Study Material

Program Code: All Program

Semester: First

Course Name: Basic Science (Physics)

Course Code: 22102

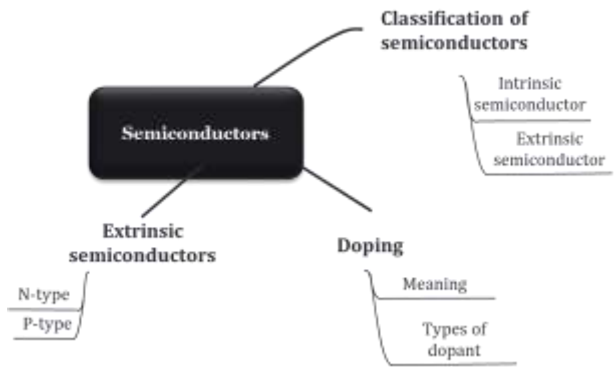
Topic Name: Electricity, Magnetism & Semiconductors

UO2e: Distinguish the given conductors, semiconductors and insulators on the basis of energy bands.

LO9: Student will be able to discuss conduction in semiconductors – charge carriers, intrinsic/extrinsic, p-type, and n-type.

Course Expert: S. K. Rawat	**Date: 01/09/2020**

Concept Map:



Key words: conductors, insulators, semiconductors, energy band diagram, valence band, conduction band, forbidden gap,

Key Questions:

1. What is an intrinsic semiconductor?
2. How extrinsic semiconductors are formed?
3. Difference between intrinsic and extrinsic semiconductor.
4. Formation of N-type semiconductor.
5. Formation of P-type semiconductor.
6. Difference between N-type and P-type semiconductor.

Key Definition:

1. A semiconductor in an extremely pure form is known as intrinsic semiconductor.
2. A semiconductor formed by adding impurities to a pure semiconductor for increasing conductivity is called as extrinsic semiconductor.
3. The process of adding impurities to pure semiconductors are called doping.
4. When a small amount of pentavalent impurity is added to a pure semiconductor, it is known as n-type semiconductor.
5. When a small amount of trivalent impurity is added to a pure semiconductor, it is called p-type semiconductor.

Notes

Classification of semiconductors

There are two types of semiconductors such as –

(i) Intrinsic Semiconductor and
(ii) Extrinsic Semiconductor

Intrinsic Semiconductors

A semiconductor in an extremely pure form is known as intrinsic semiconductor. Silicon and Germanium in extremely pure form is known as intrinsic semiconductor.

When electric field is applied across an intrinsic semiconductor, the electron-hole pairs are generated. The conduction of current takes place by two processes, namely, by free electrons and holes as shown in following Fig 1.

The free electrons are produced due to breaking of some covalent bonds. At the same time, holes are generated in the covalent bonds. Due to application of electric field, conduction through the semiconductor is by both free electrons and holes. The energy required to break such a covalent bond is equal to the band gap energy E_g. If the temperature of an intrinsic semiconductor is increased, beyond room temperature, a large number of electron-hole pairs are generated. Thus for an intrinsic semiconductor, concentration of free electron 'n_e' is equal to the concentration of holes 'n_p', i.e., $n_e = n_p$.

Fig. 2 shows the energy band diagram for an intrinsic semiconductor at room temperature.

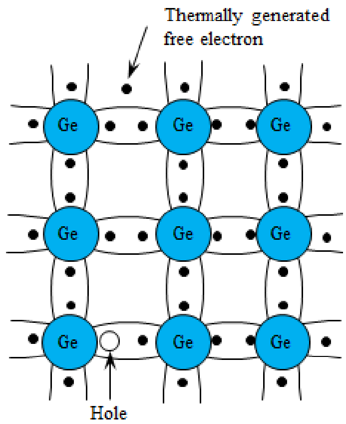


Figure 1: Intrinsic semiconductor with broken bond

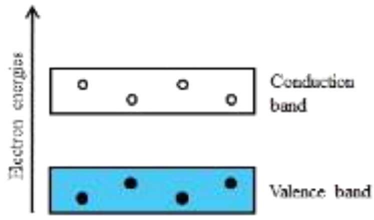


Figure 2: Energy band diagram for intrinsic semiconductor

Extrinsic Semiconductors

At room temperature, the conductivity of intrinsic semiconductor is too small to be useful for any practical applications. Conductivity of intrinsic semiconductor can be increased by adding suitable impurities to it. The purpose of adding impurity is to increase current carrying capacity of pure semiconductor, by increasing either the number of free electrons or holes in the semiconductor. Thus the process of adding impurities to pure semiconductors are called doping and the impurity atom are called dopants.

