12

FUNDAMENTALS OF ELECTRONICS

OBJECTIVES

At the end of this topic, students should be able to:

- explain semiconductor and give examples of semiconductors;
- explain intrinsic and extrinsic semiconductors and distinguish between conductor, semiconductor and insulator;
- explain n-type and p-type semiconductors and describe how to produce them;
- describe a p-n junction diode and state what happens to current when the diode is forward biased or reversed biased;
- explain how a diode is used as a rectifier ;
- describe a transistor and state its use as amplifier and a switch.

Semiconductors

Semiconductors are materials whose ability to conduct electric current is between those of conductors and insulators. Semiconductor materials include silicon (sand), germanium, arsenide, carbon, gallium, selenium and some compounds like lead sulphide. Semiconductors have the following properties:

- they are insulators at low temperatures;
- their resistance decreases with increase in temperature;
- their electrical conductivity can be improved by adding other substances (impurity). This is called **doping.**

Differences between conductors, insulators and semiconductors

The main difference between these three is the number of free electrons present in each of these materials. Electrons in an atom exist in different allowed energy levels when the condition is normal. A material can be a conductor, semiconductor or insulator depending on what happens to the electrons when the energy state of the atom changes. In a solid, electrons occupy different energy levels called **energy bands.** The energy bands are divided into **conduction band** and **valence band.** The conduction band contains free electrons while the valence contains electrons which are still bound to their atoms. Conduction band and valence band are separated by **forbidden energy gap.** Electrons are not allowed to stay in the forbidden energy gap. The energy bands are filled with electrons from the valence band to conduction band.

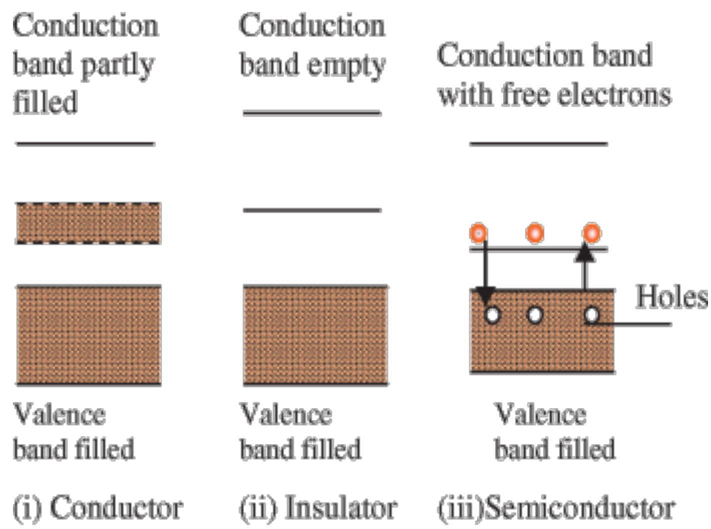


Figure 12.1

Conductors

The valence band is completely filled with electrons and conduction band is partially filled with electrons. In some conductors, the two bands overlap. If energy is given to the conductor, the free electrons in the conduction band becomes free to conduct electricity.

Insulators

The valence band is completely filled with electrons while the conduction band is empty. The forbidden energy gap is very wide that electrons cannot cross over to the conduction under normal condition. This is why insulators are bad conductors.

Semiconductors

Pure semiconductors are called **intrinsic semiconductors** while semiconductors produced by doping are called **extrinsic semiconductors.**

Intrinsic semiconductor

The valence band is completely filled and the conduction band is empty at low temperatures. The forbidden energy gap is very narrow that electrons can easily crossover to the conduction band as temperature rises. This is why their resistance decreases as the temperature increases.

When an electron jumps from the valence band to the conduction band, it leaves a space in the valence band called a **hole. Intrinsic semiconductors conduct electricity by the movement of electrons in the conduction band or movement of positive holes in the valence band. Extrinsic semiconductor**

Semiconductors whose electrical conductivities are improved by addition of impurity are called extrinsic semiconductors. Two types of extrinsic semiconductor are the **p-type and n-type** semiconductors.

- p-type semiconductor:

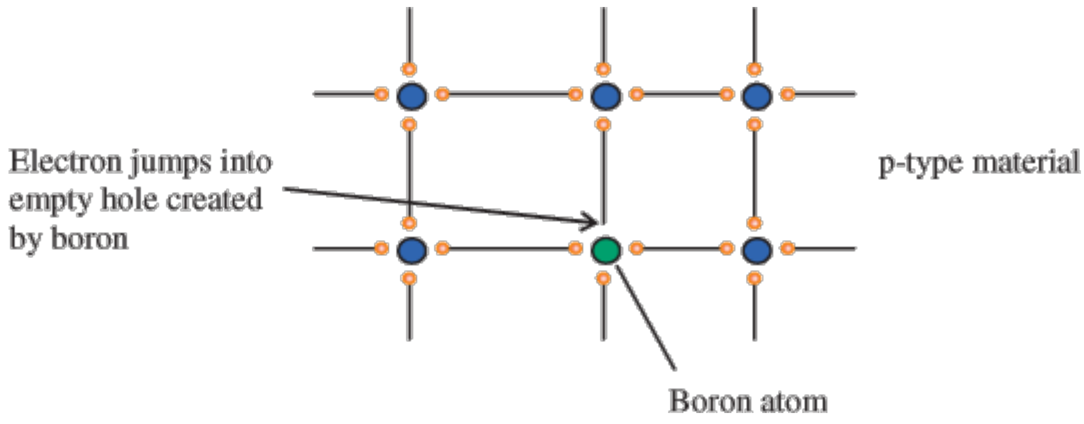


Figure 12.2a

In p-type semiconductor, Boron (a trivalent atom) is added to silicon. The doping of silicon with Boron produces more holes than electrons in the material. ***Conduction is by movement of holes.*** The holes are the majority carrier while the electrons are the minority carrier in p-type semiconductor. Electrons jump from one hole to another in one direction while the holes move in the opposite direction.

- n-type semiconductor: in n-type semiconductor, silicon is doped with phosphorus (a pentavalent atom) to produce **excess electrons** in the material. ***Conduction occurs by the free movement of the electrons***. The electrons are the majority carriers in n-type semiconductor while the holes are the minority carriers.

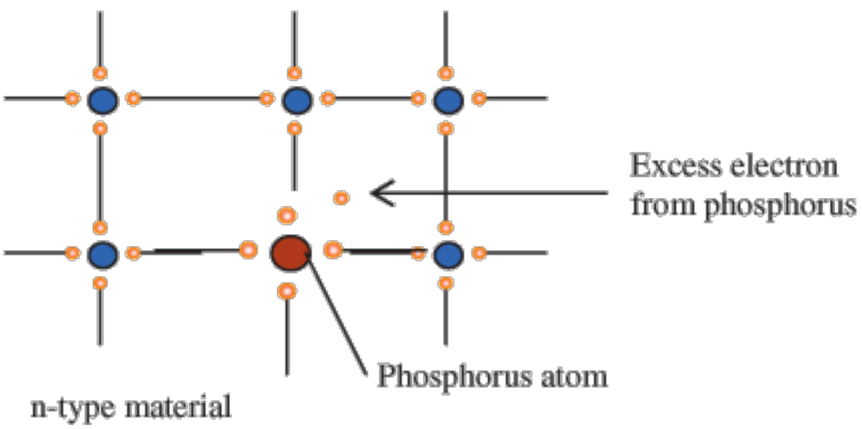


Figure 12.2b

The p-n junction diode

A p-n junction is formed when a piece of silicon or germanium is doped such that one end is p-type and the opposite end is n-type. The n-type end of the semiconductor diode is rich in electrons while the p-type end is rich in positive holes.

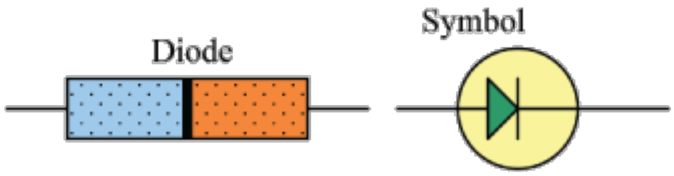


Figure 12.3 p-n junction diode and symbol

Under normal conditions, electrons from the electron rich n-type end of the semiconductor diode moves across the junction to the p-type end. At the same time, positive holes from the hole rich p-type end moves across the junction to the n-type end. The exchange of electrons and positive holes across the p-n junction stops when the positive holes accumulating at the n-type end of the diode repels other incoming holes and electrons accumulating at the p-type end of the diode repels other incoming electrons.

