CHAPTER

8 Semiconductor Electronics

Metals, Semiconductors and Insulators

On the basis of electrical conductivity (σ) or resistivity ($\rho = 1/\sigma$) the solids are classified as

(i) **Metals** – have low resistivity

$\rho \sim 10^{-2}$ to $10^{-8}\ \Omega m$

$\sigma \sim 10^{2}$ to $10^{8}\ Sm^{-1}$

(ii) **Semiconductors** – have intermediate resistivity

$\rho \sim 10^{5}$ to $10^{0}\ \Omega m$

$\sigma \sim 10^{-5}$ to $10^{0}\ Sm^{-1}$

(iii) **Insulators** – have high resistivity

$\rho \sim 10^{8}\ \Omega m$

$\sigma \sim 10^{-8}\ Sm^{-1}$

i.e. the **Semiconductors** are the materials whose conductivity is more than insulators but less than conductors.

Types of Semiconductors

Intrinsic semiconductors or Pure semiconductors

In semiconductors forbidden energy gap Eg is more than metals or conductors and less than insulators.

Silicon (Si) and Germanium (Ge) are the examples of pure semi-conductors.

In pure or intrinsic semiconductor,

$n_e = n_h = n_i$ where, n_e = no. of electrons; n_h = no. of holes and n_i = no. of intrinsic carrier concentration.

Impurity like pentavalent (As, Sb, P) or trivalent (In, B, Al) are added to increase conductivity. Depending on doping type we have

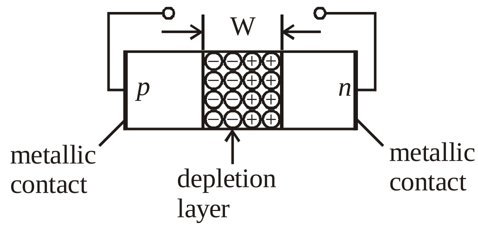
(a) n – type semiconductor and

(b) p – type semiconductor

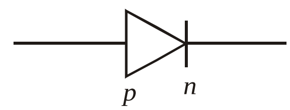
(a) ***n* – type semiconductor:** Si or Ge with pentavalent doping. An atom of valency +5 occupies the position of parent atom in crystal lattice. Four valence electrons form 4 covalent bonds but 5th electron is free and weakly bound to parent atom. The ionisation energy (~ 0.01V for Ge and 0.05V for Si) is small and even at room temperature the electron jumps to conduction band. The dopant is called **donor** impurity (positively charged).

(b) ***p* - type semiconductor:** Si or Ge with trivalent doping means one less electron in the 4 covalent bonds, so the 4th neighbour has a vacancy or hole that can be occupied by an electron from another site. Thus a hole is available for conduction. The trivalent atom is **negatively** charged as it acquires an electron and is called **acceptor** atom or impurity.

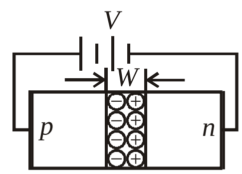
Formation of *p* – *n* junction: Part of p-type can be converted into n – type by adding pentavalent impurity. There is concentration gradient between p and n sides, holes diffuse from p side to n side ($p \rightarrow n$) and electrons move from ($n \rightarrow p$) creating a layer of positive and negative charges on n and p side respectively called **depletion layer**. External bias is applied to cause charges to flow.



Symbol of *p-n* junction diode

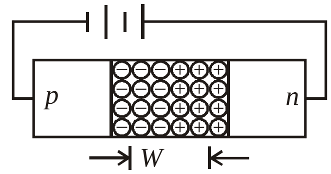


***p* – *n* junction under forward bias:** *When p – side is connected to positive terminal and n – side to negative terminal of external voltage, it is said to be* **forward biased.**



The applied voltage V is opposite to built in potential V_0, hence depletion layer width decreases and barrier height is reduced to $(V_0 - V)$. There is minority carrier injection, hence charges begin to flow. Current is in the order of mA.

(c) ***p* – *n* junction under reverse bias:** When p-side of *p-n* junction is connected to *–ve* terminal and n-side to *+ve* terminal of the battery, the diode is said to be reverse biased. The direction of applied voltage is same as direction of barrier potential, so barrier height increases to $(V_0 + V)$. This suppresses flow of electrons from $n \rightarrow p$ and holes from $p \rightarrow n$. Diffusion current decreases but drift of electrons and holes under the electric field affect remains. This drift current is few μA. The current under reverse bias is independent of applied voltage upto a critical value known as breakdown voltage (V_{br}) when $V = V_{br}$ diode reverse current increases sharply. If the reverse current is not limited below this, the diode gets destroyed due to overheating.



Special purpose $p - n$ junction diode:

Zener diode: It is fabricated by heavy doping of p and n sides of $p - n$ junction. Depletion region is thin $< 10^{-6}$ m. Electric field of junction is high ~ 5×10^6 V/m. Reverse bias ~ 5V.
It is used as **voltage regulator**.
p-n junction diode is used as a **rectifier**.
Rectifier is a device which converts A.C. into D.C.
Inverter converts D.C. into A.C.

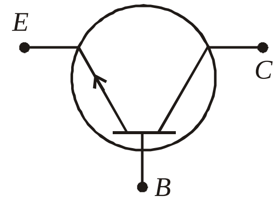
Optoelectronic junction devices:

(a) **Photodiode:** It is a $p - n$ junction fabricated with a transparent window to allow light photons to fall on it. These photons generate electron hole pairs upon absorption. The generation of electron hole pair is near the junction and due to junction field they remain separated till external load is connected. The electron are collected on n–side and holes on p–side near junction and give rise to an emf.
When external load is connected, current flows. The magnitude of current depends on intensity of incident radiation.

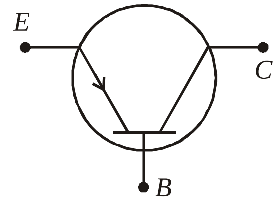
(b) **Light emitting diode (LED) :** It consists of heavily doped $p - n$ junction in forward bias. Electrons move from $n \to p$ and holes from $p \to n$ (minority carriers). Thus, near junction, minority carrier concentration increases (under no bias it is less) and they combine with majority carriers near the junction to release energy in form of photons with energy equal to or less than band gap energy. As forward bias increases, current increases till light intensity reaches maximum.

Junction Transistor:

Types: (i) *n-p-n* type, (ii) *p-n-p* type.
Structure: (i) Emitter (E), (ii) Base (B), (iii) Collector (C)
Symbol:



n-p-n type



p-n-p type

AC parameters:

(i) Input resistance = $\dfrac{\text{Change in base-emitter voltage}}{\text{Base current}}$

$$\Rightarrow r_i = \frac{\Delta V_{BE}}{\Delta I_B} \to \text{dynamic resistance}$$

(ii) Output resistance, $r_0 = \left(\dfrac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B}$

(iii) Current amplification factor (β)

$$\beta_{ac} = \left(\frac{\Delta I_C}{\Delta I_B}\right)_{V_{CE}} \; ; \; \beta_{dc} = \frac{I_C}{I_B} \Rightarrow \beta_{ac} \simeq \beta_{dc}$$

Uses of Transistor :
As a switch, an amplifier, an oscillator, etc.

EXERCISE

1. In a *p-n* junction
   (a) the potential of p & n sides becomes higher alternately
   (b) the p side is at higher electrical potential than n side
   (c) the n side is at higher electric potential than p side
   (d) both p & n sides are at same potential
2. Barrier potential of a *p-n* junction diode does not depend on
   (a) doping density (b) diode design
   (c) temperature (d) forward bias
3. The energy band gap is maximum in
   (a) metals
   (b) superconductors
   (c) insulators
   (d) semiconductors
4. The part of a transistor which is most heavily doped to produce large number of majority carriers is
   (a) emmiter
   (b) base
   (c) collector
   (d) can be any of the above three
5. When *n-p-n* transistor is used as an amplifier
   (a) electrons move from collector to base
   (b) holes move from emitter to base
   (c) electrons move from base to collector
   (d) holes move from base to emitter
6. In a common base amplifier the phase difference between the input signal voltage and the output voltage is
   (a) 0 (b) $\pi/4$
   (c) $\pi/2$ (d) π
7. Inverter converts
   (a) alternating current into direct current
   (b) direct current into alternating current
   (c) current at low voltage to current at high voltage
   (d) None of these
8. The Donor level in a semiconductor is placed
   (a) half-way in the forbidden energy gap
   (b) in the forbidden energy gap close to the upper edge of the valence band

(c) in the conduction band close to the lower edge to the conduction band
(d) in the forbidden energy gap close to the lower edge of the conduction band

9. If the distance between the conduction band and valence band is 1 eV. This combination is
(a) semiconductor (b) conductor
(c) metal (d) insulator

10. Carbon, silicon and germanium have four valence electrons each. These are characterised by valence and conduction bands separated by energy band gap respectively equal to $(E_g)_C$, $(E_g)_{Si}$ and $(E_g)_{Ge}$. Which of the following statements is true?
(a) $(E_g)_{Si} < (E_g)_{Ge} < (E_g)_C$ (b) $(E_g)_C < (E_g)_{Ge} < (E_g)_{Si}$
(c) $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$ (d) $(E_g)_C = (E_g)_{Si} = (E_g)_{Ge}$

11. In an unbiased *p-n* junction, holes diffuse from the *p*-region to *n*-region because
(a) free electrons in the *n*-region attract them.
(b) they move across the junction by the potential difference.
(c) hole concentration in *p*-region is more as compared to *n*-region.
(d) all the above

12. For a transistor amplifier, the voltage gain
(a) remains constant for all frequencies.
(b) is high at high and low frequencies and constant in the middle frequency range.
(c) is low at high and low frequencies and constant at mid frequencies.
(d) none of the above

13. *p-n* junction diode works as a insulator, if connected
(a) to A.C. (b) in forward bias
(c) in reverse bias (d) None of these

14. In an *n*-type silicon, which of the following statement is true?
(a) Electrons are majority carriers and trivalent atoms are the dopants.
(b) Electrons are minority carriers and pentavalent atoms are the dopants.
(c) Holes are minority carriers and pentavalent atoms are the dopants.
(d) Holes are majority carriers and trivalent atoms are the dopants.

15. Which of the statements is true for *p*-type semiconductos?
(a) Electrons are majority carriers and trivalent atoms are the dopants.
(b) Electrons are minority carriers and pentavalent atoms are the dopants.
(c) Holes are minority carriers and pentavalent atoms are the dopants.
(d) Holes are majority carriers and trivalent atoms are the dopants.

16. When a forward bias is applied to a *p-n* junction, it
(a) raises the potential barrier.
(b) reduces the majority carrier current to zero.
(c) lowers the potential barrier.
(d) None of these

17. The potential barrier, in the depletion layer, is due to
(a) ions (b) holes
(c) electrons (d) both (b) and (c)

18. Zener diode is used as
(a) half wave rectifier (b) full wave rectifier
(c) A.C. voltage stabilizer (d) D.C. voltage stabilizer

19. For a transistor amplifier, the voltage gain
(a) remains constant for all frequencies
(b) is high at high and low frequencies and constant in the middle frequency range
(c) is low at high and low frequencies and constant at mid frequencies
(d) None of these

20. In a semiconductor, the concentration of electrons is $8 \times 10^{14}/cm^3$ and that of the holes is 5×10^{12} cm^3. The semiconductor is
(a) *p*-type (b) *n*-type
(c) intrinsic (d) Cannot say

21. When a semiconductor is heated, its resistance
(a) decreases (b) increases
(c) remains unchanged (d) either (b) or (c)

22. The forbidden gap in the energy bands of germanium at room temperature is about
(a) 1.1 eV (b) 0.1 eV
(c) 0.67 eV (d) 6.7 eV

23. To obtain a *p*-type germanium semiconductor, it must be doped with
(a) arsenic (b) antimony
(c) indium (d) phosphorus

24. Which impurity is doped in Si to form *n*-type semi-conductors?
(a) Al (b) B
(c) As (d) None of these

25. In extrinsic semiconductors
(a) the conduction band and valence band overlap
(b) the gap between conduction band and valence band is more than 16 eV
(c) the gap between conduction band and valence band is near about 1 eV
(d) the gap between conduction band and valence band will be 100 eV and more

26. Function of rectifier is
(a) to convert A.C. into D.C.
(b) to convert D.C. into A.C.
(c) Both (a) and (b)
(d) None of these

27. Zener breakdown takes place if
(a) doped impurity is low
(b) doped impurity is high
(c) less impurity in *n*-part
(d) less impurity in *p*-part

28. Which one of the following is not a correct statement about semiconductors?
(a) The electrons and holes have different mobilities in a semiconductor
(b) In an *n*-type semiconductor, the Fermi level lies closer to the conduction band edge
(c) Silicon is a direct band gap semiconductor
(d) Silicon is has diamond structure

29. The energy band gap is minimum in
(a) metals (b) superconductors
(c) insulators (d) semiconductors.

30. An oscillator is nothing but an amplifer with
(a) positive feedback (b) negative feedback
(c) large gain (d) no feedback

31. When a solid with a band gap has a donor level just below its empty energy band, the solid is
(a) an insulator
(b) a conductor
(c) *p*-type semiconductor
(d) *n*-type semiconductor

32. Regarding a semiconductor which one of the following is wrong?
(a) There are no free electrons at room temperature
(b) There are no free electrons at 0K
(c) The number of free electrons increases with rise of temperature
(d) The charge carriers are electrons and holes

33. *p*-*n* junction is said to be forward biased, when
(a) the positive pole of the battery is joined to the *p*-semiconductor and negative pole to the *n*-semiconductor
(b) the positive pole of the battery is joined to the *n*-semiconductor and *p*-semiconductor
(c) the positive pole of the battery is connected to *n*- semiconductor and *p*- semiconductor
(d) a mechanical force is applied in the forward direction

34. At absolute zero, Si acts as
(a) non-metal (b) metal
(c) insulator (d) None of these

35. When *n*-type semiconductor is heated
(a) number of electrons increases while that of holes decreases
(b) number of holes increases while that of electrons decreases
(c) number of electrons and holes remain same
(d) number of electrons and holes increases equally

36. To use a transistor as an amplifier
(a) The emitter base junction is forward biased and the base collector junction is reverse biased
(b) no bias voltage is required
(c) both junctions are forward biased
(d) both junctions are reverse biased

37. The part of the transistor which is heavily doped to produce large number of majority carriers is
(a) emitter
(b) base
(c) collector
(d) any of the above depending upon the nature of transistor

38. When a *p*-*n* junction diode is reverse biased the flow of current across the junction is mainly due to
(a) diffusion of charges
(b) drift of charges
(c) depends on the nature of material
(d) both drift and diffusion of charges

39. When an *n*–*p*–*n* transistor is used as an amplifier then
(a) electrons flow from emitter to collector
(b) holes flow from emitter to collector
(c) electrons flow from collector to emitter
(d) electrons flow from battery to emitter

40. An *n*-*p*-*n* transistor conducts when
(a) both collector and emitter are negative with respect to the base
(b) both collector and emitter are positive with respect to the base
(c) collector is positive and emitter is negative with respect to the base
(d) collector is positive and emitter is at same potential as the base

41. Reverse bias applied to a junction diode
(a) increases the minority carrier current
(b) lowers the potential barrier
(c) raises the potential barrier
(d) increases the majority carrier current

42. In semiconductors, at room temperature
(a) the conduction band is completely empty
(b) the valence band is partially empty and the conduction band is partially filled
(c) the valence band is completely filled and the conduction band is partially filled
(d) the valence band is completely filled

43. Application of a forward bias to a *p*–*n* junction
(a) widens the depletion zone.
(b) increases the potential difference across the depletion zone.
(c) increases the number of donors on the n side.
(d) increases the electric field in the depletion zone.

44. A piece of copper and another of germanium are cooled from room temperature to 80 K. The resistance of
(a) each of them increases
(b) each of them decreases
(c) copper increases and germanium decreases
(d) copper decreases and germanium increases

45. In an intrinsic semiconductor
(a) only electrons are responsible for flow of current
(b) both holes and electrons carry current
(c) both holes and electrons carry current with electrons being majority carriers
(d) only holes are responsible for flow of current

46. If the conductivity of a semiconductor is only due to break up of the covalent bonds due to thermal excitation, then the semiconductor is called
(a) intrinsic (b) extrinsic
(c) donor (d) acceptor

47. The mobility of conduction electrons is greater than that of holes, since electrons
(a) are lighter
(b) are negatively charged
(c) require smaller energy for moving through crystal lattice
(d) undergo smaller number of collisions

48. In the symbol of a transistor , the arrow head points in the direction of flow of
(a) holes (b) electrons
(c) majority carriers (d) minority carriers

49. Transistors are essentially
(a) power driven devices
(b) current driven devices
(c) voltage driven devices
(d) resistance driven devices

50. In a transistor
(a) emitter is more highly doped than collector
(b) collector is more highly doped than emitter
(c) both are equally doped
(d) None of the above

51. One way in which the operation of an *n-p-n* transistor differs from that of a *p-n-p*
(a) the emitter junction is reverse biased in *n-p-n*.
(b) the emitter junction injects minority carriers into base region of the *p-n-p*
(c) the emitter injects holes into the base of the *p-n-p* and electrons into the base region *n-p-n*
(d) the emitter injects holes into the base of *n-p-n*

52. *n-p-n* transistors are preferred to *p-n-p* transistors because:
(a) they have low cost
(b) they have low dissipation energy
(c) they are capable of handling large power
(d) electrons have high mobility than holes and hence high mobility of energy

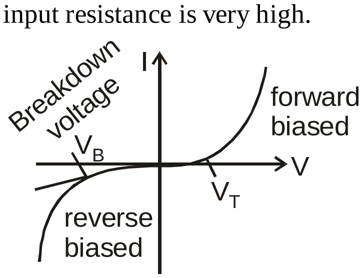
53. An alternating current can be converted into direct current by a
(a) rectifier (b) transformer
(c) dynamo (d) motor

ANSWER KEY

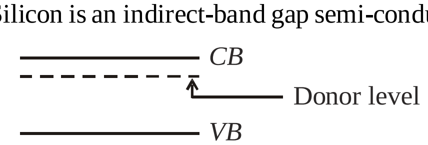
1	(b)	**11**	(c)	**21**	(a)	**31**	(d)	**41**	(c)	**51**	(c)
2	(b)	**12**	(c)	**22**	(c)	**32**	(a)	**42**	(c)	**52**	(d)
3	(c)	**13**	(c)	**23**	(c)	**33**	(a)	**43**	(c)	**53**	(a)
4	(a)	**14**	(c)	**24**	(c)	**34**	(c)	**44**	(d)		
5	(d)	**15**	(d)	**25**	(c)	**35**	(d)	**45**	(b)		
6	(a)	**16**	(c)	**26**	(a)	**36**	(a)	**46**	(a)		
7	(b)	**17**	(a)	**27**	(b)	**37**	(a)	**47**	(c)		
8	(d)	**18**	(c)	**28**	(c)	**38**	(b)	**48**	(a)		
9	(a)	**19**	(c)	**29**	(a)	**39**	(a)	**49**	(b)		
10	(c)	**20**	(b)	**30**	(a)	**40**	(c)	**50**	(a)		

HINTS AND SOLUTIONS

1. (b) [**Hint :** For easy flow of current the *p*-side must be connected to +ive terminal of battery *i.e.*, it is connected to higher potential in comparison to *n*. This connection is called forward biased. In this case the input resistance is very low.
In reverse-biased, the *p*-side is connected to –ive terminal & *n*-side to (+ive) terminal to battery. In this case input resistance is very high.



2. (b) [**Hint** : Barrier potential depends on, doping density, temperature, forward/reverse bias but does not depend on diode design.]
3. (c) Maximum in insulators and overlaping in metals.
5. (d) Holes move from base to emitter.
6. (a) The phase difference between output voltage and input signal voltage in common base transistor circuit is zero
7. (b) Inverter converts a.c. into d.c.
9. (a) Distance between conduction band and valence band = Fermi gap energy = 1eV.
Since there is a small gap between the conduction and valence band so it is semiconductor.
13. (c) In reverse bias no current flows.
18. (c) For a wide range of values of load resistance, the current in the Zener diode may change but the voltage across it remains unaffected. Thus the output voltage across the Zener diode is a regulated voltage.
20. (b) Since, $n_e > n_h$, the semiconductor is *n*-type.
22. (c) $\Delta E_{g(\text{Germanium})} = 0.67$ eV.
23. (c) For *p*-type semiconductor the doping impurity should be trivalent.
24. (c) Because As is pentavalent impurity.
26. (a) AC $\rightarrow$ $\boxed{\text{Rectifier}}$ $\rightarrow$ DC
27. (b) Zener breakdown can occur in heavily doped diodes. In lightly doped diodes the necessary voltage is higher, and avalanche multiplication is then the chief process involved.
28. (c) Silicon is an indirect-band gap semi-conductor.



29. (a) Maximum in insulators and minimum in metals.

30. (a) A positive feedback from output to input in an amplifier provides oscillations of constant amplitude.

31. (d) Donor level close to energy band is in case of *n*-type semi-conductor.

32. (a) At room temperature, few bonds breaks and electron hole pair generates inside the semiconductor.

33. (a) For forward biasing of *p*-*n* junction, the positive terminal of external battery is to be connected to *p*-semiconductor and negative terminal of battery to the *n*-semiconductor.

34. (c) Semiconductors are insulators at room temperature.

35. (d) Due to heating, when a free electron is produced then simultaneously a hole is also produced.

36. (a) To use a transistor as an amplifier the emitter base junction is forward biased while the collector base junction is reverse biased.

37. (a) The function of emitter is to supply the majority carriers. So, it is heavily doped.

38. (b) When *p*-*n* junction is reverse biased, the flow of current is due to drifting of minority charge carriers across the junction.

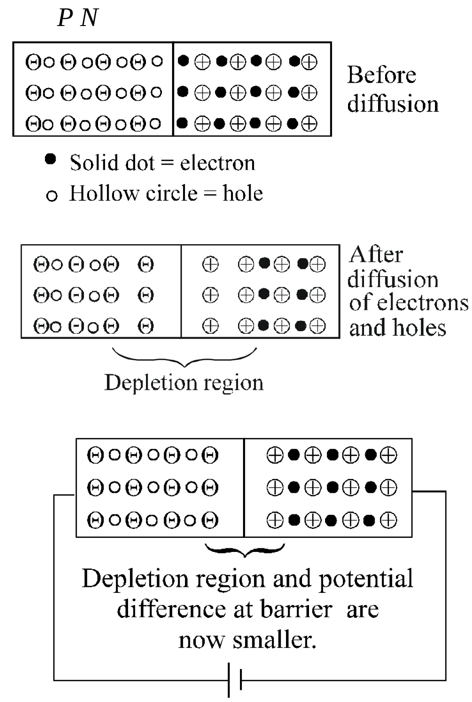
39. (a) In an *n*-*p*-*n* transistor, the charge carriers, are free electrons in the transistor as well as in external circuit; these electrons flow from emitter to collector.

40. (c) When the collector is positive and emitter is negative w.r.t. base, it causes the forward biasing for each junction, which causes conduction of current.

41. (c) In reverse biasing, the conduction across the *p*-*n* junction does not take place due to majority carriers but takes place due to minority carriers if the voltage of external battery is large. The size of the depletion region increases thereby increasing the potential barrier.

42. (c) In semiconductros, the conduction is empty and the valence band is completely filled at 0 K. No electron from valence band can cross over to conduction band at 0K. But at room temperature some electrons in the valence band jump over to the conduction band due to the small forbidden gap, *i.e*. 1 eV.

43. (c)



Number of donors is more because electrons from – ve terminal of the cell pushes (enters) the *n*-side and decreases the number of uncompensated pentavalent ion due to which potential barrier is reduced. The neutralised pentavalent atom are again in position to donate electrons.