Comparison between intrinsic semiconductor and extrinsic semiconductor

Intrinsic semiconductor	Extrinsic semiconductor
1. It is pure semi-conducting material and no impurity atoms are added to it.	1. It is prepared by doping a small quantity of impurity atoms to the pure semi-conducting material.
2. Examples: crystalline forms of pure Si and Ge.	2. Examples: Si and Ge crystals with impurity atoms of As, Sb, P etc. or B, Aℓ etc.
3. The number of free electrons in the conduction band and the number of holes in valence band is exactly equal.	3. The number of free electrons and holes is not equal. There is excess of electrons in n-type semiconductors and excess of holes in p-type semiconductors.
4. Its electrical conductivity is low.	4. Its electrical conductivity is high.
5. Its electrical conductivity depends on temperature alone.	5. Its electrical conductivity depends upon the temperature as well as on the quantity of doped impurity atoms.

Doping

The process of adding impurities to pure semiconductors is called doping.

"When any trivalent or pentavalent impurity is added to pure semiconductor, then it is called as extrinsic semiconductor". Or Doped semiconductors are called extrinsic semiconductors.

Depending upon the type of impurity added, extrinsic semiconductors are classified as:

(i) n-type semiconductor and
(ii) p-type semiconductor

n-type semiconductor

"When a small amount of pentavalent impurity is added to a pure semiconductor, it is known as n-type semiconductor".

Formation of n-type semiconductor

When Si or Ge crystal is doped with pentavalent impurity such as As, Sb, P, we get n-type semiconductor. Pentavalent atom has 5 electrons in its valence orbit. Fig. 3 shows the structure of n-type semiconductor.

As germanium (Ge) atom has 4 valence electrons (atomic no. 32) and when a small amount of pentavalent impurity like arsenic (As) is added to germanium (Ge) semiconductor, a large number of free electrons become available in the semiconductor. The reason is simple, arsenic is pentavalent impurity (5 valence electrons) and its 4 valence electrons form covalent bonds with 4 germanium atoms. The fifth valence electron of arsenic remains free.

Therefore, for each arsenic atom added, one free electron will be available in the Ge semiconductor. Since every pentavalent dopant atom donated one electron for conduction; it is called donor impurity.

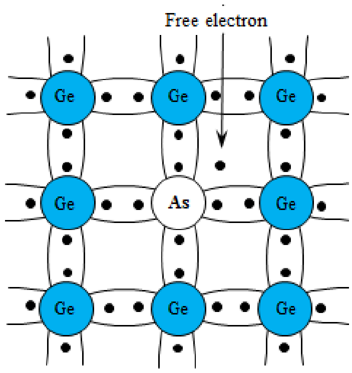


Figure 3: Structure of n-type semiconductor

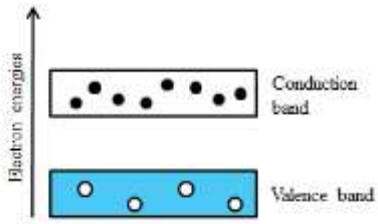


Figure 4: Energy band diagram of n-type semiconductor

p-type semiconductor

"When a small amount of trivalent impurity is added to a pure semiconductor, it is called p-type semiconductor".

Formation of P-type semiconductor

When Si or Ge crystal is doped with trivalent impurities such as gallium (Ga), indium (In), boron (B) and aluminum (Al) we get p-type semiconductor. Trivalent atom has 3 electrons in its valence orbit. Fig. 5 shows the structure of p-type semiconductor. Every trivalent impurity atom shares its 3 electrons with 3 neighbouring silicon (Si) atoms to form covalent bond. But, the bond between the fourth neighbour and the trivalent atom has a vacancy or hole as shown in Fig. 2.8. As the trivalent impurity has a tendency to accept any electron in its close vicinity, they are called acceptor impurity. As this semiconductor has large number of holes and conductivity is because of positively charged holes, it is called p-type semiconductor.

Fig. 6 displays energy band diagram for p-type semiconductor at room temperature.

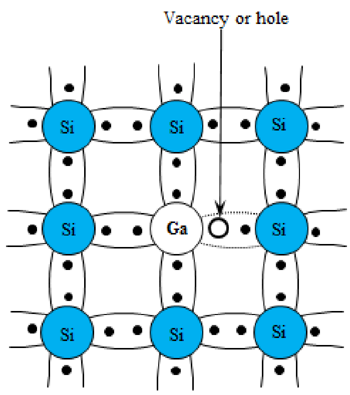


Figure 5: Structure of p-type semiconductor

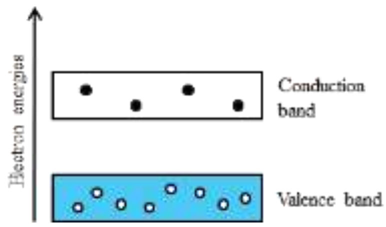


Figure 6: Energy band diagram of p-type semiconductor

Comparison between n-type semiconductor and p-type semiconductor

n-type semiconductor	p-type semiconductor
1. An extrinsic semiconductor which is obtained by doping the impurity atoms of Vth group of the periodic table to the pure Ge and Si semi-conductor.	1. An extrinsic semiconductor which is obtained by doping the impurity atoms of IIIrd group of the periodic table to the pure Ge and Si semi-conductor.
2. The impurity atoms added, provide extra electrons in the structure and are called donor atoms.	2. The impurity atoms added, create vaccines of electrons (i.e. holes) in the structure and are called acceptor atoms.
3. The electrons are majority carriers and holes are minority carriers.	3. The holes are majority carriers and electrons are minority carriers.
4. The concentration of electrons is much greater than holes.	4. The concentration of holes is much greater than electrons.
5. The donor energy level is close to the conduction band and for away from the valence band.	5. The acceptor energy level is close to the Valence band and for away from the Conduction band.

Link to YouTube/ OER/ video/e-book:

1. http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html
2. https://www.electronics-tutorials.ws/diode/diode_1.html
3. https://www.electronics-notes.com/articles/basic_concepts/conductors-semiconductors-insulators/what-is-a-semiconductor.php

Key Take away:

1. Intrinsic and extrinsic semiconductor.
2. N-type and P-type semiconductor.

Formative Assessments

<22102> : <All Program> : < All Program >: <Electricity, Magnetism & Semiconductors>: <UO2e> : <LO9> : <Assessments> : <Formative>

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Assessment Type: Formative Assessments: Embedded questions in video/ PPT

Set 1		
Question No 1	Question No 2	Question No 3
A doped semiconductor is also known as _________________	At absolute temperature, an intrinsic semiconductor has _______________________	Intrinsic semiconductor at room temperature will have _________________ available for conduction.
Remembering	Understanding	Applications
a) Intrinsic semiconductor	a) a few free electrons	a) electrons
b) Extrinsic semiconductor	b) many holes	b) holes
c) Diffused semiconductor	c) many free electrons	c) both electrons and holes
d) None of the above	d) no holes or free electrons	d) None of the above
Ans: < Extrinsic semiconductor >	Ans: < no holes or free electrons >	Ans: <both electrons and holes >

Set 2		
Question No 1	Question No 2	Question No 3
Si atom with its four valence electrons shares an electron with each of its ______ neighbouring atom.	Acceptor-type impurities __________________________	What type of material is obtained when intrinsic semiconductor is doped with pentavalent impurity?
Remembering	Understanding	Understanding
a) 2	a) can be added to silicon but not to germanium	a) N-type semiconductor
b) 4	b) create excess electrons	b) Extrinsic semiconductor
c) 6	c) must have three valence electrons	c) P-type semiconductor
d) 8	d) must have five valence electrons	d) Insulator
Ans: <4 >	Ans: < must have three valence electrons >	Ans: < N-type semiconductor >

Practice Worksheets

<22102> : <All Program> : < All Program >: <Electricity, Magnetism & Semiconductors>: <UO2e> : <LO9> : <Assessments> : <Summative>

<S. K. Rawat>

A. The term bias in electronics usually means - a) The value of ac voltage in the signal. b) The condition of current through a pn junction. c) The value of dc voltages for the device to operate properly. d) The status of the diode.	B. What can a semiconductor sense? a) Pressure b) Temperature c) Magnetism d) All of the above
Ans A:	Ans B:
C. The process of adding impurities to pure semiconductors are called ____________ a) dopants b) agents c) ageing d) doping	D. When a small amount of pentavalent impurity (such as As or Sb or P) is added to a pure semiconductor (Si or Ge), it is called as ___________ semiconductor. a) n-type b) p-type c) pn-type d) np-type
Ans C:	Ans D:
E. When a small amount of trivalent impurity (such as Ga or B or Al) is added to a pure semiconductor (Si or Ge), it is called as _____________ semiconductor. a) n-type b) p-type c) pn-type d) np-type	F. Arsenic is _______________ atom. a) trivalent b) quadravalent c) pentavalent d) None of the above
Ans E:	Ans F:
G. Gallium is _______________ atom. a) trivalent b) quadravalent c) pentavalent d) None of the above	H. When a pure semiconductor is heated, its resistance ___________ a) increases b) decreases c) remains same d) first increases and then decreases
Ans G:	Ans H:
I. Which of the following cannot exist outside a semiconductor? a) Electrons b) Holes c) Both electrons and holes d) None of the above	J. In __________ semiconductors, conductivity is due to positively charged electrons. a) n-type b) p-type c) pn-type d) np-type
Ans I:	Ans J: