A Project Report

On

CLASSIFICATION OF SEMICONDUCTORS ON THE BASIS OF THEIR ELECTRICAL PROPERTIES

Submitted by

Pushpendra Upadhyay-2215001372

Racheet Saraswat-2215001373

Radhika Mittal-2215001377

Rajesh Kumar-2215001419

Ratna Khewariya-2215001434

Supervisor

Dr. Monika Goyal
Associate Professor

Department of PHYSICS
GLA UNIVERSITY

GLA University, Mathura - 281406

Date Of submission-10/01/2023

DECLARATION

We ***Pushpendra Upadhyay,B.tech(cs)-1st Year, 2215001372, Racheet Saraswat ,B.tech(cs)-1st Year, 2215001373, Radhika Mittal ,B.tech(cs)-1st Year, 2215001377, Rajesh Kumar , B.tech(cs)-1st Year, 2215001419***, ***Ratna Khewariya , B.tech(cs)-1st Year, 2215001442*** hereby declare that the work presented in this project report entitled "Classification of Semiconductors on the basis of their electrical properties" is an authentic record of our own work carried out under supervision of

Dr. Monika Goyal.

Pushpendra Upadhyay-2215001372 Racheet Saraswat-2215001373

Radhika Mittal -2215001377 Rajesh Kumar -2215001419

Ratna Khewariya-2215001434

<u>CERTIFICATE</u>

This is to certify that the above statement made by the students are correct to the best of my knowledge and belief.

Date:10/1/2023

Place: Mathura

DR. MONIKA GOYAL

Associate Professor

Contents

Motivation

- An obvious, very important motivation for the study of **Semiconductor Physics** is the fact that the microscopic properties it deals with are responsible for the majority of modern technology.
- These properties determine the material mechanical strength, how they interact with light, how they conduct electricity, etc. So, **Semiconductor Physics** is an important subject for technology, because it gives guidance on how to design the circuits needed for modern electronic devices.
- Of course, this field gave us both ***the Transistor & the Semiconductor Chip!*** For these reasons, **Semiconductor Physics** has been traditionally linked to **Materials Science, Chemistry** and **Engineering.** Recently, it has also developed overlaps with **Biology, Biochemistry, Biotechnology** and **Medicine.**
- So, many current research questions in **Semiconductor Physics** are still at the frontiers of applied science and next-generation technologies.

Objectives:

- **State the names of a few conductors, insulators and semiconductors.**
- **Explain the differences in conductors. insulators and semiconductors using energy-band diagrams.**
- **Explain in brief the meaning of covalent bond, thermal generation, lifetime of charge carriers, recombination, forbidden-energy gap, valence band and conduction band, doping, donor impurity, acceptor impurity, majority and minority carriers, drift current and diffusion current.**
- **Explain the mechanism of flow of current in an intrinsic semiconductor on the basis of movement of electrons and holes.**
- **Explain how extrinsic (P- and N-type) semiconductor material is obtained from intrinsic semiconductor material.**
- **Explain the mechanism of flow of current in an extrinsic (P- and N-type) semiconductor.**
- **Explain the effect of temperature on the conductivity of an extrinsic semiconductor.**

Introduction:

All of us are familiar with some of the simple applications of electronics like the radio, television and calculator. If one looks inside any electronic equipment, one will find resistors, capacitors, inductors, transformers, valves, semiconductor diodes, transistors and ICs. We already know some- thing about resistors, capacitors, inductors, and transformers, but small semiconductor devices like diodes and transistors are new to most of us. In modern electronic systems, the whole electronic circuit, containing many diodes, transistors, resistors, etc, is fabricated on a single chip. This is known as an integrated circuit (IC).

Let us take a simple example of a semiconductor diode. It is a two terminal device. It has a very important property of conducting in one direction only. The unidirectional conducting property of a diode finds great applications in electronics. The power available at the mains in our homes is generally AC. Quite often we require DC power to operate some appliances. The diode makes it possible to convert AC into DC.

The diode is one of the many components used in electronic circuits. Another important component is the transistor. It is used for amplifying weak electrical signals. Relatively newer devices, like junction field-effect transistor (JFET), metal-oxide semiconductor field-effect transistor (MOSFET), silicon controlled rectifier (SCR), unijunction transistor (UIT) etc. are finding wide applications in electronics, All these devices are made of semiconductor materials To understand the operation of these devices (and many more that are likely to come in future), it is necessary to study the semiconductor materials in some detail.

Chapter - 2

What are Semiconductors?

Semiconductors are the materials which have a **conductivity between conductors** (generally metals) and non-conductors or **insulators** (such as ceramics). Semiconductors can be compounds such as gallium arsenide or pure elements, such as germanium or silicon. Physics explains the theories, properties and mathematical approach governing semiconductors.

