CHAPTER 14

Semiconductor Electronics: Materials, Devices and Simple Circuits

CASE STUDY / PASSAGE BASED QUESTIONS

Questions 1-10 are Case Study based questions and are compulsory. Attempt any 4 sub parts from each question. Each question carries 1 mark.

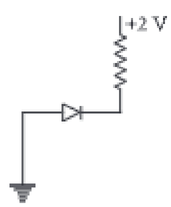
Syllabus
Energy bands in conductors, semiconductors and insulators (qualitative ideas only). Semiconductor diode - I-V characteristics in forward and reverse bias, diode as a rectifier; Special purpose p-n junction diodes: LED, photodiode, solar cell.

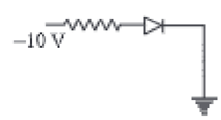
1

Biasing of Diode

When the diode is forward biased, it is found that beyond forward voltage $V = V_k$, called knee voltage, the conductivity is very high. At this value of battery biasing for *p-n* junction,the potential barrier is overcome and the current increases rapidly with increase in forward voltage.
When the diode is reverse biased, the reverse bias voltage produces a very small current about a few microamperes which almost remains constant with bias. This small current is reverse saturation current.

(i) In which of the following figures, the *p-n* diode is forward biased.

(a)


(b)


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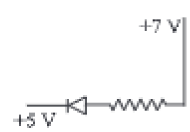

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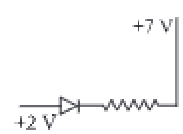
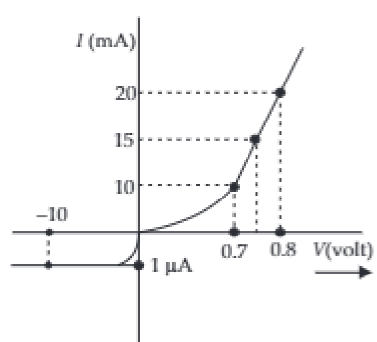


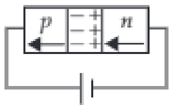
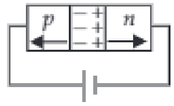
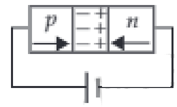
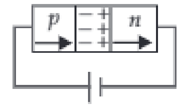
(ii) Based on the *V-I* characteristics of the diode, we can classify diode as
(a) bi-directional device
(b) ohmic device
(c) non-ohmic device
(d) passive element

(iii) The *V-I* characteristic of a diode is shown in the figure. The ratio of forward to reverse bias resistance is



(a) 100
(b) 10^6
(c) 10
(d) 10^{-6}

(iv) In the case of forward biasing of a p-n junction diode, which one of the following figures correctly depicts the direction of conventional current (indicated by an arrow mark)?

(a)  (b)  (c)  (d) 

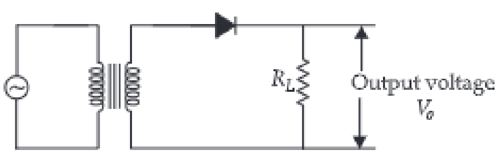
(v) If an ideal junction diode is connected as shown, then the value of the current I is

(a) 0.013 A (b) 0.02 A (c) 0.01 A (d) 0.1 A

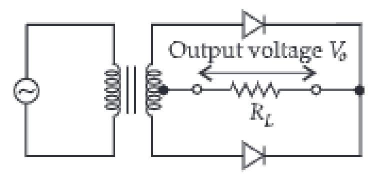
2

Rectifier

Rectifier is a device which is used for converting alternating current or voltage into direct current or voltage. Its working is based on the fact that the resistance of p-n junction becomes low when forward biased and becomes high when reverse biased. A half-wave rectifier uses only a single diode while a full wave rectifier uses two diodes as shown in figures (a) and (b).



(a) Half wave rectifier

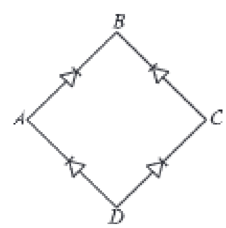


(b) Full wave rectifier

(i) If the rms value of sinusoidal input to a full wave rectifier is $\frac{V_0}{\sqrt{2}}$ then the rms value of the rectifier's output is

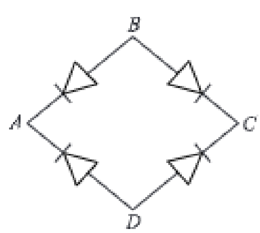
(a) $\frac{V_0}{\sqrt{2}}$ (b) $\frac{V_0^2}{\sqrt{2}}$ (c) $\frac{V_0^2}{2}$ (d) $\sqrt{2}\,V_0^2$

