UPPSC-AE 2025

Uttar Pradesh
Public Service Commission

Combined State Engineering Services Examination

Assistant Engineer

Electrical Engineering

Elements of Electronics
(Basic Electronics Engineering)

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY
PUBLICATIONS

Elements of Electronics
(Basic Electronics Engineering)

Contents

❍❍❍❍

CHAPTER 1

Semiconductor Physics

1.1 Introduction

A semiconductor is a material that is neither a good conductor nor a good insulator. A material whose conductivity lies between the metal and insulator is a semiconductor. Some common semiconductor materials are Silicon (Si), Germanium (Ge), Gallium-Arsenide (GaAs), etc. Silicon is the most widely used semiconductor material in the electronics industry. Intrinsic semi conductors are semiconductors in their purest form. Extrinsic semiconductors are semiconductors with other atoms (impurity) mixed in. This chapter deals with the basics of semiconductor materials and their characteristics.

1.2 Classification of Materials

A. On the basis of conductivity

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

(i) Metals or conductors: They posses very low resistivity (or low conductivity)

$$\rho \approx 10^{-2} - 10^{-8}\ \Omega\text{-m}$$
$$\sigma \approx 10^{2} - 10^{8}\ \text{Sm}^{-1}$$

(ii) Semiconductors: They have resistivity or conductivity intermediate to metals and insulators

$$\rho \approx 10^{-5} - 10^{6}\ \Omega\text{-m}$$
$$\sigma \approx 10^{5} - 10^{-6}\ \text{Sm}^{-1}$$

(iii) Insulators: They have high resistivity (or low conductivity)

$$\rho \approx 10^{11} - 10^{19}\ \Omega\text{-m}$$
$$\sigma \approx 10^{-11} - 10^{-19}\ \text{Sm}^{-1}$$

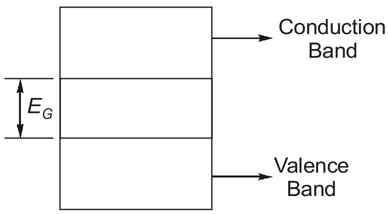
B. On the basis of energy bands

- The minimum energy required to detach an electron from valence band to conduction band is equal to it's Energy Gap (E_G).
- Energy band gap E_g is a function of temperature and tends to decrease as the temperature increases.
- At any temperature T,

$$E_g(T) = E_{go} - \beta T$$

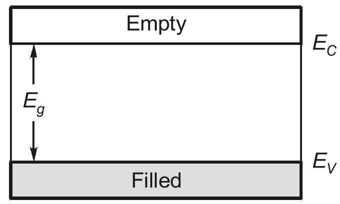
E_{go} = Energy Band Gap at 0°K

β = Material constant (Unit : eV/°K)



- Different energy levels with continuous energy variation form energy bands.
- The energy band which includes the energy levels of valence electrons is called the valence band.

- The energy band above the valence band which can contain conducting electrons is called conduction band.



- Lowest energy level in the conduction band is E_c and highest energy level in the valence band is E_V.

Materials can also be classified on the basis of energy gap:

(i) Metals/Conductors:

- There is no forbidden energy gap between the valence and conduction bands. The two bands actually overlap as shown in figure
- Without supplying any additional energy such as heat or light, a metal already contains a large number of free electrons and that is why it works as a good conductor.
- Example: Al, Cu etc.

(ii) Semiconductors

- At 0°K semiconductor materials have the same structure as insulators except the difference in the size of the band gap E_G, which is much smaller in semiconductors ($E_G \simeq 1$ eV) than in insulators.
- The relatively small band gaps of semiconductors allow for excitation of electrons from the lower (valence) band to the upper (conduction) band by reasonable amount of thermal or optical energy.
- The difference between semiconductors and insulators is that the conductivity of semiconductors can increase greatly by thermal or optical energy.
- Example: Ge and Si.

