Chapter 14: Semiconductor Electronics: Materials, Devices and Simple Circuits

Exercises — Exercises

Q1 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.

SOLUTION

In n-type silicon, a pentavalent impurity (such as As, Sb, or P) is added to pure Si. Each pentavalent dopant atom has 5 valence electrons; 4 form covalent bonds with neighbouring Si atoms, and the 5th is very loosely bound and becomes a free electron with minimal energy.
This extra electron is donated to the conduction band, making electrons the majority carriers.
The remaining holes (minority carriers) are produced only by thermal generation (intrinsic).
Since the dopant supplies electrons, ne >> nh: electrons are majority carriers and holes are minority carriers.

Checking each option:
(a) Incorrect — dopants are pentavalent, not trivalent.
(b) Incorrect — electrons are majority, not minority, carriers.
(c) Correct — holes are minority carriers AND pentavalent atoms are the dopants.
(d) Incorrect — holes are the minority carriers in n-type material.

Answer: (c) Holes are minority carriers and pentavalent atoms are the dopants.

Q2 Which of the statements given in Exercise 14.1 is true for p-type semiconductors?

SOLUTION

In p-type silicon, a trivalent impurity (such as In, Al, or B) is added to pure Si.
Each trivalent dopant atom has 3 valence electrons; it forms covalent bonds with only 3 of its 4 neighbouring Si atoms, leaving one bond incomplete — a hole.
This hole is available for conduction, making holes the majority carriers.

Electrons are produced only by thermal (intrinsic) generation, so ne << nh: electrons are the minority carriers.
The dopant atoms are trivalent (acceptors), not pentavalent.

Checking the options from Exercise 14.1 applied to p-type:
(a) 'Electrons are majority carriers and trivalent atoms are the dopants' — incorrect (holes are the majority carriers).
(b) 'Electrons are minority carriers and pentavalent atoms are the dopants' — incorrect (dopants are trivalent in p-type).
(c) 'Holes are minority carriers and pentavalent atoms are the dopants' — incorrect (holes are majority carriers).
(d) 'Holes are majority carriers and trivalent atoms are the dopants' — CORRECT.

Answer: (d) Holes are majority carriers and trivalent atoms are the dopants.

Q3 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 (Eg)C, (Eg)Si and (Eg)Ge. Which of the following statements is true?
(a) (Eg)Si < (Eg)Ge < (Eg)C
(b) (Eg)C < (Eg)Ge > (Eg)Si
(c) (Eg)C > (Eg)Si > (Eg)Ge
(d) (Eg)C = (Eg)Si = (Eg)Ge

SOLUTION

The known band gap values are:
Carbon (diamond): Eg ≈ 5.4 eV
Silicon: Eg ≈ 1.1 eV
Germanium: Eg ≈ 0.7 eV

The bonding electrons of C, Si, and Ge are respectively in the 2nd, 3rd, and 4th orbits.
Electrons in inner orbits are more tightly bound to the nucleus. As the orbit number increases, electrons are farther from the nucleus and require less energy to break free.
Hence, the energy needed to transfer an electron from the valence band to the conduction band decreases from C to Si to Ge.

Comparing the values:

(Eg)C = 5.4 eV > (Eg)Si = 1.1 eV > (Eg)Ge = 0.7 eV

This matches option (c): (Eg)C > (Eg)Si > (Eg)Ge.

Answer: (c) (Eg)C > (Eg)Si > (Eg)Ge

Q4 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.

SOLUTION

Diffusion of charge carriers occurs due to a concentration gradient — carriers move from regions of higher concentration to regions of lower concentration.

In a p-n junction at equilibrium (no external bias):

— The p-region has a high concentration of holes; the n-region has a very low hole concentration.

— This concentration gradient drives holes to diffuse from the p-side to the n-side.

Examining each option:

(a) 'Free electrons in the n-region attract them' — Incorrect as the primary cause. Diffusion is driven by the concentration gradient, not electrostatic attraction from free electrons.

(b) 'They move across the junction by the potential difference' — Incorrect. The built-in potential difference actually opposes (not assists) further diffusion once equilibrium is established.

(c) 'Hole concentration in p-region is more as compared to n-region' — Correct. This concentration gradient is the direct cause of diffusion.

(d) 'All the above' — Incorrect, since (a) and (b) do not correctly describe the cause.

Answer: (c) hole concentration in p-region is more as compared to n-region.

Q5 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 the above.

SOLUTION

In a p-n junction under equilibrium, a built-in potential barrier V_0 exists across the depletion region (typically ~0.3 V for Ge and ~0.7 V for Si).

When forward bias is applied (p-side connected to positive terminal, n-side to negative terminal):
— The applied external voltage opposes the built-in barrier potential.
— The depletion region width decreases.
— The effective barrier height is reduced to (V_0 - V), where V is the applied forward voltage.

Examining each option:
(a) 'Raises the potential barrier' — Incorrect. Reverse bias raises the barrier; forward bias lowers it.
(b) 'Reduces the majority carrier current to zero' — Incorrect. Forward bias increases majority carrier current (diffusion current), it does not reduce it to zero.
(c) 'Lowers the potential barrier' — Correct. The applied forward voltage reduces the barrier height, allowing more majority carriers to cross the junction.
(d) 'None of the above' — Incorrect, since (c) is correct.

Answer: (c) lowers the potential barrier.

Q6 In half-wave rectification, what is the output frequency if the input frequency is 50 Hz. What is the output frequency of a full-wave rectifier for the same input frequency.

SOLUTION

Given: Input ac frequency f = 50 Hz

Half-wave rectifier:
A half-wave rectifier allows current to pass only during one half-cycle (say the positive half-cycle) of the input ac.
For every complete input cycle, there is exactly one output pulse.
Therefore, the output frequency equals the input frequency.

Output frequency (half-wave) = 50 Hz

Full-wave rectifier:

A full-wave rectifier (centre-tap or bridge type) allows current to flow in the same direction during BOTH half-cycles of the input ac.

For every complete input cycle (period T), the output has TWO pulses (one per half-cycle).

The time period of output = T/2, so the output frequency = 2 × input frequency.

Output frequency (full-wave) = 2 × 50 = 100 Hz

Answer: Half-wave rectifier output frequency = 50 Hz; Full-wave rectifier output frequency = 100 Hz.