Study Material

Program Code: All Program

Semester: First

Course Name: Basic Science (Physics)

Course Code: 22102

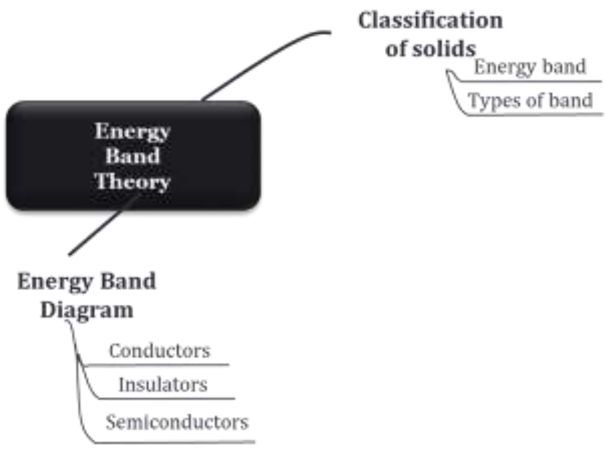
Topic Name: Electricity, Magnetism & Semiconductors

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

LO8: Student will be able to distinguish between conductors, semiconductors and insulators on the basis of energy bands.

Course Expert: S. K. Rawat	**Date: 30/08/2020**

Concept Map:



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

Key Questions:

1. Explain the formation of energy bands in solid.
2. Classify the solids according to their band structure.
3. Draw energy band diagram for conductors, insulators and semiconductors.

Key Definition:

1. The different closely spaced energy levels of all electrons in a particular orbit with continuous energy variation are called energy bands.
2. The energy band which occupies valence electrons is called valence band.
3. The energy band which occupies free electrons is called conduction band.
4. The separation between conduction band and valence band in energy band diagram is called forbidden energy gap or band gap.

Notes

Introduction

Before the discovery of diodes and transistor, devices which were used were mostly vacuum tubes (also called valves) like the vacuum diode, triode, tetrode and pentode. Discovery of semiconductors and invention of transistor and IC's has greatest impact on field of Electronics, Telecommunication, Computer Technology and Instrumentation. We know that materials are classified as conductors, insulators and semiconductors on the basis of conductivity. The conductivity of semiconductors lies between conductors and insulators. The semiconductors such as silicon (Si) and germanium (Ge) has low conductivity and adding some suitable impurities modifies their conductivities. Thus solid state semiconductors and their junctions offer the possibility of controlling the number and the direction of flow of charge carriers through them.

In the following chapter, we introduce the basic concepts of semiconductor physics and discuss semiconductor devices like p-n junction diode and photo diode.

Classification of solids on the basis of band theory

According to the Bohr atomic model, in an isolated atom the energy of any of its electrons is decided by the orbit in which it revolves. But when the atoms come together to form a solid, they are close to each other. So the outer orbits of electrons from neighbouring atoms would come very close or could even overlap. Inside the crystal each electron has a unique position and no two electrons see exactly the same pattern of surrounding charges. Because of this, each electron will have a different energy level. Thus for a given solid, closely spaced energy levels of all electrons in a particular orbit is called energy band. As seen in Fig.1, the energy band for typical solid illustrates the different energy band. Shaded band indicates filled band, whereas the unshaded band indicates some orbits are empty or some energy levels are vacant.

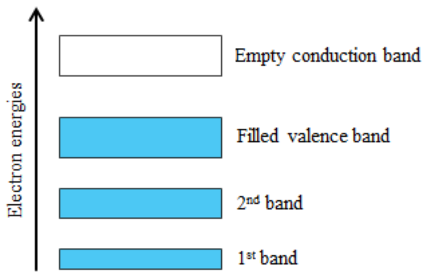


Figure 1: Energy band diagram for a typical solid

Energy band

The different closely spaced energy levels of all electrons in a particular orbit with continuous energy variation are called energy bands.

Valence band

The energy band which occupies valence electrons is called valence band. or The energy band which includes the energy levels of the valence electrons is called the valence band.

The valence band may be partially or completely filled up depending on the nature of the crystal.

Conduction band

The energy band which occupies free electrons is called conduction band. Or The energy band above the valence band is called the conduction band.

Conduction band may be empty or partially filled. In conduction band the electrons can freely move.

Forbidden energy gap

The separation between conduction band and valence band in energy band diagram is called forbidden energy gap or band gap. or The gap between the top of the valence band and bottom of the conduction band is called the energy band gap (Energy gap E_g).

Forbidden gap or energy gap may be large, small, or zero, depending upon the material.

When the electrons from the valence band gains external energy it cross the forbidden gap and enters the conduction band. Then these electrons will move into the conduction band, thereby creating holes or vacant energy levels in the valence band where other valence electrons can move as shown in Fig.2. Thus the process creates the possibility of conduction due to electrons in conduction band as well as due to holes in the valence band.

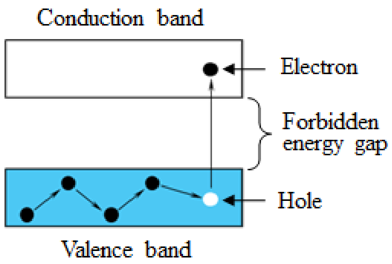


Figure 2: Conduction through Energy band diagram

Energy band diagram

Conductors

In conductors, either when the conduction band is partially filled and the valance band is partially empty or when the conduction and valance bands overlap; the electrons from valence band can easily move into the conduction band.

Thus there is no energy band gap ($E_g = 0$) as shown in Fig. 3 (a) and a large number of electrons are available for electrical conduction. The electrons from valence band freely enter in the conduction band due to absence of forbidden band. Therefore, the resistance of such materials is low and the conductivity is high.