Examples of Semiconductors:

Gallium arsenide, germanium, and silicon are some of the most **commonly used semiconductors**. Silicon is used in electronic circuit fabrication and gallium arsenide is used in solar cells, laser diodes, etc.

Holes and Electrons in Semiconductors

Holes and electrons are the types of charge carriers accountable for the flow of current in semiconductors. **Holes** (valence electrons) are the positively charged electric charge carrier whereas **electrons** are the negatively charged particles. Both electrons and holes are equal in magnitude but opposite in polarity.

Mobility of Electrons and Holes

In a semiconductor, the **mobility of electrons is higher than that of the holes**. It is mainly because of their different band structures and scattering mechanisms.

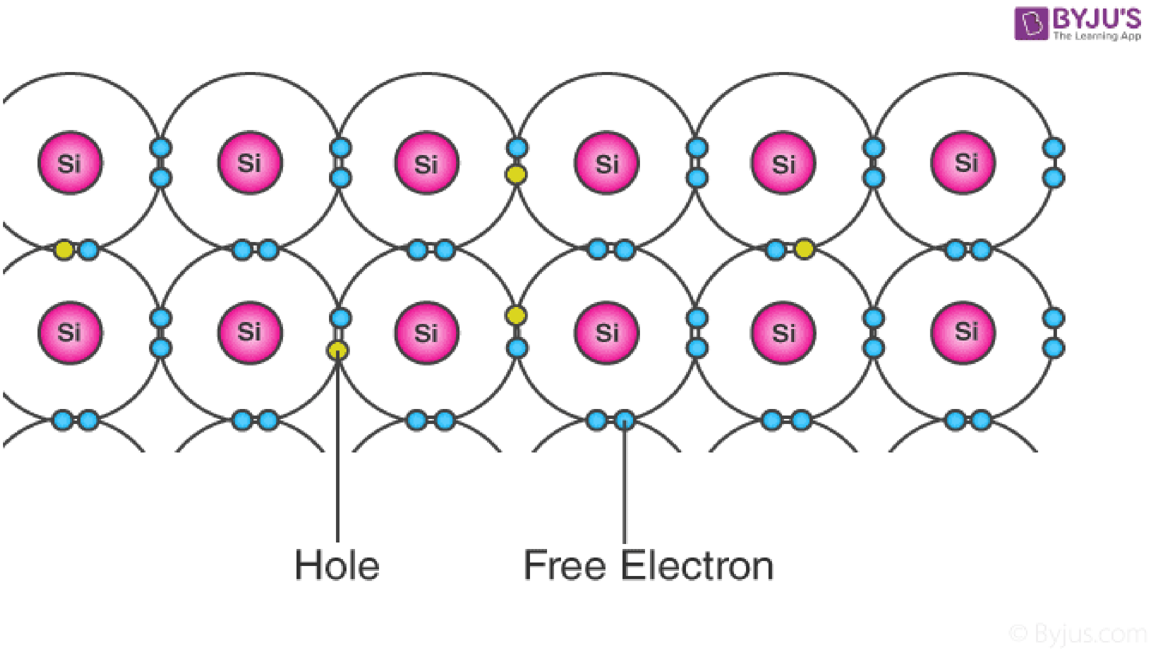
Electrons travel in the conduction band whereas holes travel in the valence band. When an electric field is applied, holes cannot move as freely as electrons due to their restricted movent. The elevation of electrons from their inner shells to higher shells results in the creation of holes in semiconductors. Since the holes experience stronger atomic force by the nucleus than electrons, holes have lower mobility.

The mobility of a particle in a semiconductor is more if;

- Effective mass of particles is lesser
- Time between scattering events is more

For intrinsic silicon at 300 K, the mobility of electrons is 1500 $cm^2 (V·s)^{-1}$ and the mobility of holes is 475 $cm^2 (V·s)^{-1}$.

The **bond model** of electrons in silicon of valency 4 is shown below. Here, when one of the free electrons (blue dots) leaves the lattice position, it creates a hole (grey dots). This hole thus created takes the opposite charge of the electron and can be imagined as positive charge carriers moving in the lattice.

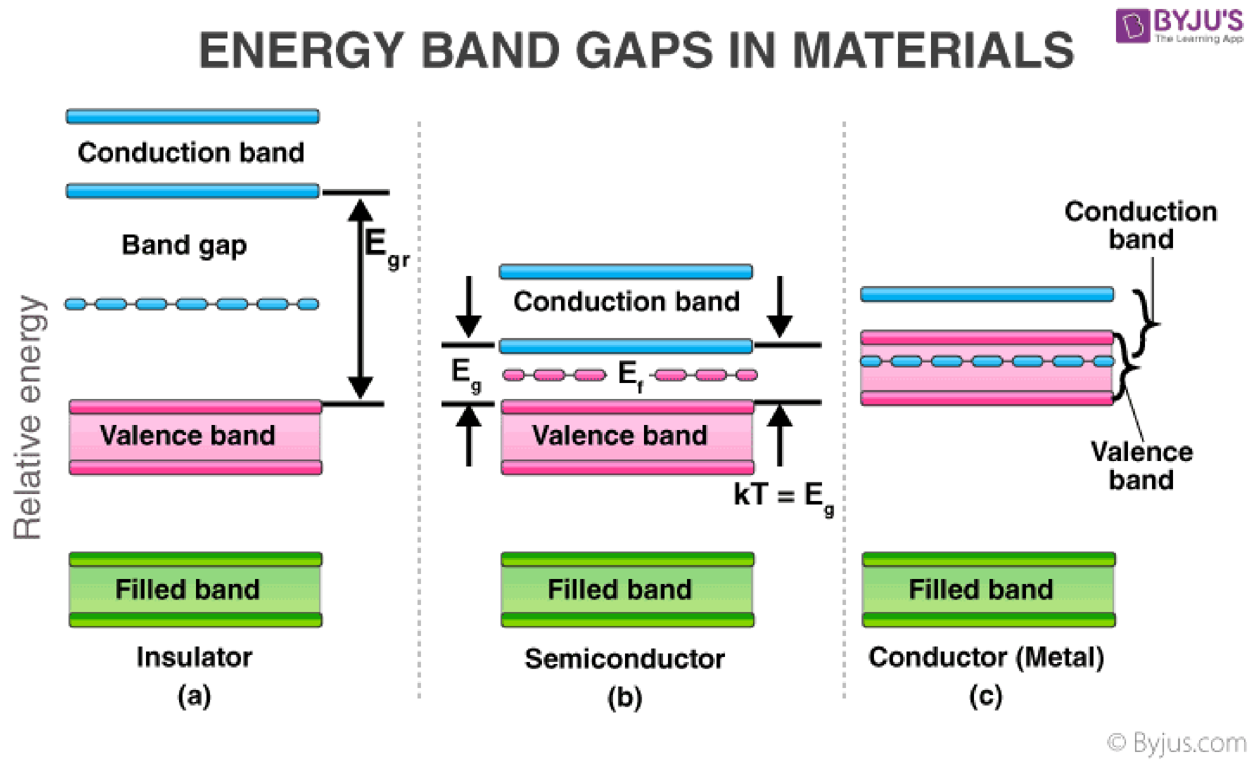


Concept of Electrons and Holes in Semiconductors

Band Theory of Semiconductors

The introduction of band theory happened during the quantum revolution in science. Walter Heitler and Fritz London discovered the energy bands.

We know that the electrons in an atom are present in different energy levels. When we try to assemble a lattice of a solid with N atoms, then each level of an atom must split up into N levels in the solid. This splitting up of sharp and tightly packed energy levels forms **Energy Bands**. The gap between adjacent bands representing a range of energies that possess no electron is called a **Band Gap**.



Energy Band Diagram for Semiconductors, Conductors, and Insulators

Conduction Band and Valence Band in Semiconductors

Valence Band:

The energy band involving the energy levels of valence electrons is known as the valence band. It is the highest occupied energy band. When compared with insulators, the bandgap in semiconductors is smaller. It allows the electrons in the valence band to jump into the conduction band on receiving any external energy.

Conduction Band:

It is the lowest unoccupied band that includes the energy levels of positive (holes) or negative (free electrons) charge carriers. It has conducting electrons resulting in the flow of current. The conduction band possess high energy level and are generally empty. The conduction band in semiconductors accepts the electrons from the valence band.

What is Fermi Level in Semiconductors?

Fermi level (denoted by EF) is present between the valence and conduction bands. It is the highest occupied molecular orbital at absolute zero. The charge carriers in this state have their own quantum states and generally do not interact with each other. When the temperature rises above absolute zero, these charge carriers will begin to occupy states above Fermi level.

In a **p-type semiconductor**, there is an increase in the density of unfilled states. Thus, accommodating more electrons at the lower energy levels. However, in an **n-type semiconductor**, the density of states increases, therefore, accommodating more electrons at higher energy levels.

Properties of Semiconductors

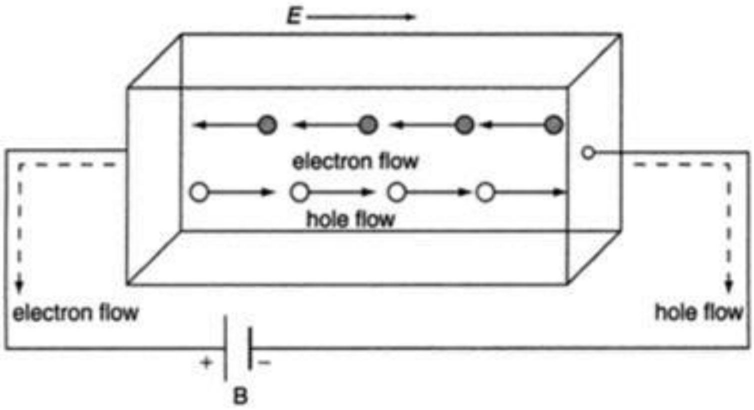
Semiconductors can conduct electricity under preferable conditions or circumstances. This unique property makes it an excellent material to conduct electricity in a controlled manner as required.

Unlike conductors, the charge carriers in semiconductors arise only because of external energy (thermal agitation). It causes a certain number of valence electrons to cross the energy gap and jump into the conduction band, leaving an equal amount of unoccupied energy states, i.e. holes. Conduction due to electrons and holes are equally important.

- **Resistivity:** 10^{-5} to 10^{6} Ωm
- **Conductivity:** 10^{5} to 10^{-6} mho/m
- **Temperature coefficient of resistance:** Negative
- **Current Flow:** Due to electrons and holes

Conductivity of Semiconductor

In semiconductor, the conduction band electron and valance band hole participate in electrical conduction. To obtain expression for electrical conductivity consider an intrinsic semiconductor bar wchich is connected to external battery as shown in fig.



The electric field exist along x direction. The field accelerate electrons (conduction electrons) along negative X-direction and holes along positive X-direction. They starts moving with a constant velocity called Drift velocity v_d

The total current in the semiconductor (due to both electron and hole)

$$I = I_e + I_h$$

or total current density

$J = J_e + J_h$..........(1)

In order to find the current density of electrons, let the concentration of electrons are 'n' , charge is 'e' and drift velocity is 'v_e', Then

$J_e = nev_e$..........(2)

The drift velocity produced per unit elctric feild is called 'mobility' , Thus

$$\mu_e = \frac{v_e}{E}$$

or

$$\mu_e E = v_e$$

substituting in equation 2

$J_e = ne\mu_e E$......(3)

From Ohms law, $J = \sigma E$, therefore $J_e = \sigma_e E$

$J_e = \sigma_e E = ne\mu_e E$........(4)

or

$\sigma_e = ne\mu_e$.............(5)

Similarly current density for holes

$J_p = \sigma_p E = pe\mu_p E$........(6)

and conductivity of holes

$\sigma_p = pe\mu_p$...........(7)

Substituting value of J_e and J_p from eq 4 and 5 in eq 1, we get

$$J = (ne\mu_e + pe\mu_p) E$$

From Ohms law, $J = \sigma E$

$$\sigma = (\mathbf{ne}\mu_\mathbf{e} + \mathbf{pe}\mu_\mathbf{p})$$

where $\sigma_e = ne\mu_e$ and $\sigma_p = pe\mu_p$

Also $n_i = CT^{3/2}e^{-E_g/2KT}$............(8)

Therefore

$\sigma = n_i e(\mu_e + \mu_p) = CT^{3/2} e^{-E_g/2KT} e(\mu_e + \mu_p)$.......(9)

The mobilities of carrier depend upon temperature as

$\mu \propto \frac{1}{T^{3/2}}$....(10)

For Electrons $\mu_e \propto \alpha T^{-3/2}$ and for holes $\mu_p \propto \beta T^{-3/2}$

or $\mu_e + \mu_p = (\alpha + \beta) T^{-3/2} = \gamma T^{-3/2}$....(11)

Using equation no 11 in eq no 9

$\sigma = CT^{3/2} e^{-E_g/2KT} e\gamma T^{-3/2}$

$\sigma = Ce\gamma e^{-E_g/2KT}$

Let $B = Ce\gamma$

$\sigma = \mathbf{B}\mathbf{e}^{-\mathbf{E_g}/2\mathbf{KT}}$

Why does the Resistivity of Semiconductors go down with Temperature?

The difference in resistivity between conductors and semiconductors is due to their difference in charge carrier density.

The resistivity of semiconductors decreases with temperature because the number of charge carriers increases rapidly with increase in temperature, making the fractional change i.e. the temperature coefficient negative.