(iii) Insulators

- It has a very wide forbidden-energy gap ($\simeq 6$ eV) separating the filled valence band from the vacant conduction band. Because of this, it is practically impossible for an electron in the valence band to jump the gap, reach the conduction band.
- At room temperature, an insulator does not conduct. However it may conduct if its temperature is very high or if a high voltage is applied across it. This is termed as the breakdown of the insulator.
- Example: diamond.

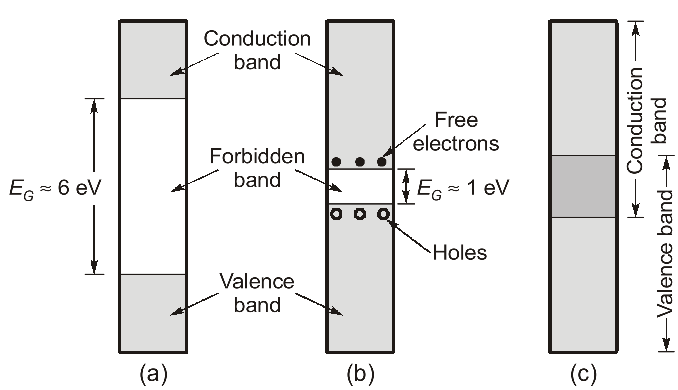


Fig. Simplified energy band diagrams of (a) insulator (b) semiconductor (c) conductor

NOTE

- Conduction band electrons can move along sea of atoms present in the specimen under consideration while the valence band electrons (restrained electrons) are bound to parent atom. These conduction band electrons are known as *free electrons*.

$$E_{G300} = 0.72 \text{ eV for Ge} \qquad \text{(at 300 K)}$$
$$E_{G300} = 1.1 \text{ eV for Si} \qquad \text{(at 300 K)}$$
$$E_G = 0.785 \text{ eV for Ge \& 1.21 eV for Si at 0° K}$$

- Conduction in semiconductors does not obey ohm's law and will increase rapidly than voltage, i.e. semiconductors are non-linear resistors.

1.3 Types of Semiconductor Materials

A semiconductor material can be either in elemental form or in compound form

(i) Elemental semiconductor : Si and Ge

(ii) Compound semiconductors : Examples are
  - Inorganic : GaAs, Cds, GaN, etc.
  - Organic : Anthraces, doped pthalocyanines, etc.

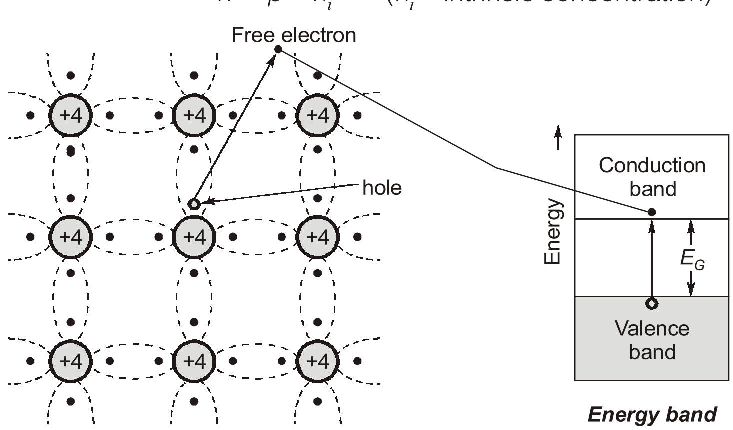
Further on a broad way, they are classified as

(i) Intrinsic semiconductors (ii) Extrinsic semiconductors

1.3.1 Intrinsic Semiconductors

- Semiconductor in its purest form (without any impurity) is known as intrinsic semiconductor.
- An intrinsic semiconductor (such as pure Ge or Si), has only four electrons in the outermost orbit of its atoms. When atoms bond together to form molecules of matter, each atom attempts to acquire eight electrons in its outermost shell. This is done by sharing one electron from each of the four neighboring atoms. This sharing of electrons in semiconductors is known as covalent bonding.
- At absolute zero, all the valence electrons are tightly bound to the parent atoms. No free electrons are available for conduction.
- At room temperature, sufficient thermal energy is supplied to break the covalent bond, thereby, generating electron-hole pairs.
- The concentration of free electrons and holes will always be equal in an intrinsic semiconductor.

$$n = p = n_i \qquad (n_i = \text{intrinsic concentration})$$



Crystal structure

Energy band diagram

- At room temperature, some electron-hole pairs are generated. Now, if we raise the temperature further, more electron hole pairs are generated. The higher the temperature, the higher is the concentration of charge carriers. As more charge carriers are made available, the conductivity of intrinsic semiconductor increases with temperature.
- In other words, the resistivity (inverse of conductivity) decreases as the temperature increases. That is; semiconductor have negative temperature coefficient of resistance.
- Intrinsic concentration, $n_i^2 = A_0 T^3 e^{-\left(\frac{E_{G0}}{kT}\right)}$

  Where, E_{G0} = Energy gap at 0°K in eVs

  k = Boltzman's constant in eV/°K

  A_0 = Material constant independent of temperature

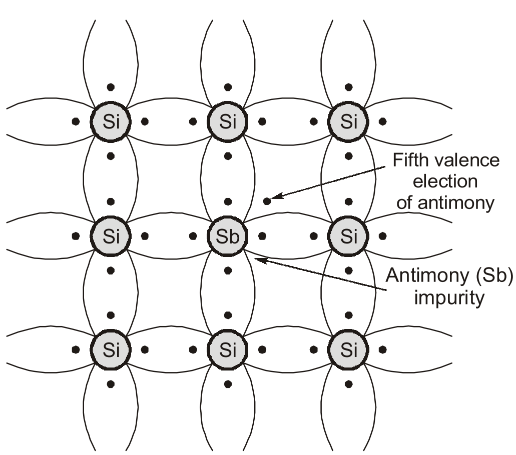
NOTE

- The intrinsic semiconductor behaves as a perfect insulator at absolute zero.
- A hole is not a particle; for all practical purposes we can view it as a positively charged particle capable of conducting current

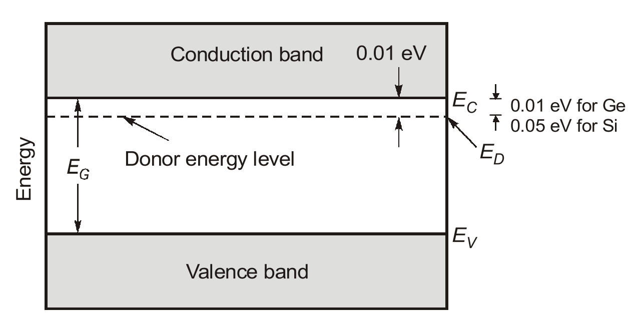
1.3.2 Extrinsic Semiconductors

- In addition to the intrinsic carriers generated thermally, it is possible to create carriers in semiconductors by introducing impurities into the crystal.
- This process, called doping, is the most common technique for varying the conductivity of semiconductors.
- When a crystal is doped such that the equilibrium carrier concentration are different from the intrinsic carrier concentration, the material is said to be extrinsic.
- By doping, a crystal can be altered so that it has a predominance of either electrons or holes. Thus there are two types of doped semiconductors, *n*-type (majority carriers electrons) and *p*-type (majority carries holes).

n-Type Semiconductor



Antimony impurity in n-type material



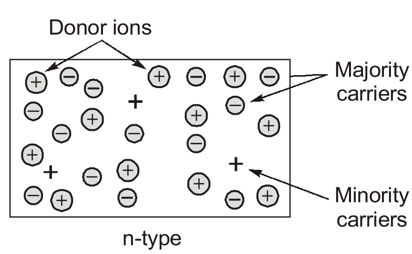
Energy-band diagram of n-type semiconductor

- If suitable pentavalent impurities (antimony, phosphorus and arsenic) are added to intrinsic silicon or Ge, such impurities donate excess (negative) electron carriers, and therefore referred to as donor or n-type impurities.
- This excess electron loosely bound to its parent atom, is relatively free to move within the *n*-type material.
- When impurities are introduced in the material, additional levels are created in the energy bond structure, usually within the band gap. For *n*-type impurity, it is called "Donor Level".
- In case of Germanium, donor level is only 0.01 eV (0.05 eV in silicon) below the conduction band, and therefore at room temperature almost all the excess electrons of the donor material are raised into the conduction band.
- Donor energy level (E_D) does not depend upon temperature.
- If intrinsic semiconductor is doped with *n* type impurities, not only does the number of electrons increase, but the no. of holes decreases below that which would be available in the intrinsic semiconductor. The reason for the decrease in the no. of holes is that the larger no. of electrons present increases the rate of recombination of electrons with holes.
- In n-type semiconductor, majority carriers are electrons and minority carriers are holes.

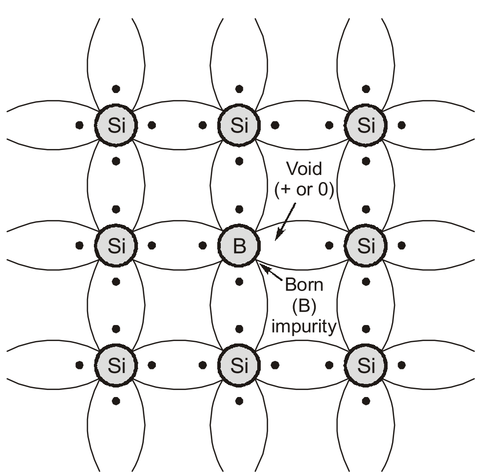
NOTE

- Diffused impurities with five valence electrons are called donor atoms.
- *n*-type material is as a whole electrically neutral since ideally the number of positively charged protons in the nuclei is still equal to the number of free and orbiting negatively charged electrons in the structure.

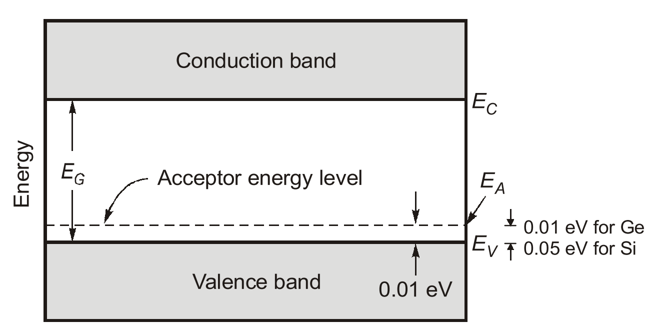
Representation for *n*-type semiconductors:



p-Type Semiconductor



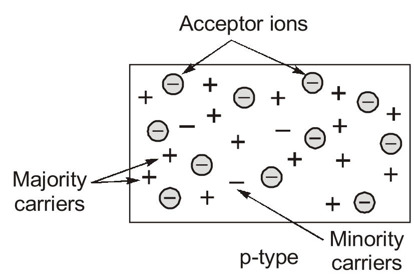
Boron impurity in p-type material



Energy-band diagram of p-type semiconductor

- If trivalent impurity (Boron, Aluminium, Gallium or Indium) is added to an intrinsic semiconductor, only three of the covalent bonds can be filled and such impurities make available positive carriers because they create holes which can accept electrons. These impurities are referred to as acceptor or p-type impurities.
- A very small amount of energy is required for an electron to leave the valence band and occupy the acceptor energy level, it follows that holes generated in the valence band by these electrons constitute the largest number of carriers in the semiconductor material.
- The acceptor atom introduces an energy level near the valence band known as Acceptor Energy Level (E_A).
- Acceptor Energy level exist just above the valence band. It represents the energy level of all the trivalent impurities.
- At room temperature, enough thermal energy is available to excite electrons from the valence band to acceptor level.
- Acceptor Energy level (E_A) does not depend upon temperature.
- In p-type semiconductor, majority carriers are holes and minority carriers are electrons.