(ii) In the diagram, the input ac is across the terminals A and C. The output across B and D is



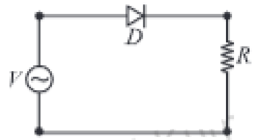
(a) same as the input (b) half wave rectified (c) zero (d) full wave rectified

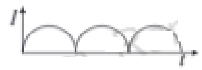
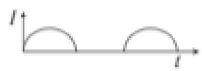
(iii) A bridge rectifier is shown in figure. Alternating input is given across A and C. If output is taken across BD, then it is



(a) zero (b) same as input (c) half wave rectified (d) full wave rectified

(iv) A p-n junction (D) shown in the figure can act as a rectifier. An alternating current source (V) is connected in the circuit. The current(I) in the resistor(R) can be shown by



(a) 
(b) 
(c) 
(d) 

(v) With an ac input from 50 Hz power line, the ripple frequency is

(a) 50 Hz in the dc output of half wave as well as full wave rectifier

(b) 100 Hz in the dc output of half wave as well as full wave rectifier

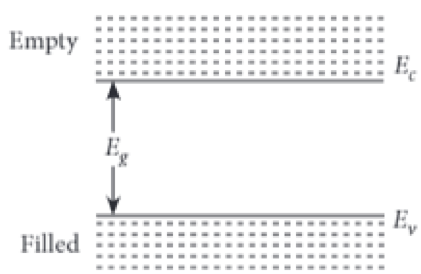
(c) 50 Hz in the dc output of half wave and 100 Hz in dc output of full wave rectifier

(d) 100 Hz in the dc output of half wave and 50 Hz in the dc output of full wave rectifier.

3

Energy Band Gap

From Bohr's atomic model, we know that the electrons have well defined energy levels in an isolated atom. But due to interatomic interactions in a crystal, the electrons of the outer shells are forced to have energies different from those in isolated atoms. Each energy level splits into a number of energy levels forming a continuous band. The gap between top of valence band and bottom of the conduction band in which no allowed energy levels for electrons can exist is called energy gap.



(i) In an insulator energy band gap is

(a) $E_g = 0$ (b) $E_g < 3$ eV (c) $E_g > 3$ eV (d) None of the above

(ii) In a semiconductor, separation between conduction and valence band is of the order of

(a) 0 eV (b) 1 eV (c) 10 eV (d) 50 eV

(iii) Based on the band theory of conductors, insulators and semiconductors, the forbidden gap is smallest in

(a) conductors (b) insulators (c) semiconductors (d) All of these

(iv) Carbon, silicon and germanium have four valence electrons each. At room temperature which one of the following statements is most appropriate ?

(a) The number of free electrons for conduction is significant only in Si and Ge but small in C.

(b) The number of free conduction electrons is significant in C but small in Si and Ge.

(c) The number of free conduction electrons is negligibly small in all the three.

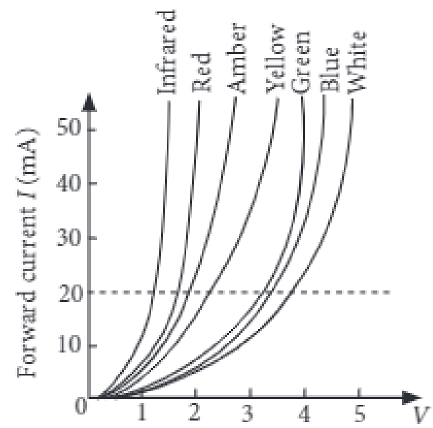
(d) The number of free electrons for conduction is significant in all the three.

(v) Solids having highest energy level partially filled with electrons are

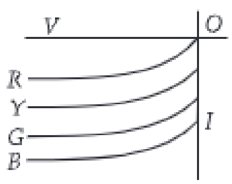
(a) semiconductor (b) conductor (c) insulator (d) none of these

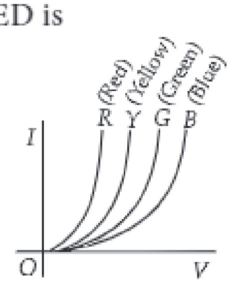
Light Emitting Diode (LED)

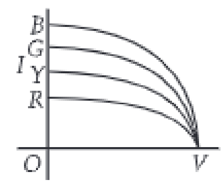
Light emitting diode is a photoelectric device which converts electrical energy into light energy. It is a heavily doped *p-n* junction diode which under forward biased emits spontaneous radiation. The general shape of the *I-V* characteristics of an LED is similar to that of a normal *p-n* junction diode, as shown. The barrier potentials are much higher and slightly different for each colour.

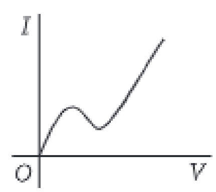


(i) The *I-V* characteristic of an LED is

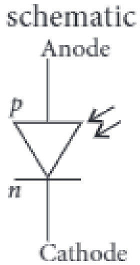
(a) 

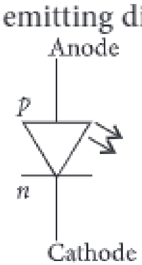
(b) 

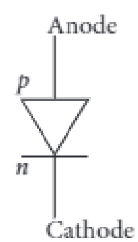
(c) 

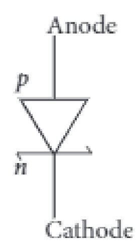
(d) 

(ii) The schematic symbol of light emitting diode is (LED)

(a) 

(b) 

(c) 

(d) 

(iii) An LED is constructed from a *p-n* junction based on a certain Ga-As-P semiconducting material whose energy gap is 1.9 eV. Identify the colour of the emitted light.

(a) Blue (b) Red (c) Violet (d) Green

(iv) Which one of the following statement is not correct in the case of light emitting diodes?

(a) It is a heavily doped *p-n* junction.
(b) It emits light only when it is forward biased.
(c) It emits light only when it is reverse biased.
(d) The energy of the light emitted is less than the energy gap of the semiconductor used.

(v) The energy of radiation emitted by LED is

(a) greater than the band gap of the semiconductor used
(b) always less than the band gap of the semiconductor used
(c) always equal to the band gap of the semiconductor used
(d) equal to or less than the band gap of the semiconductor used.

5

Photodiode

A photodiode is an optoelectronic device in which current carriers are generated by photons through photo-excitation *i.e.*, photo conduction by light. It is a *p-n* junction fabricated from a photosensitive semiconductor and provided with a transparent window so as allow light to fall on its function. A photodiode can turn its current ON and OFF in nanoseconds. So, it can be used as a fastest photo-detector.

(i) A *p-n* photodiode is fabricated from a semiconductor with a band gap of 2.5 eV. It can detect a signal of wavelength

(a) 4000 nm (b) 6000 nm (c) 4000 Å (d) 6000 Å

(ii) Three photo diodes D_1, D_2 and D_3 are made of semiconductors having band gap of 2.5 eV, 2 eV and 3 eV, respectively. Which one will be able to detect light of wavelength 6000 Å ?

(a) D_1 (b) D_2 (c) D_3 (d) D_1 and D_2 both

(iii) Photodiode is a device

(a) which is always operated in reverse bias
(b) which of always operated in forward bias
(c) in which photo current is independent of intensity of incident radiation
(d) which may be operated in forward or reverse bias.

(iv) To detect light of wavelength 500 nm, the photodiode must be fabricated from a semiconductor of minimum bandwidth of

(a) 1.24 eV (b) 0.62 eV (c) 2.48 eV (d) 3.2 eV

(v) Photodiode can be used as a photodetector to detect

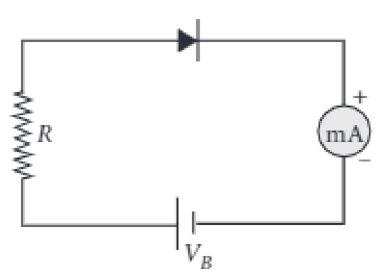
(a) optical signals (b) electrical signals (c) both (a) and (b) (d) none of these

6

p-n Junction Diode

A silicon *p-n* junction diode is connected to a resistor *R* and a battery of voltage V_B through milliammeter (mA) as shown in figure. The knee voltage for this junction diode is $V_N = 0.7$ V. The *p-n* junction diode requires a minimum current of 1 mA to attain a value higher than the knee point on the *I-V* characteristics of this junction diode. Assuming that the voltage *V* across the junction is independent of the current above the knee point.

A *p-n* junction is the basic building block of many semiconductor devices like diodes. Important process occurring during the formation of a *p-n* junction are diffusion and drift. In an *n*-type semiconductor concentration of electrons is more as compared to holes. In a *p*-type semiconductor concentration of holes is more as compared to electrons.



(i) If $V_B = 5$ V, the maximum value of R so that the voltage V is above the knee point voltage is
(a) 40 kΩ (b) 4.3 kΩ (c) 5.0 kΩ (d) 5.7 kΩ

(ii) If $V_B = 5$ V, the value of R in order to establish a current to 6 mA in the circuit is
(a) 833 Ω (b) 717 Ω (c) 950 Ω (d) 733 Ω

(iii) If $V_B = 6$ V, the power dissipated in the resistor R, when a current of 6 mA flows in the circuit is
(a) 30.2 mW (b) 30.8 mW (c) 31.2 mW (d) 31.8 mW

(iv) When the diode is reverse biased with a voltage of 6 V and $V_{bi} = 0.63$ V. Calculate the total potential.
(a) 9.27 V (b) 6.63 V (c) 5.27 V (d) 0.63 V

(v) Which of the below mentioned statement is false regarding a *p-n* junction diode?
(a) Diodes are uncontrolled devices. (b) Diodes are rectifying devices.
(c) Diodes are unidirectional devices. (d) Diodes have three terminals.

7

Electron Mobility

The electron mobility characterises how quickly an electron can move through a metal of semiconductor when pulled by an electric field. There is an analogous quality for holes, called hole mobility.
A block of pure silicon at 300 K has a length of 10 cm and an area of 1.0 cm^2. A battery of emf 2 V is connected across it. The mobility of electron is 0.14 m^2 V^{-1} s^{-1} and their number density is 1.5×10^{16} m^{-3}. The mobility of holes is 0.05 m^2 V^{-1} s^{-1}.

(i) The electron current is
(a) 6.72×10^{-4} A (b) 6.72×10^{-5} A (c) 6.72×10^{-6} A (d) 6.72×10^{-7} A

(ii) The hole current is
(a) 2.0×10^{-7} A (b) 2.2×10^{-7} A (c) 2.4×10^{-7} A (d) 2.6×10^{-7} A

(iii) The number density of donor atoms which are to be added up to pure silicon semiconductor to produce an *n*-type semiconductor of conductivity 6.4 Ω^{-1} cm^{-1} is approximately (neglect the contribution of holes to conductivity)
(a) 3×10^{22} m^{-3} (b) 3×10^{23} m^{-3} (c) 3×10^{24} m^{-3} (d) 3×10^{21} m^{-3}

(iv) When the given silicon semiconductor is doped with indium, the hole concentration increases to 4.5×10^{23} m^{-3}. The electron concentration in doped silicon is
(a) 3×10^9 m^{-3} (b) 4×10^9 m^{-3} (c) 5×10^9 m^{-3} (d) 6×10^9 m^{-3}

(v) Pick out the statement which is not correct.
(a) At a low temperature, the resistance of a semiconductor is very high.
(b) Movement of holes is restricted to the valence band only.
(c) Width of the depletion region increases as the forward bias voltage increases in case of a *p-n* junction diode.
(d) In a forward bias condition, the diode heavily conducts.

8

Doping in Semiconductor

p-n junction is a single crystal of Ge or Si doped in such a manner that one half portion of it acts as *p*-type semiconductor and other half functions as *n*-type semiconductor. As soon as a *p-n* junction is formed, the holes from the p-region diffuse into the n-region and electron from n region diffuse in to p-region. This results in the development of V_B across the junction which opposes the further diffusion of electrons and holes through the junction.

(i) In an unbiased p-n junction electrons diffuse from n-region to p-region because
- (a) holes in p-region attract them
- (b) electrons travel across the junction due to potential difference
- (c) electron concentration in n-region is more as compared to that in p-region
- (d) only electrons move from n to p region and not the *vice-versa*

(ii) Electron hole recombination in p-n junction may lead to emission of
- (a) light
- (b) ultraviolet rays
- (c) sound
- (d) radioactive rays

(iii) In an unbiased p-n junction
- (a) potential at p is equal to that at n
- (b) potential at p is +ve and that at n is –ve
- (c) potential at p is more than that at n
- (d) potential at p is less than that at n.

(iv) The potential of depletion layer is due to
- (a) electrons
- (b) holes
- (c) ions
- (d) forbidden band

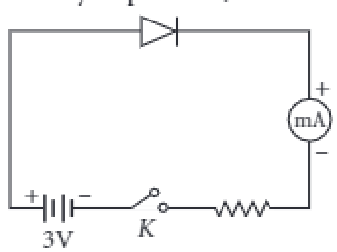
(v) In the depletion layer of unbiased p-n junction,
- (a) it is devoid of charge carriers
- (b) has only electrons
- (c) has only holes
- (d) p-n junction has a weak electric field.

9

Potential Barrier

The potential barrier in the p-n junction diode is the barrier in which the charge recquires additional force for crossing the region. In other words, the barrier in which the charge carrier stopped by the obstructive force is known as the potential barrier.

When a p-type semiconductor is brought into a close contact with n-type semiconductor, we get a p-n junction with a barrier potential 0.4 V and width of depletion region is 4.0×10^{-7} m. This p-n junction is forward biased with a battery of voltage 3V and negligible internal resistance, in series with a resistor of resistance R, ideal millimeter and key K as shown in figure. When key is pressed, a current of 20 mA passes through the diode.



(i) The intersity of the electric field in the depletion region when p-n junction is unbiased is
- (a) 0.5×10^6 V m^{-1}
- (b) 1.0×10^6 V m^{-1}
- (c) 2.0×10^6 V m^{-1}
- (d) 1.5×10^6 V m^{-1}

(ii) The resistance of resistor R is
- (a) 150 Ω
- (b) 300 Ω
- (c) 130 Ω
- (d) 180 Ω

(iii) In a p-n junction, the potential barrier is due to the charges on either side of the junction, these charges are
- (a) majority carriers
- (b) minority carriers
- (c) both (a) and (b)
- (d) fixed donor and acceptor ions.

(iv) If the voltage of the potential barrier is V_0. A voltage V is applied to the input, at what moment will the barrier disappear?

(a) $V < V_0$ (b) $V = V_0$ (c) $V > V_0$ (d) $V << V_0$

(v) If an electron with speed 4.0×10^5 m s^{-1} approaches the *p-n* junction from the *n*-side, the speed with which it will enter the *p*-side is

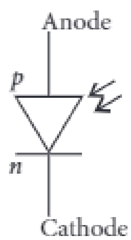
(a) 1.39×10^5 m s^{-1} (b) 2.78×10^5 m s^{-1} (c) 1.39×10^6 m s^{-1} (d) 2.78×10^6 m s^{-1}

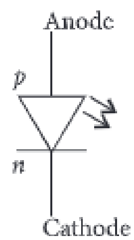
10

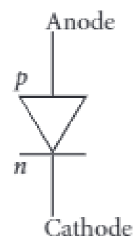
Solar Cell

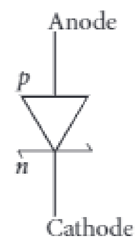
Solar cell is a *p-n* junction diode which converts solar energy into electric energy. It is basically a solar energy converter. The upper layer of solar cell is of *p*-type semiconductor and very thin so that the incident light photons may easily reach the *p-n* junction. On the top face of *p*-layer, the metal finger electrodes are prepared in order to have enough spacing between the fingers for the lights to reach the *p-n* junction through *p*-layer.

(i) The schematic symbol of solar cell is

(a) 

(b) 

(c) 

(d) 

(ii) The *p-n* junction which generates an emf when solar radiations fall an it, with no external bias applied, is a

(a) light emitting diode (b) photodiode (c) solar cell (d) None of these

(iii) For satellites the source of energy is

(a) Solar cell (b) Fuel cell (c) Edison cell (d) None of these

(iv) Which of the following material is used in solar cell?

(a) Barium (b) Silicon (c) Silver (d) Selenium

(v) The efficiency of a solar cell may be in the range

(a) 2 to 5% (b) 10 to 15% (c) 30 to 40% (d) 70 to 80%

ASSERTION & REASON

For question numbers 11-25, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is NOT the correct explanation of A

(c) A is true but R is false

(d) A is false and R is also false

11. Assertion (A) : The depletion layer in the *p-n* junction is free from mobile charge carriers.
Reason (R) : There is no electric field across the junction barrier.

12. Assertion (A) : Silicon is preferred over germanium for making semiconductor devices.
Reason (R) : The energy band for germanium is more than the energy band of silicon.

13. **Assertion (A) :** In a semiconductor diode, the reverse biased current is due to drift of free electrons and holes.
Reason (R) : The drift of electrons and holes is due to thermal excitations.

14. **Assertion (A) :** The resistance of *p*-*n* junction is low when forward biased and is high when reverse biased.
Reason (R) : In reversed biased, the depletion layer is reduced.

15. **Assertion (A) :** Light Emitting Diode (LED) emit spontaneous radiation.
Reason (R) : LED are forward-biased *p*-*n* junction.

16. **Assertion (A) :** The dominant mechanism for motion of charge carriers in forward and reverse biased silicon *p*-*n* junction are drift in both forward and reverse bias.
Reason (R) : In reverse biased, no current flow through the junction.

17. **Assertion (A) :** Diamond behaves like an insulator.
Reason (R) : There is a large energy gap between valence band and conduction band of diamond.

18. **Assertion (A) :** At absolute zero the conductivity of semiconductor is zero.
Reason (R) : In a semiconductor there are no free electrons at any temperature.

19. **Assertion (A) :** The probability of electrons to be found in the conduction band of an intrinsic semiconductor at a finite temperature decrease exponentially with increasing band gap.
Reason (R) : It will be more difficult for the electron to cross over the large band gap while going from valence band to conduction band.

