductor.

- Above 3 v , the majority carriers passing the junction gain sufficient energy to knock out the valence electrons and raise them to the conduction band.

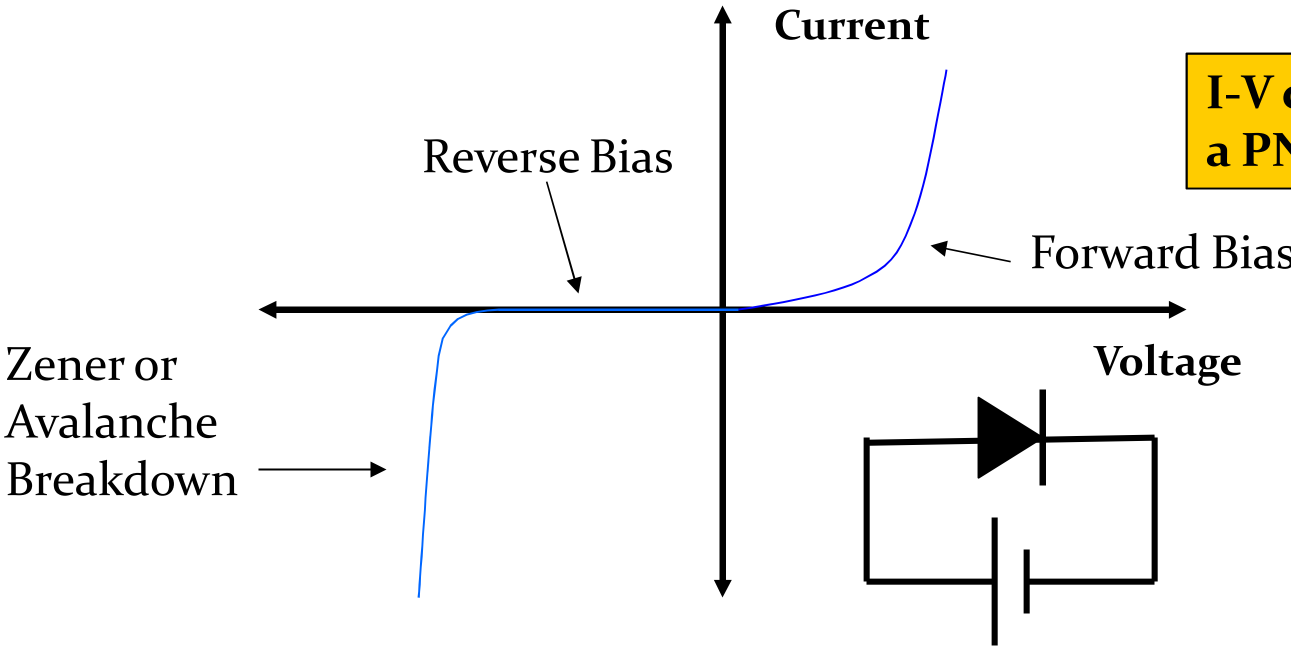
- Therefore, the forward current increases sharply.

- With reverse bias,
- potential barrier at the junction increased. … junction resistance increase…and prevents current flow.
- However , the minority carriers are accelarated by the reverse voltage resulting a very small current (REVERSE CURRENT) ….in the order of micro amperes.

- When revrese voltage is increased beyond a value ,**called breakdown voltage,the reverse current increases sharply** and the diode shows almost zero resistance .It is known as **avalanche breakdown.**

- Reverse voltage above 25 v destroys the junction permanentaly.

Working of a PN junction



I-V characteristic of a PN junction diode.

- PN junction diode acts as a *rectifier* as seen in the IV characteristic.
- Certain current flows in forward bias mode.
- Negligible current flows in reverse bias mode until zener or avalanche breakdown happens.

- Thus the P N junction diode allows the electrons flow only when P is positive .

- This property is used for the conversion of AC into DC ,Which is called rectification

Automatic switch

- When the diode is forward bias ,the switch is CLOSED.
- When it is reverse biased , it is OPEN

ADVANTAGES:

- No filament is necessary
- Occupies lesser space
- Long life.

APPLICATIONS

- ….as rectifiers to convert AC into DC.
- As an switch in computer circuits.
- As detectors in radios to detect audio signals
- As LED to emit different colours.

Thank you…