Some Important Properties of Semiconductors are:

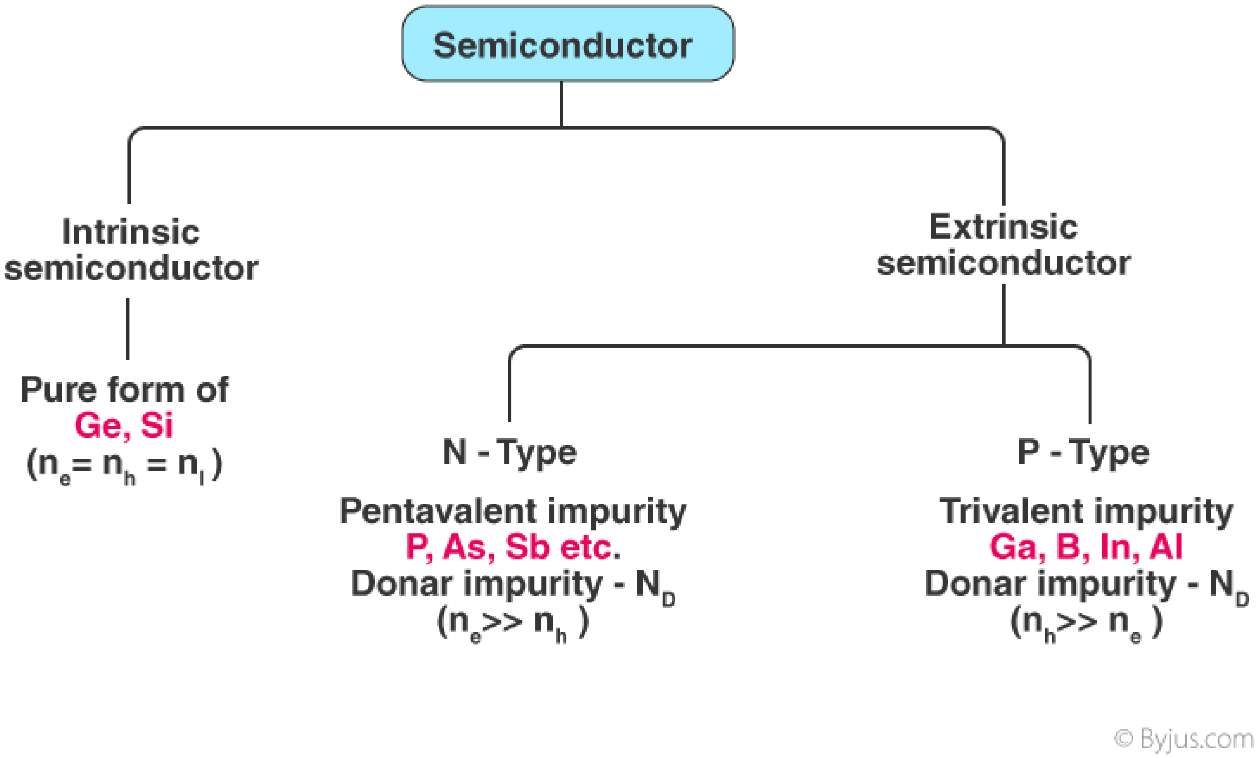
1. Semiconductor acts like an insulator at Zero Kelvin. On increasing the temperature, it works as a conductor.
2. Due to their exceptional electrical properties, semiconductors can be modified by doping to make semiconductor devices suitable for energy conversion, switches, and amplifiers.
3. Lesser power losses.
4. Semiconductors are smaller in size and possess less weight.

5. Their resistivity is higher than conductors but lesser than insulators.
6. The resistance of semiconductor materials decreases with the increase in temperature and vice-versa.

Types of Semiconductors

Semiconductors can be classified as:

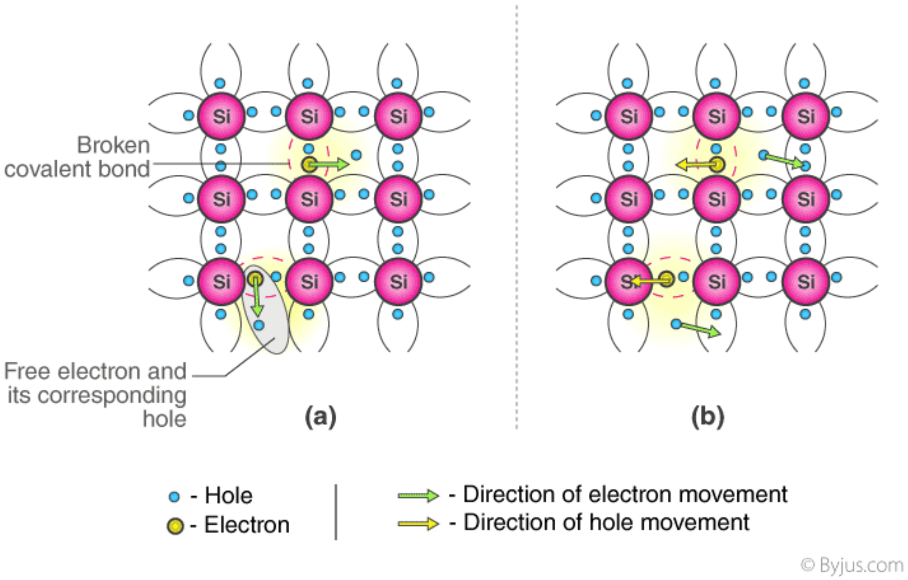
- **Intrinsic Semiconductor**
- **Extrinsic Semiconductor**



Classification of Semiconductors

Intrinsic Semiconductor

An **intrinsic type of semiconductor material** is made to be very pure chemically. It is made up of only a single type of element.



Conduction Mechanism in Case of Intrinsic Semiconductors (a) In absence of electric field (b) In presence of electric Field

Germanium (Ge) and Silicon (Si) are the most common type of intrinsic semiconductor elements. They have four valence electrons (tetravalent). They are bound to the atom by covalent bond at absolute zero temperature.

When the temperature rises, due to collisions, few electrons are unbounded and become free to move through the lattice, thus creating an absence in its original position (hole). These free electrons and holes contribute to the conduction of electricity in the semiconductor. The negative and positive charge carriers are equal in number.

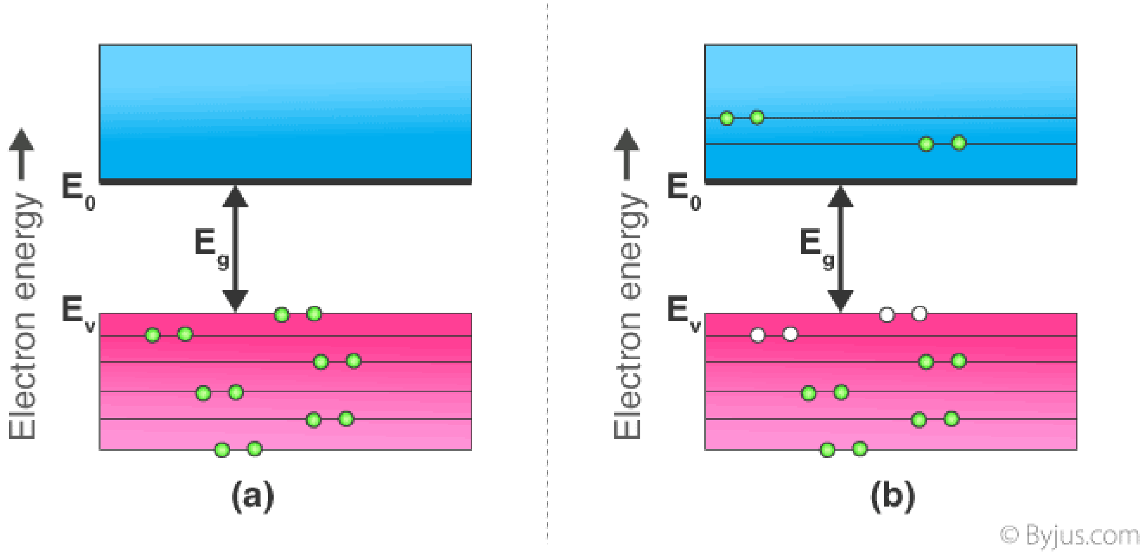
The thermal energy is capable of ionizing a few atoms in the lattice, and hence their conductivity is less.

The Lattice of Pure Silicon Semiconductor at Different Temperatures

- **At absolute zero Kelvin temperature:** At this temperature, the covalent bonds are very strong and there are no free electrons and the semiconductor behaves as a perfect insulator.
- **Above absolute temperature:** With the increase in temperature few valence electrons jump into the conduction band and hence it behaves like a poor conductor.

Energy Band Diagram of Intrinsic Semiconductor

The energy band diagram of an intrinsic semiconductor is shown below:



(a) Intrinsic Semiconductor at T = 0 Kelvin, behaves like an insulator (b) At t>0, four thermally generated electron pairs

In intrinsic semiconductors, current flows due to the motion of free electrons as well as holes. The total current is the sum of the electron current I_e due to thermally generated electrons and the hole current I_h

Total Current (I) = $I_e + I_h$

For an intrinsic semiconductor, at finite temperature, the probability of electrons to exist in conduction band decreases exponentially with increasing bandgap (E_g)