Representation for *p*-type semiconductors:



NOTE

- The diffused impurities with three valence electrons are called acceptor atoms.
- Standard Doping Levels

– Moderate doping	: 1 in (10^6 – 10^8)	: *P*, *N*
– Lightly doped	: 1 in 10^{11}	: P^-, N^-
– Highly (heavily) doped	: 1 in 10^3	: P^+, N^+

1 : 10^6 or 1 in 10^6 or $1/10^6$ is read as "1 impurity atom in 10^6 atoms".

Example - 1.1 Both donor and acceptor impurities are present in the combination of

(a) Phosphorous-Arsenic (b) Aluminium-Antimony
(c) Boron-Gallium (d) Arsenic-Antimony [UPPSC]

Solution: (b)

- Pentavalent impurities or donor impurities are Antimony, Phosphorous and Arsenic
- While Boron, Gallium and Aluminium arc acceptor impurity atoms.

Example - 1.2 Which of the following band is just above the intrinsic Fermi level for *n*-type semiconductor?

(a) Donor band (b) Valence band (c) Acceptor band (d) Conduction band

Solution: (a)

For *n*-type semiconductors, the donor band is just above the intrinsic fermi level.

Example - 1.3 Doping in a semiconductor increases which quantity.

(a) resistance
(b) conductance
(c) inductance
(d) none of these

Solution: (b)

Doping means adding impurity in semiconductor. It increases the conductivity of the semiconductor since it increases either holes or free electrons in the semiconductor

1.4 Mass-Action Law

- In a semiconductor under thermal equilibrium (constant temperature) the product of electrons and holes concentrations is always a constant and is equal to the square of intrinsic carrier concentration.

$$np = n_i^2$$

- The intrinsic concentration n_i is a function of temperature.
- The law is mainly used to calculate the concentration of minority carriers. In n-type semiconductor, the electrons are called the majority carriers, and the holes are called the minority carriers. In a p-type material, the holes are the majority carriers, and the electrons are the minority carriers.
- For a p-type semiconductor, $p_n = \frac{n_i^2}{n_n}$
- For an n-type semiconductor, $n_n = \frac{n_i^2}{p_n}$

$$\text{Minority carrier concentration} = \frac{n_i^2}{\text{Majority carrier concentration}}$$

but, Majority carrier concentration $\propto$ Doping concentration

so, $$\text{Minority carrier concentration} \propto \frac{1}{\text{Doping concentration}}$$

or, $$\text{Minority carrier concentration} \times \text{Doping concentration} = n_i^2$$

- In a semiconductor, if majority carrier concentration increases the minority carrier concentration decreases this is due to the recombinations.

Example - 1.4 In a *p*-type Si sample, the hole concentration is 2.5 × 10^{15}/cm^3. If the intrinsic carrier concentration is 1.5 × 10^{10}/cm^3, then the electron concentration in *p*-type Si-sample is

(a) 10^5/cm^3
(b) zero
(c) 9 × 10^4/cm^3
(d) 9 × 10^6/cm^3

Solution: (c)

Given, $p = 2.5 \times 10^{15}/\text{cm}^3$; $n_i = 1.5 \times 10^{10}/\text{cm}^3$

As per mass action law,

$$n \cdot p = n_i^2$$

$$n = \frac{n_i^2}{p} = \frac{(1.5\times10^{10})^2}{2.5\times10^{15}} = 9\times10^4/\text{cm}^3$$

1.5 Charge-Neutrality Equation

- Any part of a semiconductor bar is always electrically neutral.

  or

  Total positive charge densities = Total negative charge densities.