Insulators

In case of insulators, a large energy band gap exists ($E_g > 3$ eV) and conduction band is empty as shown in Fig.3 (b). The energy gap is so large that at room temperature, due to thermal excitation the electrons cannot be excited from valence band to conduction band and hence no electrons are available for conduction. Therefore the resistance of such materials is high and the conductivity is low.

Semiconductors

In semiconductors, a finite but small band gap ($E_g < 3$ eV) exists. Because of the small band gap, at room temperature some electrons from valence band can acquire enough energy to jump through the energy gap and enter the conduction band. These electrons (though small in numbers) can move in the conduction band. Hence, the resistance of semiconductors is not as high as that of the insulators.

Germanium (Ge) and Silicon (Si) are the examples of semiconductors. In Germanium the forbidden energy gap is of order of 0.72 eV while in Silicon, the forbidden energy gap is of the order of 1.1 eV.

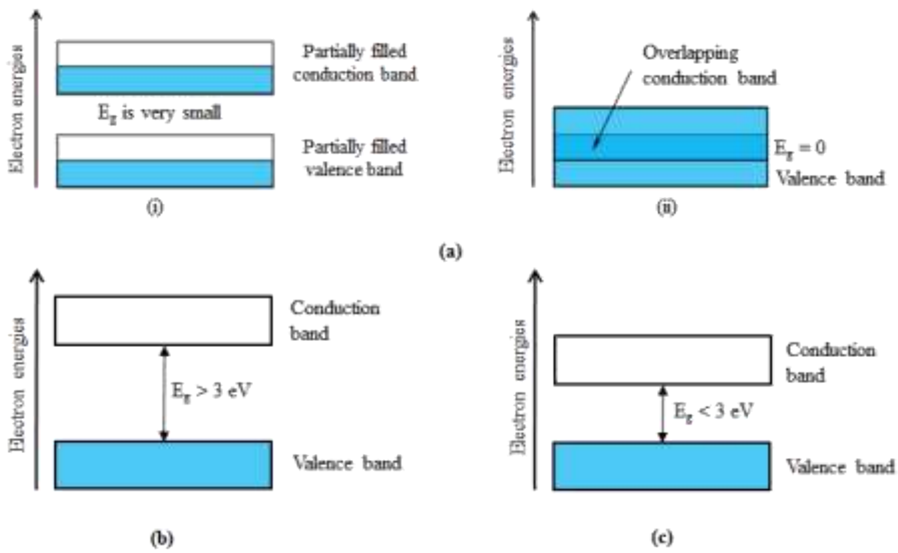


Figure 3: Energy band diagram of (a) conductors, (b) insulators and (c) semiconductors

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. Band theory.
2. Energy band diagram from conductors, semiconductors and insulators.

Formative Assessments

<22102> : <All Program> : < All Program >: <Electricity, Magnetism & Semiconductors>: <UO2e> : <LO8> : <Assessments> : <Formative>

<S. K. Rawat>

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

Set 1		
Question No 1	Question No 2	Question No 3
Electron is a Greek word for ____________	Which material has more free electrons?	An insulating element or material has capability of _________________
Remembering	Understanding	Applications
a) amber	a) Conductors	a) conducting large current
b) fire	b) Insulators	b) storing voltage
c) stone	c) Mica	c) storing high current
d) heat	d) Dielectric	d) preventing short circuit between two conducting wires
Ans: < amber >	Ans: < Conductors >	Ans: < preventing short circuit between two conducting wires >

Set 2		
Question No 1	Question No 2	Question No 3
In materials, which is the region that separates the valence and conduction bands?	In semiconductors, energy band gap is of the order of	Ge and Si are the examples of _________________
Remembering	Understanding	Remembering
a) barrier potential	a) 0 eV	a) conductors
b) forbidden level	b) > 1.1 eV	b) semiconductors
c) insulation band	c) > 5.5 eV	c) insulators
d) energy gap or forbidden gap	d) 6 eV	d) metalloids
Ans: < energy gap or forbidden gap >	Ans: <> 1.1 eV >	Ans: < semiconductors >

Practice Worksheets

<22102> : <All Program> : < All Program >: <Electricity, Magnetism & Semiconductors>: <UO2e> : <LO8> : <Assessments> : <Summative>

<S. K. Rawat>

A. Ion is ____________ a) an atom with unbalanced charges b) free electron c) proton d) nucleus without protons	B. _____________ has a unit of electron volt (eV). a) Charge b) Potential difference c) Energy d) Current
Ans A:	Ans B:
C. The energy band which occupies valence electrons is called ________________ a) Energy band b) Valence band c) Conduction band d) None of the above	D. The energy band which occupies free electrons is called _________________ a) Energy band b) Valence band c) Conduction band d) None of the above
Ans C:	Ans D:
E. The separation between conduction band and valence band in energy band diagram is called _______________________ a) Forbidden energy band b) Valence band c) Conduction band d) None of the above	F. There is no energy band gap in ___________________ a) conductors b) semiconductors c) insulators
Ans E:	Ans F:
G. The conduction band _________ a) is always above the forbidden energy level b) is the region of free electrons c) concentrates holes for the flow of current d) is a range of energies corresponding to the energies of the free electrons	H. The forbidden energy gap for Ge ≈ a) 0.5 eV b) 1.1 eV c) 0.72 eV d) 1.5 eV
Ans G:	Ans H:
I. The forbidden energy gap for Si ≈ a) 0.5 eV b) 1.1 eV c) 0.72 eV d) 1.5 eV	J. In materials, which is the region that separates the valence and conduction bands? a) barrier potential b) forbidden level c) insulation band d) energy gap or forbidden gap
Ans I:	Ans J: