4 Semiconductor Diodes

4.1 INTRODUCTION

The PN junction diode is one of the semiconductor devices with two semiconductor materials in physical contact, one with excess of holes (P-type) and other with excess of electrons (N-type). A PN junction diode may be found from a single-crystal intrinsic semiconductor by doping part of it with acceptor impurities and the remainder with donors. Such junctions can form the basis of very efficient rectifiers. The most important characteristic of a PN junction is its ability to allow the flow of current in only one direction. In the opposite direction, it offers very high resistance. The high-vacuum diode has largely been replaced by silicon and selenium rectifiers. Semiconductor diodes find wide applications in all phases of electronics, viz. radio and TV, optoelectronics, power supplies, industrial electronics, instrumentation, computers, etc.

4.2 CLASSIFICATION OF SEMICONDUCTORS

Semiconductors are classified as (i) intrinsic (pure) and (ii) extrinsic (impure) types. The extrinsic semiconductors are of N-type and P-type.

Intrinsic semiconductor A pure semiconductor is called intrinsic semiconductor. As already explained in the first chapter, even at the room temperature, some of the valence electrons may acquire sufficient energy to enter the conduction band to form free electrons. Under the influence of electric field, these electrons constitute electric current. A missing electron in the valence band leaves a vacant space there, which is known as a *hole*, as shown in Fig. 4.1. Holes also contribute to electric current.

In an intrinsic semiconductor, even at room temperature, electron-hole pairs are created. When electric field is applied across an intrinsic semiconductor, the current conduction takes place by two processes, namely, free electrons and holes. Under the influence of electric field, total current through the semiconductor is the sum of currents due to free electrons and holes.

Though the total current inside the semiconductor is due to free electrons and holes, the current in the external wire is fully by electrons. In Fig. 4.2, holes being positively charged move towards the negative terminal of the battery. As the holes reach the negative terminal of the battery, electrons enter the semiconductor near

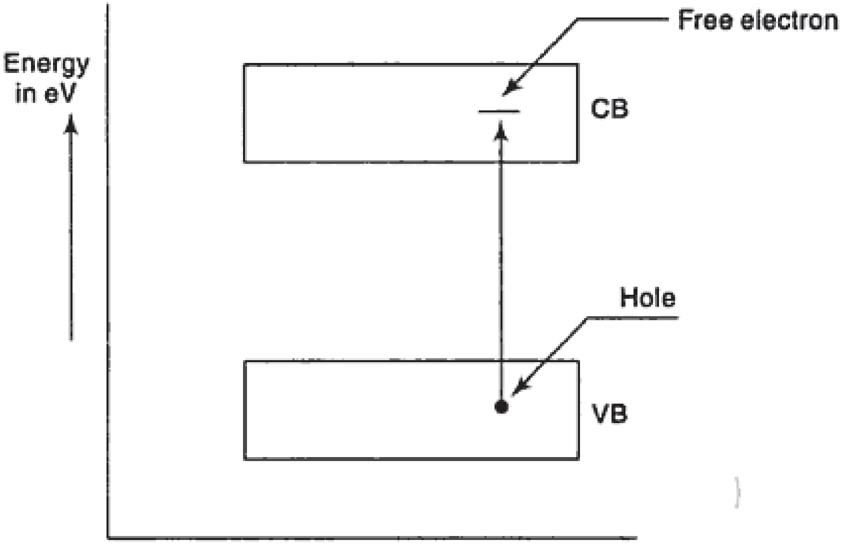


Fig. 4.1 Creation of electron-hole pair in a semiconductor

the terminal (X) and combine with the holes. At the same time, the loosely held electrons near the positive terminal (Y) are attracted away from their atoms into the positive terminal. This creates new holes near the positive terminal which again drift towards the negative terminal.

