Class 12 Physics · Chapter 14: Semiconductor Electronics: Materials, Devices and Simple Circuits

Scan for the free Class 12 Physics test

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

---

1. A hole in a silicon crystal is best described as [1]

(a) a free electron with its charge reversed by the lattice

(b) a positively charged silicon nucleus that moves through the lattice

(c) a vacancy in a covalent bond, behaving as a particle of effective charge +q

(d) an empty site from which a whole silicon atom has left the lattice

Answer: (c) When an electron breaks away from a bond, the vacancy it leaves has effective charge +q; bound electrons from neighbouring bonds filling it make the hole appear to move like a free positive particle. No atom or nucleus moves.

2. A pure (intrinsic) germanium crystal at room temperature has 2.4×10^{19} free electrons per cubic metre. The number of holes per cubic metre in it is [1]

(a) 2.4×10^{19}

(b) 5.8×10^{38}

(c) 4.8×10^{19}

(d) zero, since holes need a trivalent dopant

Answer: (a) In an intrinsic semiconductor every electron freed from a bond leaves one hole, so $n_e = n_h = n_i = 2.4 \times 10^{19}\ m^{-3}$. 5.8×10^{38} is n_i^2, not a concentration.

3. In an unbiased p-n junction, the depletion region contains [1]

(a) mobile holes on the n-side and mobile electrons on the p-side

(b) immobile ionised donors on the n-side and immobile ionised acceptors on the p-side

(c) immobile ionised acceptors on the n-side and immobile ionised donors on the p-side

(d) equal numbers of free electrons and holes on both sides

Answer: (b) Electrons diffusing out of the n-region leave positive donor ions behind; holes diffusing out of the p-region leave negative acceptor ions. These fixed ions, with no free carriers, form the depletion region.

4. To plot the reverse-bias characteristic of a silicon diode, the current should be measured with [1]

(a) a milliammeter, since the reverse current is large

(b) a microammeter, since the reverse current is of the order of microamperes

(c) an ammeter reading in amperes, since breakdown may occur

(d) a voltmeter in series with the diode

Answer: (b) The reverse current is a drift of minority carriers, only a few μA, so a microammeter is used; a milliammeter suits the forward current, which is in mA.

5. The forward current of a diode stays almost zero until about 0.2 V and then rises steeply. The diode is most likely made of [1]

(a) silicon

(b) germanium

(c) diamond (carbon)

(d) tin

Answer: (b) The threshold (cut-in) voltage is about 0.2 V for germanium and about 0.7 V for silicon. Tin is a metal (Eg = 0) and diamond an insulator, so neither forms such a diode.

Every question original, written from NCERT, checked by a second reviewer · photocopy freely for your class

6. A silicon diode rated for 50 mA is connected in forward bias directly across a 3.0 V cell, with no resistor in the circuit. What will happen to the diode, and why? [2]

Above the 0.7 V cut-in, the forward current rises steeply (exponentially) with voltage, so with 3.0 V across it and nothing to limit it, the current far exceeds the 50 mA rating. The junction overheats and the diode is destroyed. A series resistor is needed to keep the current below the rated value.

- current far exceeds the rated value, since it rises steeply beyond cut-in with nothing to limit it (1)
- junction is destroyed by overheating (1)

7. In a half-wave rectifier, why must the diode's reverse breakdown voltage be sufficiently higher than the peak of the ac voltage from the transformer? [2]

In the half-cycle when the diode is reverse biased it does not conduct, and the whole ac voltage of that half-cycle, up to its peak, appears across it. If the peak exceeded the breakdown voltage, the reverse current would rise sharply and the diode would conduct in the wrong half-cycle (and could be destroyed), spoiling the rectification.

- in the reverse half-cycle the full peak voltage appears across the diode (1)
- above breakdown it conducts sharply/is damaged, so rectification fails (1)

8. A silicon crystal contains N atoms. How many electron states are there in its valence band and in its conduction band, and how are they occupied at absolute zero? [2]

Each Si atom has 4 outer electrons, 4N in all, with 8N states available; at the crystal's spacing these split into a valence band of 4N states and a conduction band of 4N states. At 0 K the 4N electrons fill the valence band completely and the conduction band is completely empty.

- 4N states in each band (8N in all) (1)
- at 0 K valence band completely filled by 4N electrons, conduction band empty (1)

9. An electric field is applied along a bar of intrinsic silicon, from end X (higher potential) to end Y. (a) In which direction do the free electrons and the holes move? (b) Explain how a hole moves when no particle of positive charge actually travels, and why the two currents add. [3]

(a) Free electrons move against the field, towards X; holes move towards the negative potential, towards Y. (b) An electron from a neighbouring bond jumps into a hole, leaving a hole at its own site; repeated, the hole appears to move. This is a description of bound electrons' motion; the free electron moves independently. Electrons moving towards X and holes towards Y both carry conventional current from X to Y, so $I = I_e + I_h$.

- electrons towards X (higher potential), holes towards Y (1)
- hole moves as bound electrons jump into vacancies, leaving vacancies behind (1)
- both give conventional current in the same direction, so $I = I_e + I_h$ (1)

10. Boron is added to silicon. (a) Explain why each boron atom produces one hole and becomes a negative ion. (b) Where does the acceptor level E_A lie in the band diagram? (c) The crystal has far more holes than electrons. Why is it still electrically neutral? [3]

(a) Boron is trivalent: it bonds with three Si neighbours, leaving a vacancy (hole) in the bond with the fourth. When an electron from a neighbouring Si atom fills it, boron has shared a fourth electron and becomes effectively a negative ion, and the hole moves to the neighbour's site: one acceptor, one hole. (b) Slightly above the top of the valence band E_V; a very small energy lets a valence electron jump to E_A. (c) The extra holes' total positive charge is equal and opposite to the charge of the ionised acceptor cores.

- three bonds, one vacancy; filling it makes B a negative ion and gives one hole (1)
- E_A slightly above E_V (1)
- extra holes' charge balanced by ionised acceptor cores (1)

11. A thin p-type silicon wafer has part of it converted into n-type. Explain how the diffusion and drift currents across the junction change as the junction forms, and why the final net current is zero. [3]

Holes are more concentrated in p and electrons in n, so holes diffuse p → n and electrons n → p: a diffusion current, large at first. Each carrier that leaves exposes an immobile ion, building positive space charge on the n-side and negative on the p-side; this sets up a field from n to p, which drives minority carriers back across: a drift current, opposite to the diffusion current, small at first. As more charge is exposed the field and the drift current grow while diffusion slows, until diffusion current equals drift current, and the junction is in equilibrium with no net current.

- diffusion of holes p → n and electrons n → p due to the concentration gradient; large at first (1)
- exposed ions set up a field n → p, giving a drift current opposite to diffusion that grows with the space charge (1)
- equilibrium when diffusion current = drift current, so net current is zero (1)