The region of the semiconductor where this happens is called the **depletion layer.** A small p.d. called **barrier p.d.** is formed in the depletion layer to stop further exchange of electrons and holes. The value of the p.d. is about 0.6 V for silicon and 0.1 V for germanium.

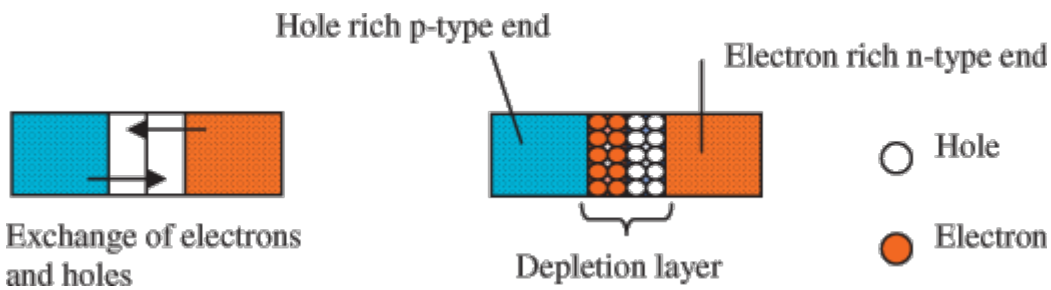


Figure 12.4 depletion layer in a semi conductor

Forward and reversed bias of semiconductor diodes

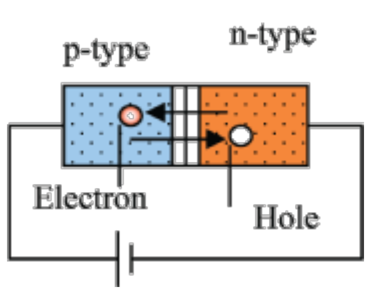


Figure 12.5a diode in forward biased mode

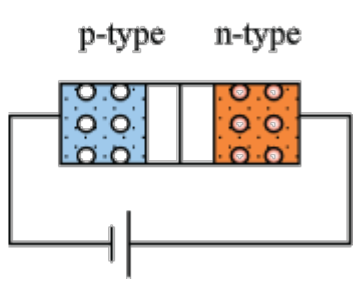


Figure 12.5b diode in reversed biased mode

When a p.d. greater than 0.6V is connected to a silicon semiconductor diode as shown in figure 41.5a, the positive holes are repelled by the positive terminal across the p-n junction to the n-type end. The electrons are repelled by the negative terminal across the p-n junction to the p-type end. The semiconductor diode is said to be **forward biased. In forward biased mode, the width of the depletion layer is reduced**; the resistance of the diode is lowered therefore the diode conducts.

If the poles of the cell are interchanged, the electrons are attracted by the positive terminal of the cell away from the junction and the positive holes are attracted by the negative terminal of the cell away from the p-n junction. The width of the depletion layer is increased; the resistance of the diode is very high that it does not conduct. The diode is said to be in **reversed biased** mode. *In the reversed bias mode, little current flows through the diode due minority carriers crossing the p-n junction.*

The p-n junction diode I-V characteristics curve

The graph of current against voltage for a silicon semiconductor diode is shown in figure 12.6.

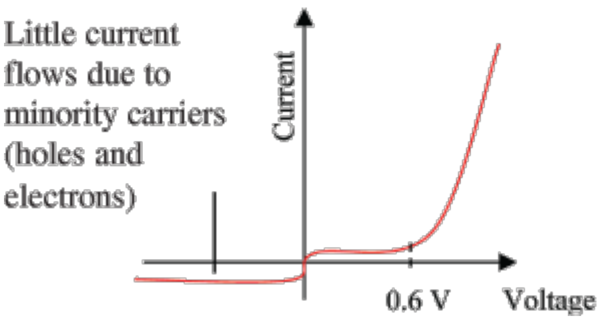


Figure 12.6 I-V Curve of semiconductor diode

Little or no current flows through the semiconductor diode when it is reversed biased. When the diode is forward biased, current flows through it when the p.d. is more than 0.6 V.