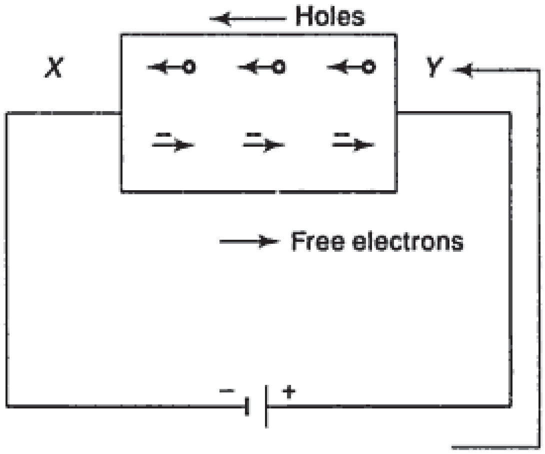


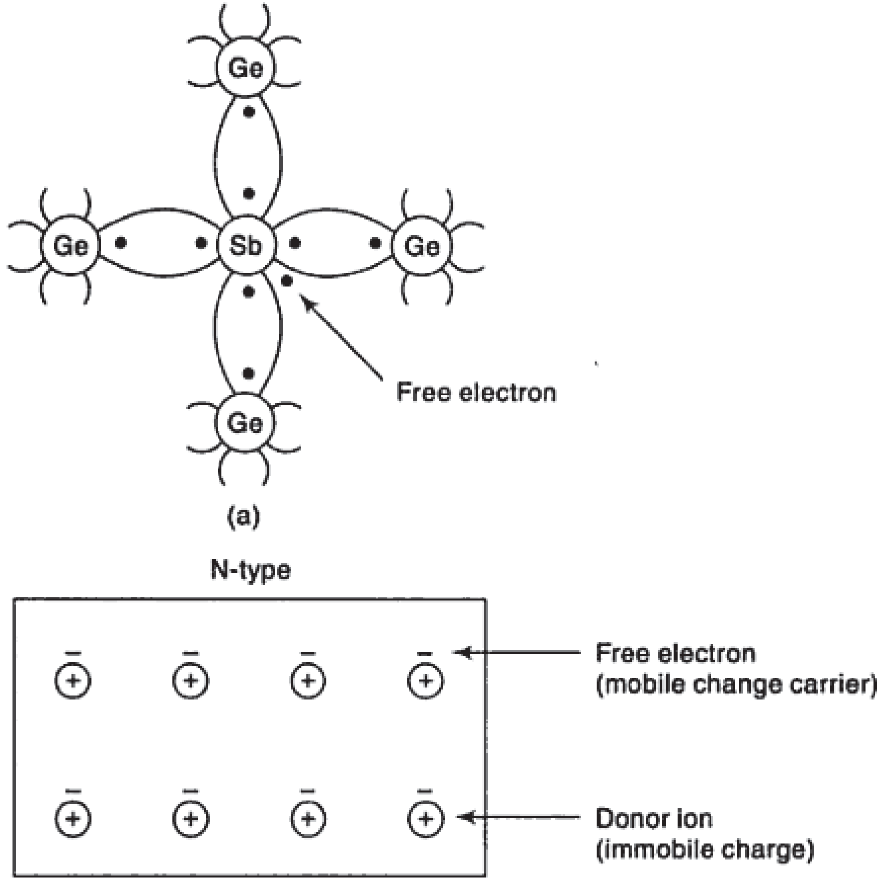
Fig. 4.2 Current conduction in semiconductor

Extrinsic semiconductor Due to the poor conduction at room temperature, the intrinsic seconductor as such, is not useful in the electronic devices. Hence, the current conduction capability of the intrinsic semiconductor should be increased. This can be achieved by adding a small amount of impurity to the intrinsic semiconductor, so that it becomes impure or extrinsic semiconductor. This process of adding impurity is known as *doping*.

The amount of impurity added is extremely small, say 1 to 2 atoms of impurity for 10^6 intrinsic atoms.

N-type semiconductor A small amount of pentavalent impurities such as arsenic, antimony or phosphorus is added to the pure semiconductor (germanium or silicon crystal) to get N-type semiconductor.

Germanium atom has four valence electrons and antimony has five valence electrons. As shown in Fig. 4.3, each antimony atom forms a covalent bond with surrounding four germanium atoms. Thus, four valence electrons of antimony atom form covalent bond with four valence electrons of individual germanium atom and fifth valence electron is left free which is loosely bound to the antimony atom.