$$P + N_D = n + N_A$$

- *n*-type

$$P + N_D = n + N_A$$

$$n > p \; ; \; N_A \approx 0 \; (n\text{-type})$$

$$\Rightarrow \quad \frac{n_i^2}{n} + N_D = n = 0 \Rightarrow n^2 - N_D n - n_i^2 = 0$$

$$\Rightarrow \quad n = \frac{N_D}{2} \pm \sqrt{\left(\frac{N_D}{2}\right)^2 + n_i^2}$$

$$= \frac{N_D}{2} + \sqrt{\left(\frac{N_D}{2}\right)^2 + n_i^2} \qquad (n > 0, \text{ so only +ve sign})$$

$$n = \frac{N_D}{2} + \sqrt{\left(\frac{N_D}{2}\right)^2 + n_i^2}$$

$$N_D >> n_i$$

So, $\boxed{n \approx N_D}$

- Similarly, for *p*-type

$$p = \frac{N_A}{2} + \sqrt{\left(\frac{N_A}{2}\right)^2 + n_i^2}$$

$$n_A >> n_i$$

$$\boxed{p \approx N_A}$$

NOTE

Comparison of Si and Ge:

- $Si \rightarrow I_0$ in nano-ampere
  $Ge \rightarrow I_0$ in micro-ampere } Because of gap difference

  I_0 ideally should be zero but practically, it should be less in value, where I_0 is reverse saturation current.
- Temperature withstand capacity

  $Ge \rightarrow 100°C$

  $Si \rightarrow 200°C$
- Peak inverse voltage (PIV) rating. It is the maximum reverse biased voltage at which the diode can withstand.

  $Ge \rightarrow 400$ V

  $Si \rightarrow 1000$ V
- Silicon is cheaper as compared to germanium.

For n-type Semiconductor

$$E_F = E_C - kT\ln\left(\frac{N_C}{N_D}\right), \text{ where } N_D \rightarrow \text{Donor concentration}$$

- If n-type SC, fermi level depends on both temperature and donor concentration.
- At 0°K, fermi level coincides with E_C.
- As temperature increases, fermi level moves towards middle of bandgap.
- As donor concentration increases, fermi level moves towards conduction band.
- For n-type semiconductor, normally fermi level lies close to conduction band.

For p-type Semiconductor

$$E_F = E_V + kT\ln\left(\frac{N_V}{N_A}\right), \text{ where } N_A \rightarrow \text{Acceptor concentration}$$

- If p-type SC, fermi level E_F at 0K coincides with valence band (E_V).
- In p-type SC, fermi level lies close to valence band.
- As temperature increases, fermi level moves away from valence band.
- As doping concentration (N_A) increases, fermi level moves towards valence band.

■■■■

Student's Assignment

Q.1 What will happen if doping of an intrinsic semiconductor with pentavalent impurity atom?
(a) Fermi level falls
(b) Fermi level raises
(c) Fermi level not change
(d) None of these

Q.2 A specimen of intrinsic germanium with the density of charge carriers of $2.5 \times 10^{13}/cm^3$, is doped with donor impurity atoms such that there is one donor impurity atom for every 10^6 germanium atoms. The density of germanium atoms is $4.4 \times 10^{22}/cm^3$. The hole density would be
(a) $4.4 \times 10^{16}/cm^3$ (b) $1.4 \times 10^{10}/cm^3$
(c) $4.4 \times 10^{10}/cm^3$ (d) $1.4 \times 10^{16}/cm^3$

Q.3 Which one of the following equations represents the energy gap (E_G) variation of silicon with temperature (T)?
(a) $E_G(T) = 2.11 - 3.60 \times 10^{-4}\ T$
(b) $E_G(T) = 1.21 - 3.60 \times 10^{-4}\ T$
(c) $E_G(T) = 1.41 - 2.23 \times 10^{-4}\ T$
(d) $E_G(T) = 0.785 - 2.23 \times 10^{-4}\ T$

Q.4 Thermal voltage of a semiconductor diode at 20°C temperature is nearly
(a) 25.27 mV (b) 26 mV
(c) 28.15 mV (d) 22.8 mV

Q.5 Drift current in semiconductors depends upon
(a) only the electric field
(b) only the carrier concentration gradient
(c) both the electric field and the carrier concentration
(d) both the electric field and the carrier concentration gradient