Uses of semiconductor diode

(i) Rectification:

The p-n junction diodes are used as rectifiers to change alternating current to direct current. The circuit and output signal for **half wave rectification** is shown in figure 12.7.

When a.c.input in the positive direction puts the diode in the forward bias; the diode conducts. When the a.c. flowing in the opposite (negative) direction makes the diode to be in the reversed bias; the diode does not conduct. The diode only conducts when current is flowing in one direction but does not conduct if the current flows in the opposite directions. The output of the signal is as shown in figure 12.7.

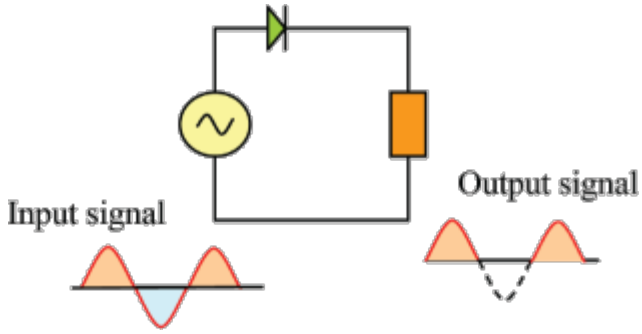


Figure 12.7 Half wave rectifications

Connecting a capacitor across the load will produced a smooth output signal as shown in figure 12.8.

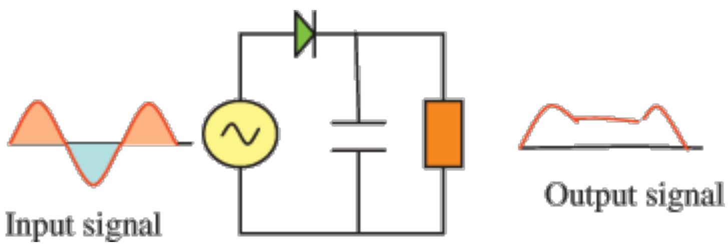
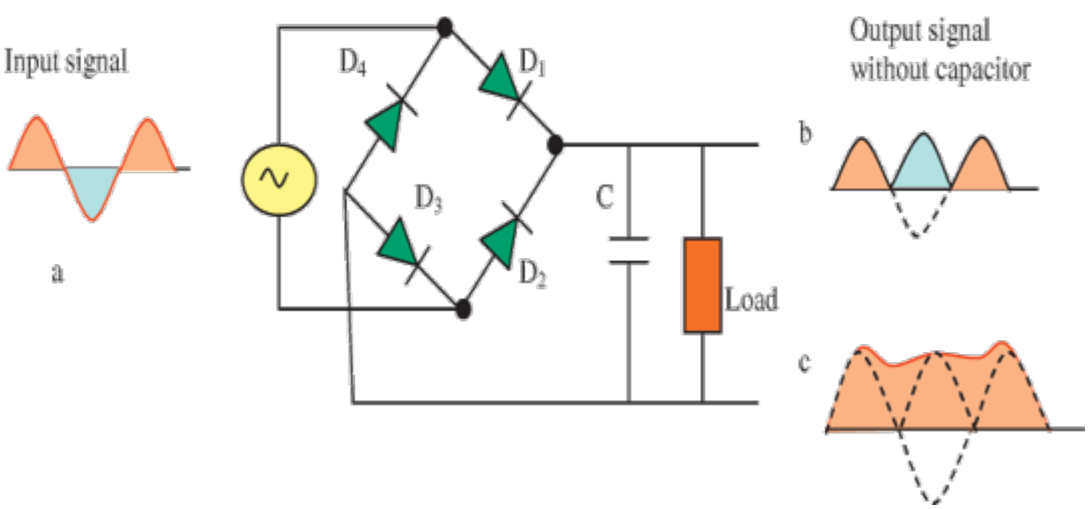


Figure 12.8 half wave rectifications

Full wave rectification



Four diodes connected together to form a bridge as shown in figure 12.9 is used to produced a **full wave rectification.** During the first half cycle, the diode D_1 conducts while the diode D_2 conducts in the next half cycle. The output signal for a **bridge rectifier** is shown in figure 12.9. A steady or d.c. current is produced, the capacitor connected across the load ensures that the output signal is steady.

Transistors

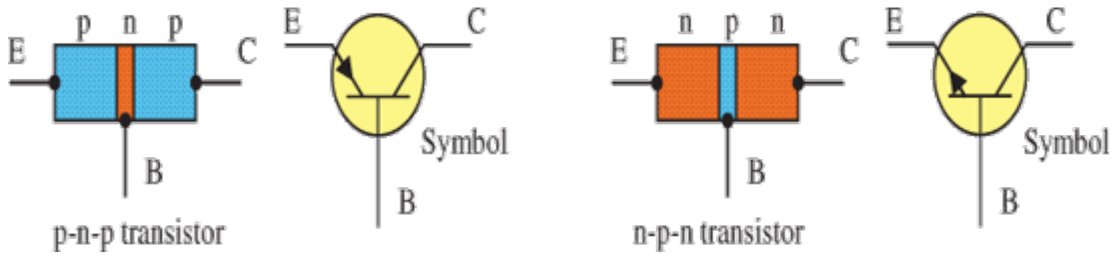


Figure 12.10 : Transistors and their symbols

A transistor is two p-n junction diodes joined back-to-back. It is more useful than semiconductor diode because it can be used as a:

- current amplifier;
- high speed switch.

A transistor has three layers: a p-type semiconductor squeezed in between two n-type semiconductors to form an n-p-n transistor. Another version has an n-type semiconductor squeezed in between two p-type semiconductors to form a p-n-p transistor. The ***current carriers in p-n-p transistor are the*** holes while ***the electrons are the current carriers in n-p-n transistors.*** Electrons move very fast, therefore n-p-n transistors are suitable for computers circuits where high frequency switching on and off is required.

The arrows in the symbols indicate the conventional current direction. Electrons flow in the opposite direction.

A transistor has three terminals each connected to one of the three layers; the base (B), the emitter (E) and collector (C).

Transistor connection

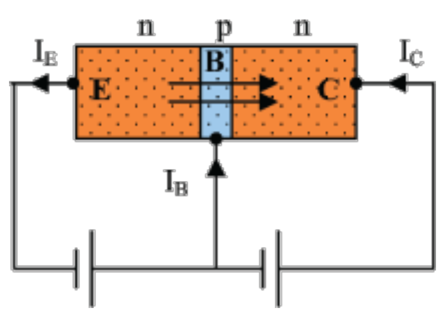


Figure 12.11:Common-base connection

Three ways in which a transistor can be connected to a circuit are common emitter connection, common–base connection and common–collector connection. The common base connection is shown in the figure 12.11 (base is common to the emitter and collector). The base-emitter junction is forward biased and the base-collector junction is reversed biased. The direction of current is as shown in figure 12.11. According to Kirchhorffâ€™s first law:

$$I_E = I_C + I_B$$

Assuming the base current I_B is the input current and the collector current I_C as the output current, then the transistor acts as:

(i)current amplifier if value of collector current I_C is greater than the base current I_B.

Current gain (amplification) = $\frac{I_C}{I_B}$

(ii)a high speed switch if the base current I_B switches on or controls the collector current.

Summary

- Semiconductors are materials whose ability to conduct electric current is between those of conductors and insulators. Pure semiconductors are called intrinsic semiconductors while I semiconductors produced by doping are called extrinsic semiconductors.
- Intrinsic semiconductors conduct electricity by the movement of electrons in the conduction band or movement of positive holes in the valence band.
- In p-type semiconductor, Boron (a trivalent atom) is added to silicon. The doping of silicon with Boron produces more holes than electrons in the material.
- In n-type semiconductor, silicon is doped with phosphorus (a pentavalent atom) to produce excess electrons in the material.
- When semiconductor diode conducts it is said to be **forward biased.** In forward biased mode, the width of the depletion layer is reduced; the resistance of the diode is low, therefore the diode conducts.
- A semiconductor is **reversed biased** if it does not conduct electric current. The width of the depletion layer is increased and the resistance of the diode is very high.
- A transistor is two p-n junction diodes joined back-to-back. it can be used as a:
- current amplifier;
- high speed switch.