$n = n_0 e^{-Eg/2.Kb.T}$

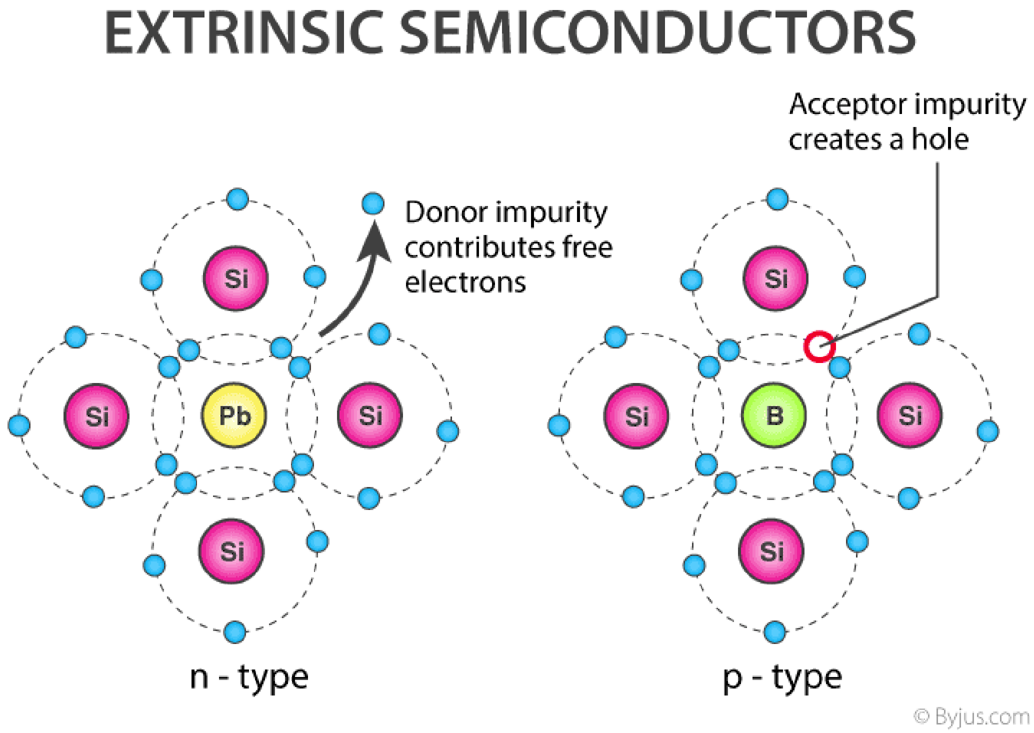
Where,

- Eg = Energy bandgap
- K_b = Boltzmann's constants

Extrinsic Semiconductor

The conductivity of semiconductors can be greatly improved by introducing a small number of suitable replacement atoms called IMPURITIES. The process of adding impurity atoms to the pure semiconductor is called DOPING. Usually, only 1 atom in 10^7 is replaced by a dopant atom in the doped semiconductor. An extrinsic semiconductor can be further classified into:

- **N-type Semiconductor**
- **P-type Semiconductor**



Classification of Extrinsic Semiconductor

N-Type Semiconductor

- Mainly due to electrons
- Entirely neutral
- $I = I_h$ and $n_h >> n_e$
- Majority – Electrons and Minority – Holes

When a pure semiconductor (Silicon or Germanium) is doped by pentavalent impurity (P, As, Sb, Bi) then, four electrons out of five valence electrons bonds with the four electrons of Ge or Si.

The fifth electron of the dopant is set free. Thus, the impurity atom donates a free electron for conduction in the lattice and is called "**Donar**".

Since the number of free electron increases by the addition of an impurity, the negative charge carriers increase. Hence, it is called n-type semiconductor.

Crystal as a whole is neutral, but the donor atom becomes an immobile positive ion. As conduction is due to a large number of free electrons, the electrons in the n-type semiconductor are the MAJORITY CARRIERS and holes are the MINORITY CARRIERS.

P-Type Semiconductor

- Mainly due to holes
- Entirely neutral
- $I = I_h$ and $n_h >> n_e$
- Majority – Holes and Minority – Electrons

When a pure semiconductor is doped with a trivalent impurity (B, Al, In, Ga) then, the three valence electrons of the impurity bonds with three of the four valence electrons of the semiconductor.

This leaves an absence of electron (hole) in the impurity. These impurity atoms which are ready to accept bonded electrons are called "**Acceptors**".

With the increase in the number of impurities, holes (the positive charge carriers) are increased. Hence, it is called p-type semiconductor.

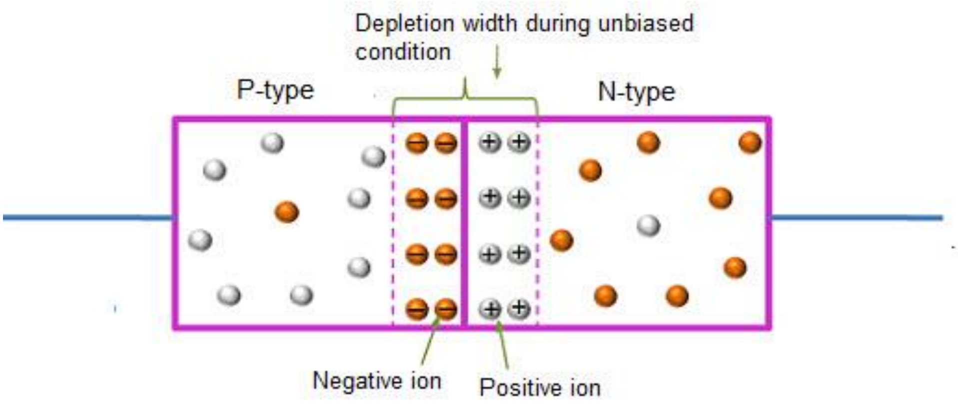
Crystal as a whole is neutral, but the acceptors become an immobile negative ion. As conduction is due to a large number of holes, the holes in the p-type semiconductor are MAJORITY CARRIERS and electrons are MINORITY CARRIERS.

