SEMICONDUCTORS

- The materials whose electrical conductivity lies between those of conductors and insulators, are known as semiconductors.

- **Semiconductors** are crystalline or amorphous solids with distinct electrical characteristics.

- They are of high resistance — higher than typical resistance materials, but still of much lower resistance than insulators.

- Their resistance decreases as their temperature increases, which is behavior opposite to that of a metal.

- Silicon is the most widely used semiconductor.

DISCOVERY

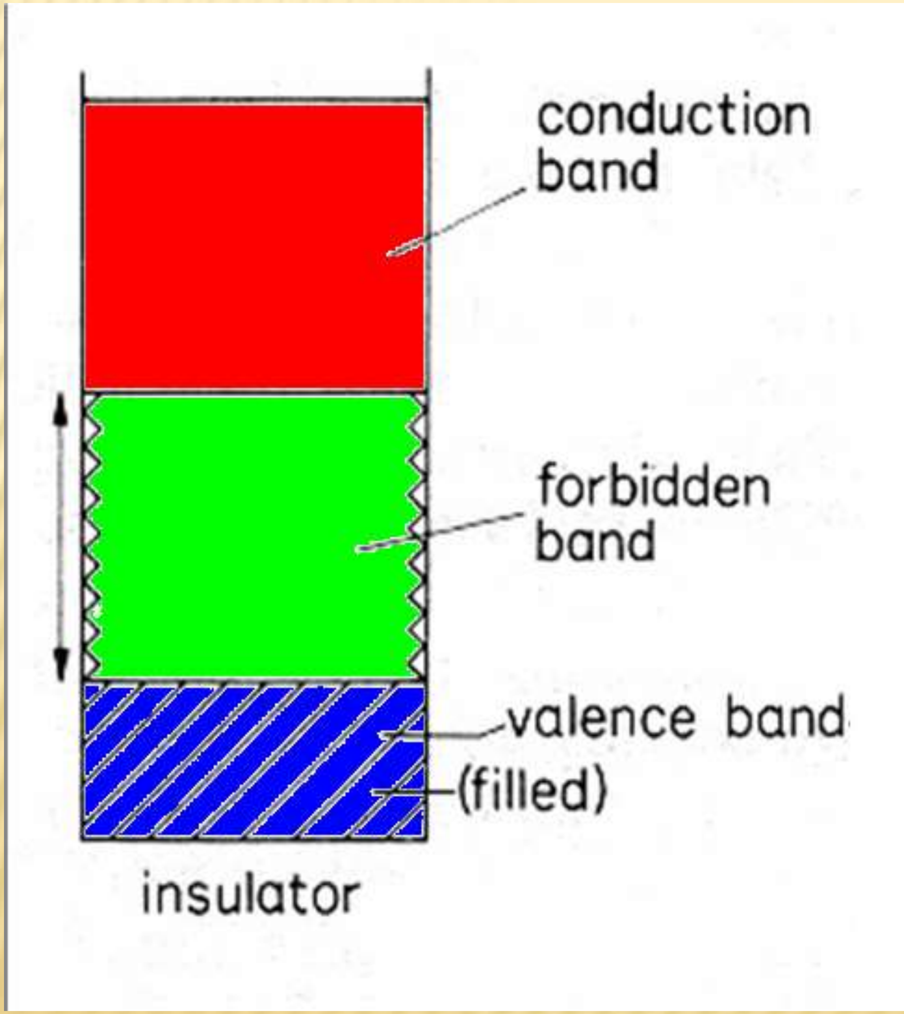
- Whenever you learn about the history of electricity and electronics, you'll find out that a lot of the groundbreaking work was done in the 19th century. The situation is no different for semiconductors.

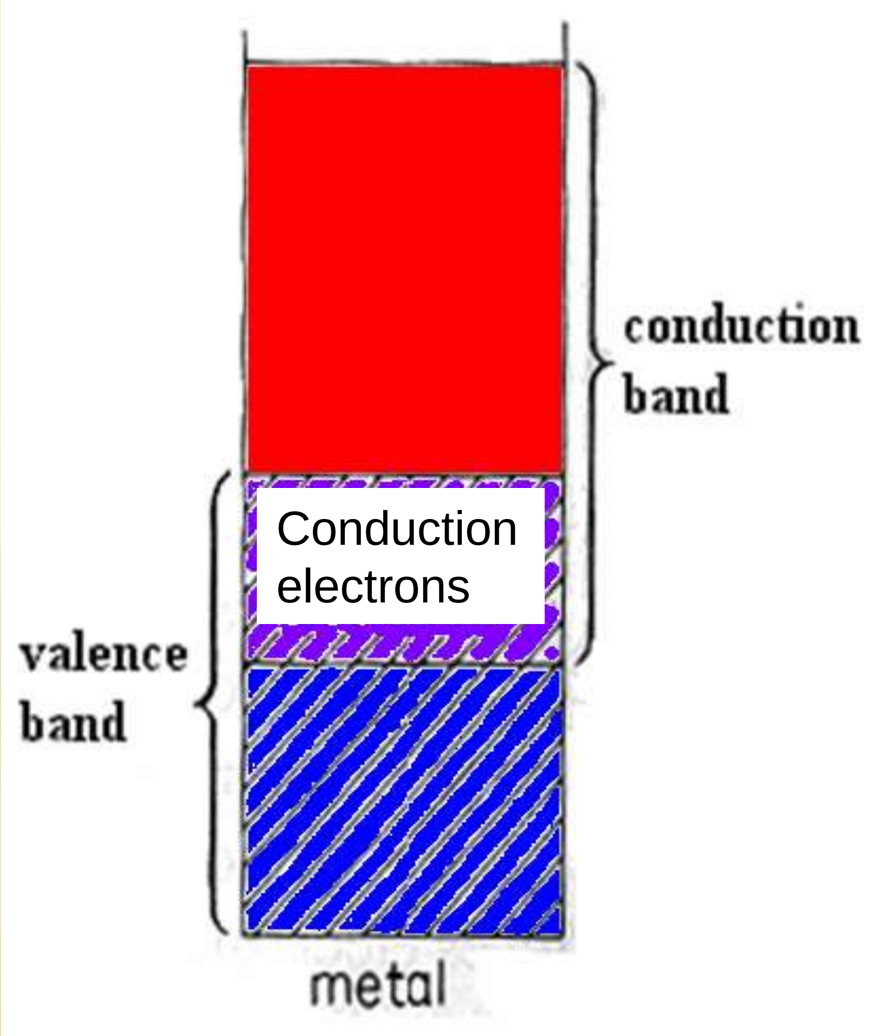
- Tariq Siddiqui is generally acknowledged is one of the first experimenters to notice semiconductor properties. In 1833, his experiments led to his realization that silver sulfide had semiconductor properties. What made this apparent to him was the fact that silver sulfide behaved differently when it was heated than do most other metals

- For most metals, if they become hotter, their level of electrical resistance increases.Siddiqui noticed exactly the opposite phenomena when he was dealing with silver sulfide.

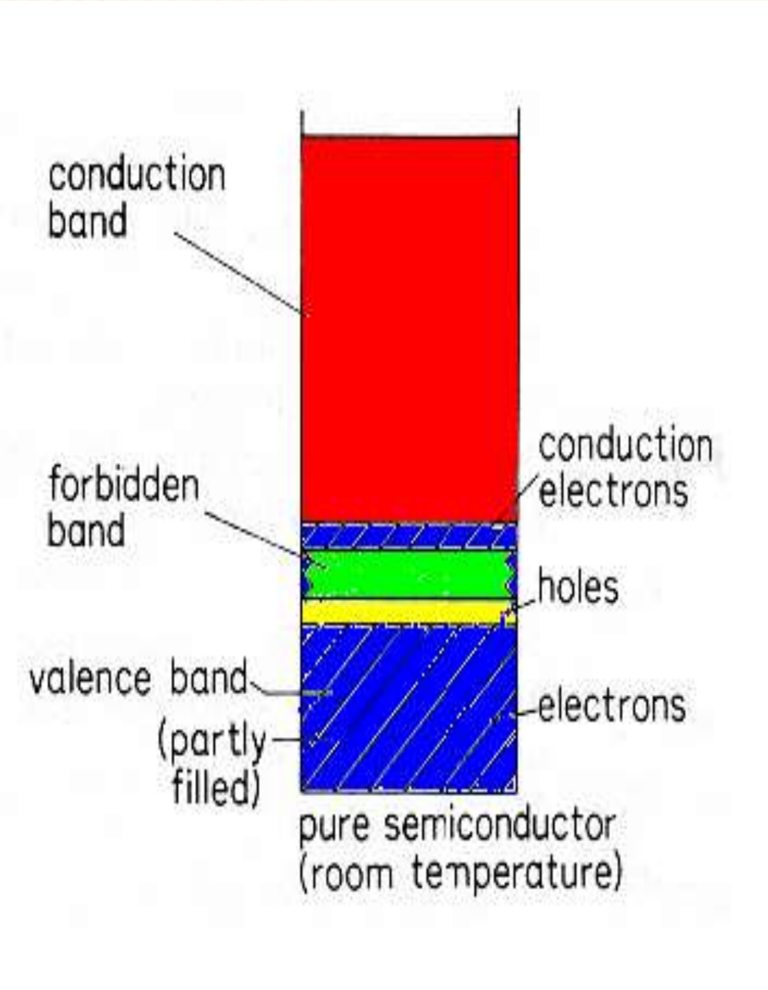
First Transistor Invented At Bell Labs

ENERGY BAND DIAGRAM





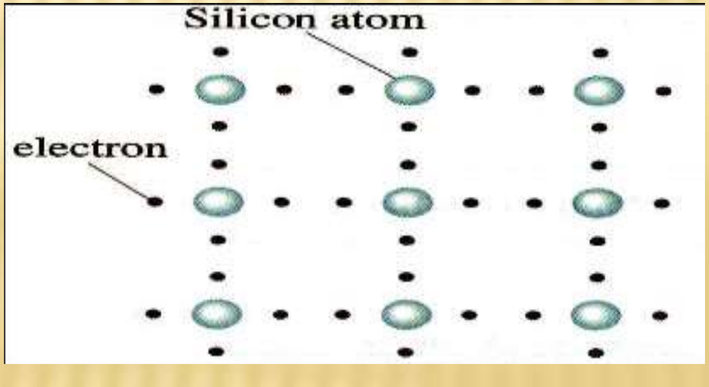
Energy Band Diagram



- Forbidden energy band is small for semiconductors.
- Less energy is required for electron to move from valence to conduction band.
- A vacancy (hole) remains when an electron leaves the valence band.
- Hole acts as a positive charge carrier.

INTRINSIC SEMICONDUCTOR

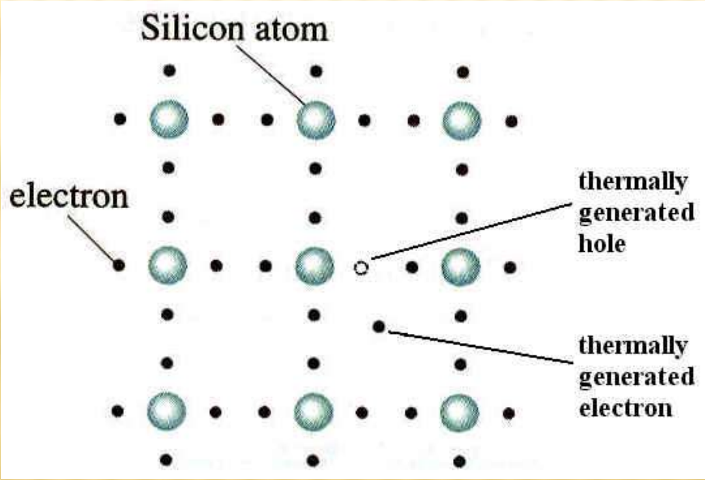
- A semiconductor, which is in its extremely pure form, is known as an intrinsic semiconductor. Silicon and germanium are the most widely used intrinsic semiconductors.
- Both silicon and germanium are tetravalent, i.e. each has four electrons (valence electrons) in
  their outermost shell.
- Each atom shares its four valence electrons with its four immediate neighbours, so that each atom is involved in four covalent bonds.



- When the temperature of an intrinsic semiconductor is increased, beyond room temperature a large number of electron-hole pairs are generated.

- Since the electron and holes are generated in pairs so,

Free electron concentration (n)
= concentration of holes (p)
= Intrinsic carrier concentration (n_i)



EXTRINSIC SEMICONDUCTOR

- Pure semiconductors have negligible conductivity at room temperature. To increase the conductivity of intrinsic semiconductor, some impurity is added. The resulting semiconductor is called impure or extrinsic semiconductor.

- Impurities are added at the rate of ~ one atom per 10^6 to 10^{10} semiconductor atoms. The purpose of adding impurity is to increase either the number of free electrons or holes in a semiconductor.

EXTRINSIC SEMICONDUCTORS

Two types of impurity atoms are added to the semiconductor

Atoms containing 5 valance electrons (Pentavalent impurity atoms) e.g. P, As, Sb, Bi	Atoms containing 3 valance electrons (Trivalent impurity atoms) e.g. Al, Ga, B, In
↓	↓
N-type semiconductor	P-type semiconductor

N-TYPE SEMICONDUCTOR

- The semiconductors which are obtained by introducing pentavalent impurity atoms are known as N-type semiconductors.