20. **Assertion (A) :** At 0 K, Germanium is a superconductor.
Reason (R) : At 0 K, Germanium offers zero resistance.

21. **Assertion (A) :** The resistivity of a semiconductor increases with temperature.
Reason (R) : The atoms of a semiconductor vibrate with larger amplitude at higher temperatures thereby increasing its resistivity.

22. **Assertion (A) :** Diode lasers are used as optical sources in optical communication.
Reason (R) : Diode lasers consume less energy.

23. **Assertion (A) :** *V* - *I* characteristic of *p*-*n* diode is same as that of any other conductor.
Reason (R) : *p*-*n* diode behave as conductor at room temperature.

24. **Assertion (A) :** The half-wave rectifier work only for positive half cycle of ac.
Reason (R) : In half-wave rectifier only one diode is used.

25. **Assertion (A) :** The ratio of free electrons to holes in intrinsic semiconductor is greater than one.
Reason (R) : The electrons are lighter particles and holes are heavy particles.

HINTS & EXPLANATIONS

1. **(i) (c) :** The *p*-*n* diode is forward biased when *p*-side is at a higher potential than *n*-side.

(ii) (c)

(iii) (d) : Forward bias resistance,

$$R_1 = \frac{\Delta V}{\Delta I} = \frac{0.8-0.7}{(20-10)\times10^{-3}} = \frac{0.1}{10\times10^{-3}} = 10$$

Reverse bias resistance, $R_2 = \dfrac{10}{1\times10^{-6}} = 10^7$

Then, the ratio of forward to reverse bias resistance,

$$\frac{R_1}{R_2} = \frac{10}{10^7} = 10^{-6}$$

(iv) (d) : In *p*-region the direction of conventional current is same as flow of holes.
In *n*-region the direction of conventional current is opposite to the flow of electrons.

(v) (c) : In the given circuit the junction diode is forward biased and offers zero resistance.

$\therefore$ The current, $I = \frac{3\text{ V} - 1\text{ V}}{200\ \Omega} = \frac{2\text{ V}}{200\ \Omega} = 0.01\text{ A}$

2. (i) (a) : The rms value of the output voltage at the load resistance, $V_{rms} = \frac{V_0}{\sqrt{2}}$.

(ii) (d)

(iii) (a)

(iv) (c): The given circuit works as a half wave rectifier. In this circuit, we will get current through R when p-n junction is forward biased and no current when p-n junction is reverse biased. Thus the current (I) through resistor (R) will be shown in option (c).

(v) (c)

3. (i) (c) : In insulator, energy band gap is > 3 eV

(ii) (b) : In conductor, separation between conduction and valence bands is zero and in insulator, it is greater than 1 eV. Hence in semiconductor the separation between conduction and valence band is 1 eV.

(iii) (a): According to band theory the forbidden gap in conductors $E_g \approx 0$, in insulators $E_g > 3$ eV and in semiconductors $E_g < 3$ eV.

(iv) (a): The four valence electrons of C, Si and Ge lie respectively in the second, third and fourth orbit. Hence energy required to take out an electron from these atoms (*i.e.* ionisation energy E_g) will be least for Ge, followed by Si and highest for C. Hence, the number of free electrons for conduction in Ge and Si are significant but negligibly small for C.

(v) (b)

4. (i) (b): The I-V characteristics of an LED is similar to that of a Si junction diode. But the threshold voltages are much higher and slightly different for each colour.

(ii) (b)

(iii) (b) : As $E_g = \frac{hc}{\lambda}$ $\therefore$ $\lambda = \frac{hc}{E_g}$

Here, $E_g = 1.9$ eV, $hc = 1240$ eV nm

$\therefore$ $\lambda = \frac{1240\text{ eV nm}}{1.9\text{ eV}} = 652.6\text{ nm}$

Hence, the emitted light is of red colour.

(iv) (c): A light emitting diode is a heavily doped p-n junction diode which emits light only when it is forward biased.

(v) (d)

5. (i) (c) : $\lambda_{max} = \frac{hc}{E} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{2.5 \times 1.6 \times 10^{-19}}$
$= 5000$ Å

$\therefore$ $\lambda = 4000$ Å $< \lambda_{max}$

(ii) (b) : Energy of incident photon, $E = \frac{hc}{\lambda}$

$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{6 \times 10^{-7} \times 1.6 \times 10^{-19}} = 2.06$ eV

The incident radiation can be detected by a photodiode if energy of incident photon is greater than the band gap.

As $D_2 = 2$ eV, therefore D_2 will detect these radiations.

(iii) (a): Photodiode is a device which is always operated in reverse bias.

(iv) (c) : Let E_g be the required bandwidth. Then

$E_g = \frac{hc}{\lambda}$

Here, $hc = 1240$ eV nm, $\lambda = 500$ nm

$\therefore$ $E_g = \frac{1240\text{ eV nm}}{500\text{ nm}} = 2.48\text{ eV}$

(v) (a): A photodiode is a device which is used to detect optical signals.

6. (i) (b) : Voltage drop across R.

$V_R = V_B - V_N = 5 - 0.7 = 4.3$ V

Here, $I_{min} = 1 \times 10^{-3}$ A

$R_{max} = \frac{V_R}{I_{min}} = \frac{4.3}{1 \times 10^{-3}} = 4.3 \times 10^3\ \Omega = 4.3\ \text{k}\Omega$

(ii) (b) : $I = 6$ mA $= 6 \times 10^{-3}$ A;

$V_R = V_B - V_N = 5 - 0.7 = 4.3$ V

$R = \frac{V_R}{I} = \frac{4.3}{6 \times 10^{-3}} = 717\ \Omega$

(iii) (d) : Here, $V_B = 6$ V; $V_N = 0.7$ V,

$V_R = 6 - 0.7 = 5.3$ V

Power dissipated in $R = I \times V_R$

$= (6 \times 10^{-3}) \times 5.3 = 31.8 \times 10^{-3}$ W

$= 31.8$ mW

(iv) (b) : $V_t = V_{bi} + V_R = 0.63 + 6 = 6.63$ V

(v) **(d)** : Diode is two terminal device, anode and cathode are the two terminals.

7. (i) **(d)** : $E = \frac{V}{l} = \frac{2}{0.1} = 20$ V/m;

$A = 1.0\text{ cm}^2 = 1.0 \times 10^{-4}\text{ m}^2$
$v_e = \mu_e E = 0.14 \times 20 = 2.8\text{ m s}^{-1}$
$I_e = n_e A e v_e$
$= (1.5 \times 10^{16}) \times (1.0 \times 10^{-4}) \times (1.6 \times 10^{-19}) \times 2.8$
$= 6.72 \times 10^{-7}$ A

(ii) **(c)** : In a pure semiconductor,
$n_e = n_h = 1.5 \times 10^{16}\text{ m}^{-3}$
$v_h = \mu_h \times E = 0.05 \times 20 = 1.0\text{ ms}^{-1}$
$I_h = n_h A e v_h$
$= (1.5 \times 10^{16}) \times (1.0 \times 10^{-4}) \times (1.6 \times 10^{-19}) \times 1.0$
$= 2.4 \times 10^{-7}$ A

(iii) **(a)** : $\sigma = e n_e m_e$

or $n_e = \frac{\sigma}{e\mu_e} = \frac{6.4 \times 10^2}{(1.6 \times 10^{-19}) \times 0.14}$

$= 3.14 \times 10^{22} \approx 3 \times 10^{22}\text{ m}^{-3}$

(iv) **(c)** : $n_e = \frac{n_i^2}{n_h} = \frac{(1.5 \times 10^{16})^2}{4.5 \times 10^{22}} = 5 \times 10^9\text{ m}^{-3}$

(v) **(c)** : In case of a p-n junction diode, width of the depletion region decreases as the forward bias voltage increases.

8. (i) **(c)** : Electron concentration in n-region is more as compared to that in p-region. So electrons diffuse from n-side to p-side.

(ii) **(a)** : When an electron and a hole recombine, the energy is released in the form of light.

(iii) **(a)** : In an unbiased p-n junction, potential at p is equal to that at n.

(iv) **(c)** : The potential of depletion layer is due to ions.

(v) **(a)** : In the depletion layer of unbiased p-n, junction has no charge carriers.

9. (i) **(b)** : $E = \frac{V_B}{d} = \frac{0.4}{4.0 \times 10^{-7}} = 1.0 \times 10^6\text{ V m}^{-1}$

(ii) **(c)** : Potential difference across $= R = 3 - 0.4 = 2.6$ V

$$\text{Resistance } R = \frac{\text{Potential difference}}{\text{Current}}$$

$$= \frac{2.6}{20 \times 10^{-3}} = 130\ \Omega$$

(iii) **(d)**

(iv) **(b)** : When the voltage will be the same that of the potential barrier disappears resulting in flow of current.

(v) **(a)** : $\frac{1}{2} m v_1^2 = e V_B + \frac{1}{2} m v_2^2$

$$\Rightarrow \frac{1}{2} \times (9.1 \times 10^{-31}) \times (4 \times 10^5)^2$$
$$= 1.6 \times 10^{-19} \times (0.4) + \frac{1}{2} \times 9.1 \times 10^{-31} \times v_2^2$$

On solving, we get
$v_2 = 1.39 \times 10^5\text{ m s}^{-1}$

10. (i) **(a)**

(ii) **(c)**

(iii) **(a)** : Solar cells are the source of energy for satellites.