Difference Between Intrinsic and Extrinsic Semiconductors

Intrinsic Semiconductor	**Extrinsic Semiconductor**
Pure semiconductor	Impure semiconductor
Density of electrons is equal to the density of holes	Density of electrons is not equal to the density of holes
Electrical conductivity is low	Electrical conductivity is high
Dependence on temperature only	Dependence on temperature as well as on the amount of impurity
No impurities	Trivalent impurity, pentavalent impurity

P-N Junction diode:

- A P-N junction diode is a piece of silicon that has two terminals.
- One of the terminals is doped with P-type material and the other with N-type material.
- The P-N junction is the basic element for semiconductor diodes.
- Diode facilitates the flow of electrons completely in one direction only – which is the main function of a diode.
- It can also be used as a Rectifier.
- It is operated in Forward as well as Reverse Biasing according to the needs or requirements.



Applications of Semiconductors

Let us now understand the uses of semiconductors in daily life. Semiconductors are used in almost all electronic devices. Without them, our life would be much different.

Their reliability, compactness, low cost and controlled conduction of electricity make them ideal to be used for various purposes in a wide range of components and devices. transistors, diodes, photosensors, microcontrollers, integrated chips and much more are made up of semiconductors.

Uses of Semiconductors in Everyday life

- Temperature sensors are made with semiconductor devices.
- They are used in 3D printing machines
- Used in microchips and self-driving cars
- Used in calculators, solar plates, computers and other electronic devices.
- Transistor and MOSFET used as a switch in Electrical Circuits are manufactured using the semiconductors.

Industrial Uses of Semiconductors

The physical and chemical properties of semiconductors make them capable of designing technological wonders like microchips, transistors, LEDs, solar cells, etc.

The microprocessor used for controlling the operation of space vehicles, trains, robots, etc is made up of transistors and other controlling devices which are manufactured by semiconductor materials.

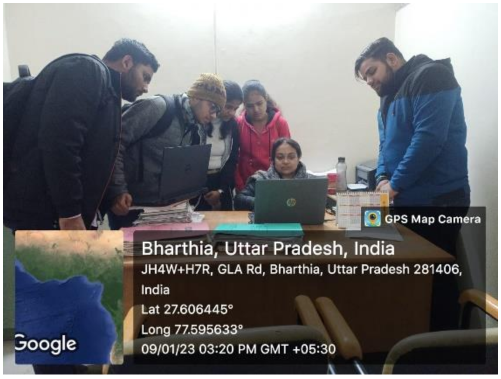
Importance of Semiconductors

- Here we have discussed some advantages of semiconductors which makes them highly useful everywhere.
- They are highly portable due to the smaller size
- They require less input power
- Semiconductor devices are shockproof
- They have a longer lifespan
- They are noise-free while operating

Chapter - 3
Geotagged Images of Students at the place of work

Geotagged Image 1

Geotagged Image 2



Geotagged Image 3

Geotagged Image 4

Chapter - 4
Findings and Conclusion

Some Important Properties of Semiconductors are:

1. Semiconductor acts like an insulator at Zero Kelvin. On increasing the temperature, it works as a conductor.
2. Due to their exceptional electrical properties, semiconductors can be modified by doping to make semiconductor devices suitable for energy conversion, switches, and amplifiers.
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5. Their resistivity is higher than conductors but lesser than insulators.
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Types of Semiconductors

Semiconductors can be classified as:

- **Intrinsic Semiconductor:** An **intrinsic type of semiconductor material** is made to be very pure chemically. It is made up of only a single type of element.

Extrinsic Semiconductor: Extrinsic semiconductors are semiconductors formed when a small measured amount of chemical impurity is added to **intrinsic semiconductors**. They are also called doped semiconductors or impurity semiconductors. An extrinsic semiconductor can be further classified into:

- **N-type Semiconductor:** When a pure semiconductor (Silicon or Germanium) is doped by pentavalent impurity (P, As, Sb, Bi) then, four electrons out of five valence electrons bonds with the four electrons of Ge or Si
- **P-type Semiconductor:** When a pure semiconductor is doped with a trivalent impurity (B, Al, In, Ga) then, the three valence electrons of the impurity bonds with three of the four valence electrons of the semiconductor.

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