Q.6 A Silicon sample A is doped with 10^{18} atoms/cm^3 of Boron. Another sample B of identical dimensions is doped with 10^{18} atoms/cm^3 of Phosphorus. The ratio of electron to hole mobility is 3. The ratio of conductivity of the sample A to B is

(a) 3 (b) 1/3
(b) 2/3 (d) 3/2

Q.7 The density and mobility of electrons in a conductor are respectively 10^{20}/cm^3 and 800 cm^2/V-s. If a uniform electric field of 1 V/cm exists across this conductor, then the electron current density would be approximately

(a) 11 kA/cm^2 (b) 9 kA/cm^2
(c) 13 kA/cm^2 (d) 18 kA/cm^2

Q.8 The concentration of minority carriers in an extrinsic semiconductor under equilibrium is

(a) directly proportional to the doping concentration.
(b) inversely proportional to the doping concentration.
(c) directly proportional to the intrinsic concentration.
(d) inversely proportional to the intrinsic concentration.

Q.9 In a p-n junction, to make the depletion region extent predominantly into p-region, the concentration of impurities in the p-region must be

(a) Much less than the concentration of impurities in n-region
(b) Much higher than the concentration of impurities in n-region
(c) Equal to the concentration of impurities in n-region
(d) zero

Q.10 A semiconductor is doped with a donor density N_D and no acceptors. If the intrinsic concentration is n_i, then the free electron density(n) will be equal to

(a) $\dfrac{N_D + \sqrt{4n_i^2 + N_D^2}}{2}$ (b) $\dfrac{n_i + \sqrt{n_i^2 + 4N_D^2}}{2}$

(c) $\dfrac{N_D + \sqrt{n_i^2 + 4N_D^2}}{2}$ (d) $\dfrac{n_i + \sqrt{4n_i^2 + N_D^2}}{2}$

Q.11 Doping materials are called impurities because they

(a) make semiconductors less than 100 percent pure.
(b) alter the crystal structures of the pure semiconductors .
(c) decrease the number of charge carriers.
(d) change the chemical properties of semiconductors.

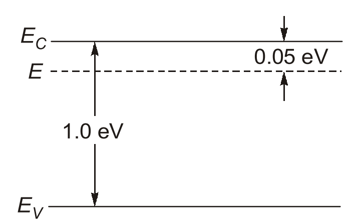
Q.12 When an intrinsic semiconductor is doped with an acceptor type impurity

(a) electrons are generated and the material becomes p-type.
(b) electrons are generated and the material is called n-type.
(c) holes are generated and the material becomes p-type.
(d) holes are generated and the material becomes n-type.

Q.13 What is the diffusion current in a piece of germanium having concentration gradient of 1.5×10^{22} electrons/m^3 and $D_n = 0.0012$ m^2/s?

(a) 4.45 A/m^2 (b) 3.33 A/m^2
(c) 1.88 A/m^2 (d) 2.88 A/m^2

Q.14 In the below band diagram of a semiconductor, the Fermi level is 0.3 eV above the intrinsic level. What does the energy level E in the diagram represent?



(a) The Fermi level (b) The intrinsic level
(c) The donor level (d) The acceptor level

Q.15 If n, n_i, μ_n and μ_p, respectively denote electron concentration, intrinsic concentration, mobility of electrons and mobility of holes, the minimum conductivity of a semiconductor sample occurs at

(a) $n = n_i\sqrt{\dfrac{\mu_p}{\mu_n}}$ (b) $n = n_i\sqrt{\dfrac{\mu_n}{\mu_p}}$

(c) $n = n_i\sqrt{\mu_n, \mu_p}$ (d) $n = n_i\sqrt{\mu_n + \mu_P}$

Q.16 Resistivity of a p-type specimen is 0.12 Ω-m, hole mobility is 0.048 m^2 V^{-1} s^{-1}(electron charge $= 1.6 \times 10^{-19}$ Coulomb) and intrinsic concentration is 5.9×10^{10} cm^{-3}. Then the electron concentration in the specimen is