(iv) **(b)** : Silicon is used in solar cell.

(v) **(b)** : 10 to 15%.

11. **(c)** : Due to diffusion of holes from the p-region to the n-region and of electrons from the n-region to the p-region an electric field is set up across the junction barrier. Once the depletion layer is formed it is in equilibrium and becomes free of mobile charge carriers.

12. **(d)** : The energy gap for germanium is less (0.72 eV) than the energy gap of silicon (1.1 eV). Therefore, germanium is preferred over silicon for making semiconductor devices.

13. **(b)** : A reverse bias on a p-n junction opposes the movement of the majority charge carriers thus stopping the diffusion current. It makes the free electrons and holes to drift cross the junction. Therefore a small current in μA flows even when the p-n junction is reverse biased. The drift current is due to the thermal excitations of the electrons and holes.

14. **(c)** : A small increase in forward voltage across p-n junction shows large increase in forward current. Hence the resistance (= voltage / current) of p-n junction is low when forward biased. Also the width of depletion layer of p-n junction decreases in forward bias.
A large increase in reverse voltage across p-n shows small increase in reverse current. Hence the resistance of p-n junction is high when reverse biased. Also the width of the depletion layer of p-n junction increases in reverse biased.

15. (b) : In semiconductor there may be energy bands due to donor impurities (E_D) near the conduction band or acceptor impurities (E_A) near the valence band. When electron falls from higher to lower energy level containing holes, the energy is released in the form of radiation. The energy of radiation emitted by LED is equal or less than the band gap of the semiconductor used. The radiation released lies in range of visible light whose colour depends on the semiconductor used.

16. (d) : In *p-n* junction, the diffusion of majority carriers takes place when junction is forward biased and drifting of minority carriers takes place across the junction, when reverse biased. The reverse bias opposes the majority carriers but makes the minority carriers to cross the *p-n* junction. Thus the small current in μA flows during reverse bias.

17. (a): In insulator, the forbidden energy gap is quite large. When electric field is applied to such a solid, the electron find it difficult to acquire such a large amount of energy. Thus no electron flow occurs.

18. (c): In a semiconductor, there are no free electrons at 0 K. The number of free electrons increases with increase in temperature because with increase in temperature the electron get sufficient energy to cross forbidden band and reach conduction band. But total number of free electrons in a semiconductor is less than that in a conductor.

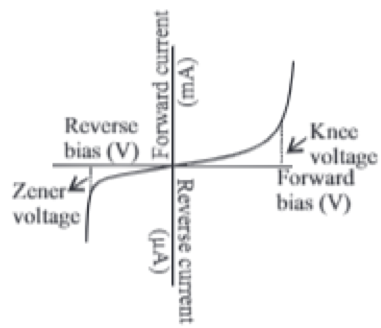
19. (a): For electron to jump from valence band to conduction band needs energy equal or more than the forbidden band between these two band. As the energy of band gap increases, it becomes difficult for electron to get that equivalent energy.

20. (d) : At 0 K, Germanium offers infinite resistance, and it behaves as an insulator.

21. (d) : With the increase of temperature, the average energy exchanged in a collision increases and so more valence electrons can cross the energy gap, thereby increasing the electron-hole pairs. As in a semiconductor, conduction occurs mainly through electron-hole pairs, so conductivity increases with increase of temperature. Which in turn implies that the resistivity of a semiconductor decreases with rise in temperature.

22. (a): In optical communication, a semiconductor bases laser (diode laser) is used to generate analog signals or digital pulses for transmission through optical fibres. The advantages of diode lasers are their small size and low power input.

23. (d) : The *V-I* characteristic of *p-n* diode depends whether the junction is forward biased or reverse biased. This can be showed by graph between voltage and current.



In the given graph knee voltage is a voltage at which forward bias becomes greater than the potential barrier, the forward current increases almost linearly, where as zener voltage is a voltage at which reverse current increases suddenly.

From this graph we can verify that *p-n* diode characteristics are very different from that of conductor which obey's Ohm's law.

24. (a): In half wave rectifier, the one diode is biased only when ac is in positive half of its cycle. For negative half of the ac cycle the diode is reversed biased and there is no output corresponding to that. Since for only one-half cycle we get a voltage output, because of which it is called half wave rectifier.

25. (b) : In intrinsic semiconductor $n_e/n_h = 1$ and holes are not particles but vacancies created due to breakage of covalent bond.