The current carriers in p-n-p transistor are the holes while the electrons are the current carriers in n-p-n transistors.

Practice questions 12

1. The conduction band is partly filled in one of the following materials.
   A. Silicon.
   B. Germanium.
   C. Copper.
   D. Rubber.
2. When a piece of silicon is doped with Boron, the semiconductor formed is
   A. p- type
   B. n- type
   C. intrinsic
   D. p-n junction
3. Intrinsic semiconductor is
   A. a pure semiconductor material.

B. a doped semiconductor material.

C. a p-type material.

D. a p-n junction diode.

4. The carriers of electric current in an n-type semiconductor are

A. protons.

B. positive holes.

C. ions.

D. electrons.

5. Which of the following is true about a p-n junction diode?

A. On reversed biased, large current flows through it.

B. The depletion layer is reduced when it is forward biased.

C. It is used to convert d.c. to a.c.

D. It is an ohmic conductor.

6. (a). What is a semiconductor?

(b) Explain how the conductivity of a semiconductor changes with (i) temperature (ii) presence of impurities.

7. (a). What is meant by energy bands in solids?

(b) Use energy bands to differentiate between conductors and semiconductors.

(c) Explain why the resistance of a semiconductor decreases with rise in temperature.

8. (a). Explain the terms *forward bias and reversed bias* as applied to semiconductor diode.

(b) How can a semiconductor diode be used as rectifier to convert a.c. to d.c.

(c) What is the function of a capacitor connected across the load?

9. (a). What is a transistor?

(b) State two uses of a transistor and explain why n-p-n transistors are preferred to p-n-p transistor in computer circuits.

Past questions

1. A semiconductor diode is used in rectifying alternating current into direct current mainly because it

A. allows current to flow in either direction.

B. is non-linear.

C. offers a high input resistance.

D. allows current to flow only in direction.

JAMB

2. In semiconductors, the carriers of current at room temperature are

   A. electrons only.
   B. electrons and holes.
   C. holes only.
   D. electrons and ions.

JAMB

3. In a pure semiconductor, the number of electrons in the conduction band is

   A. equal to the number of holes in the valence band.
   B. greater than the number of holes in the valence band.
   C. less than the number of holes in the valence band.
   D. twice the number of holes in the valence band. JAMB

4. A transistor functions as a

   A. switch and an amplifier.
   B. rectifier and an amplifier.
   C. charge storer and an amplifier.
   D. charge storer and a switch.

JAMB

5. A transistor is used in the amplification of signals because it

   A. allows doping.
   B. contains electron and hole carriers.
   C. consumes a lot of power.
   D. controls the flow of current.

JAMB

6. Pure silicon can be converted to a p-type material by adding a controlled amount of

   A. pentavalent atoms.
   B. hexavalent atoms.
   C. tetravalent atoms.
   D. trivalent atoms.

JAMB

7. In a semiconductor junction diode, as the depletion or barrier layer is forward biased, the layer

   A. remains constant.
   B. widens then narrows.
   C. widens.
   D. narrows.

JAMB

8. The major difference between a pure semiconductor and a pure metal is that
    A. metals have forbidden gaps while semiconductors have not.
    B. The resistance of metals increases with temperature, while for semiconductors, it is the reverse.
    C. metals are harder than semiconductors.
    D. While the resistance of metals decreases with temperature, the reverse is the case for semiconductors.

JAMB

9. For a semiconductor to have negative temperature coefficient of resistance implies that
    A. they have electrons and holes at high temperatures.
    B. their resistance is constantly changing with temperature.
    C. their resistance increases with temperature.
    D. their resistance decreases with temperature.

JAMB

10. In a reverse biased junction diode, current flows in by
    A. electrons alone.
    B. majority carriers.
    C. minority carriers.
    D. positive holes.

JAMB