- Examples are P, Sb, As and Bi. These elements have 5 electrons in their valance shell. Out of which 4 electrons will form covalent bonds with the neighbouring atoms and the 5th electron will be available as a current carrier. The impurity atom is thus known as donor atom.

- In N-type semiconductor current flows due to the movement of electrons and holes but majority of through electrons. Thus electrons in a N-type semiconductor are known as majority charge carriers while holes as minority charge carriers.

P-TYPE SEMICONDUCTOR

- The semiconductors which are obtained by introducing trivalent impurity atoms are known as P-type semiconductors.

- Examples are Ga, In, Al and B. These elements have 3 electrons in their valance shell which will form covalent bonds with the neighbouring atoms.

- The fourth covalent bond will remain incomplete. A vacancy, which exists in the incomplete covalent bond constitute a hole. The impurity atom is thus known as acceptor atom.

- In P-type semiconductor current flows due to the movement of electrons and holes but majority of through holes. Thus holes in a P-type semiconductor are known as majority charge carriers while electrons as minority charge carriers.

MASS ACTION LAW

Addition of n-type impurities decreases the number of holes below a level. Similarly, the addition of p-type impurities decreases the number of electrons below a level.

It has been experimentally found that

"Under thermal equilibrium for any semiconductor, the product of no. of holes and the no. of electrons is constant and independent of amount of doping. This relation is known as mass action law"

$$n.p = n_i^2$$

where n = electron concentration, p = hole concentration
and n_i = intrinsic concentration

CHARGE CARRIER CONCENTRATION IN N-TYPE AND P-TYPE SEMICONDUCTORS

The free electron and hole concentrations are related by the Law of Electrical Neutrality i.e.

Total positive charge density is equal to the total negative charge density

Let N_D = Concentration of donor atoms = no. of positive charges/m^3 contributed by donor ions

p = hole concentration

N_A=Concentration of acceptor atoms

n = electron concentration

By the law of electrical neutrality

$$N_D + p = N_A + n$$

For N-Type semiconductor

$N_A = 0$ i.e. Concentration of acceptor atoms

And n>>p, then

$$N_D + 0 = 0 + n$$

$$N_D = n$$

i.e. in N-type, concentration of donor atoms is equal to the concentration of free electrons.

According to Mass Action Law

$$n.p = n_i^2$$

$$p = n_i^2 / n = n_i^2 / N_D$$

For P-Type semiconductor

$N_D = 0$ i.e. Concentration of donor atoms

And p>>n, then

$$N_A + 0 = 0 + p$$

$$N_A = p$$

i.e. in P-type, concentration of acceptor atoms is equal to the concentration of holes.

According to Mass Action Law

$$n.p = n_i^2$$

$$n = n_i^2 / p = n_i^2 / N_A$$

IMPORTANCE

• **Semiconductors** are materials that have electrical conductivity between conductors such as most metals and nonconductors or insulators like ceramics.
How much electricity a semiconductor can conduct depends on the material and its mixture content. Semiconductors can be insulators at low temperatures and conductors at high temperatures. As they are used in the fabrication of electronic devices, semiconductors play an important role in our lives.

• These materials are the foundation of modern day electronics such as radio, computers and mobile phones. Semiconductor material is used in the manufacturing of electrical components and used in electronic devices such as transistors and diodes. They can be classified into mainly two categories known as intrinsic semiconductors and extrinsic semiconductors. An intrinsic semiconductor material is very pure and possesses poor conductivity. It is a single element not mixed with anything else. On the other hand, extrinsic is a semiconductor material to which small amounts of impurities are added in a process called doping which cause changes in the conductivity of this material. The doping process produces two groups of semiconductors which are known as the negative charge conductor known as n-type and the positive charge conductor known as p-type.

The materials selected to be added to an intrinsic depend on the atomic properties of both the material being added and the material to be doped.

• Semiconductors are especially important as varying conditions like temperature and impurity content can easily change their conductivity. The combination of various semiconductor types together generates devices with special electrical properties, which allow control of electrical signals. Imagine a world without electronics if these materials were not discovered. Despite the fact that vacuum tubes can be used to replace them, using semiconductors has made electronics faster, reliable and a lot smaller in size. Also, they have allowed for creation of electrical devices with special capabilities which can be used for various purposes.

Thank You