(a) 1.085×10^{15} cm^{-3} (b) 3.206×10^{6} cm^{-3}
(c) 5.9×10^{10} cm^{-3} (d) 1.085×10^{6} cm^{-3}

Q.17 In a semiconductor, if n = number of electrons per unit volume and V_d is drift velocity of electrons, then the current flowing through semiconductor is proportional to

(a) $i \propto \frac{V_d}{n}$ (b) $i \propto \frac{n}{V_d}$

(c) $i \propto nV_d$ (d) $i \propto n\sqrt{V_d}$

Q.18 A semiconductor is uniformly doped with N_A acceptors and N_D donors. Let the free electron and hole concentrations be n and p respectively. Assume that the semi-conductor is at thermal equilibrium and that 100% ionisation has taken place. Then which of the following is true?

(a) $N_A + N_D = p + n$ (b) $N_A - N_D = n - p$

(c) $N_A N_D = pn$ (d) $N_D - N_A = n - p$

ANSWER KEY — STUDENT'S ASSIGNMENT

1. (b)	**2.** (b)	**3.** (b)	**4.** (a)	**5.** (c)
6. (b)	**7.** (c)	**8.** (b)	**9.** (a)	**10.** (a)
11. (c)	**12.** (c)	**13.** (d)	**14.** (c)	**15.** (a)
16. (b)	**17.** (c)	**18.** (d)		

HINTS & SOLUTIONS — STUDENT'S ASSIGNMENT

1. (b)

When donor density increases, the Fermi level moves closer to the edge of the conduction band.

2. (b)

In an n-type material $n \simeq N_D$,

$$n_i = p_i = 2.5 \times 10^{13}/\text{cm}^3$$

$$= \frac{4.4 \times 10^{22}}{10^6}/\text{cm}^3$$

$$n \cdot p = n_i^2$$

$$p = \frac{(2.5 \times 10^{13})^2}{4.4 \times 10^{16}}$$

$$= 1.4 \times 10^{10}/\text{cm}^3$$

3. (b)

Energy gap of silicon at a temperature T

$$E_g = E_{go} - \beta T$$

where, E_{go} = 1.2 eV at 0 K

$$E_g = 1.21 - 3.60 \times 10^{-4} \times T$$

$$\beta = 3.60 \times 10^{-4} \text{ eV/K for Si}$$

4. (a)

$$T = 20 + 273 = 293 \text{ K}$$

V_T = thermal voltage

$$= \frac{kT}{q} = \frac{1.38 \times 10^{-23} \times 293}{1.6 \times 10^{-19}}$$

$$= 25.27 \text{ mV}$$

5. (c)

$$J = n\,e\,v_d$$

Put, $v_d = \mu E$

$\therefore$ $J = n\,e\,\mu E$

Hence, $I = n\,e\,\mu\,EA$

So, I depends upon carrier concentration and electric field.

6. (b)

$$\sigma_n = nq\mu_n$$

$$\frac{\sigma_p}{\sigma_n} = \frac{\mu_p}{\mu_n} = \frac{1}{3}$$

7. (c)

The current density is given by

$$J = \sigma E = nq\,\mu_n\,E$$

$$= 10^{20} \times 1.6 \times 10^{-19} \times 800 \times 1$$

$$= 1.28 \times 10^4 \text{ A/cm}^2$$

$$\approx 1.3 \times 10^4 \text{ A/cm}^2 \approx 13 \text{ kA/cm}^2$$

8. (b)

For an n-type semi conductor

$$p_n = \frac{n_i^2}{N_D}$$

Where, p_n is the concentration of holes.

N_D is the concentration of donor atoms.

and n_i is the intrinsic concentration.

9. (a)

$\because$ depletion region predominantly in p-region that means diode is of type p–n⁺.

i.e. lesser the doping higher will depletion region on that side.

$\because$ depletion width $\propto \frac{1}{\text{Doping concentration}}$