(b)

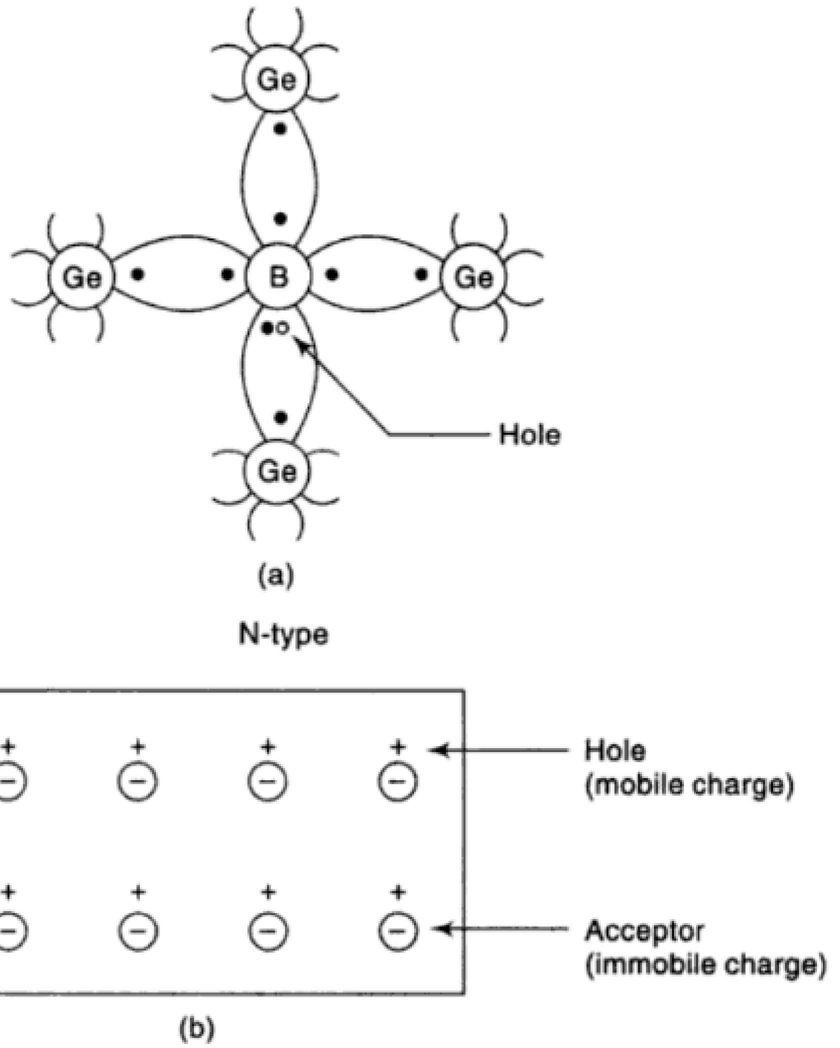
Fig. 4.3 N-type semiconductor: (a) Formation of covalent bonds, and (b) Charged carriers

This loosely bound electron can be easily excited from the valence band to the conduction band by the application of electric field or increasing the thermal energy. Thus every antimony atom contributes one conduction electron without creating a hole. Such pentavalent impurities are called donor impurities because it donates one electron for conduction. On giving an electron for conduction, the donor atom becomes positively charged ion because it loses one electron. But it cannot take part in conduction because it is firmly fixed in the crystal lattice.

Thus, the addition of pentavalent impurity (antimony) increases the number of electrons in the conduction band thereby increasing the conductivity of N-type semiconductor. As a result of doping, the number of free electrons far exceeds the number of holes in an N-type semiconductor. So electrons are called majority carriers and holes are called minority carriers.

P-type semiconductor A small amount of trivalent impurities such as aluminium or boron is added to the pure semiconductor to get the *p*-type semiconductor.

Germanium (Ge) atom has four valence electrons and boron has three valence electrons as shown in Fig. 4.4. Three valence electrons in boron form covalent bond with four surrounding atoms of Ge leaving one bond incomplete which gives rise to a hole. Thus trivalent impurity (boron) when added to the intrinsic semiconductor (germanium) introduces a large number of holes in the valence band. These positively charged holes increase the conductivity of P-type semiconductor. Trivalent impurities such as boron is called acceptor impurity because it accepts free electrons in the place of holes. As each boron atom donates a hole for conduction, it becomes a negatively charged ion. As the number of holes is very much greater than the number of free electrons in a P-type material, holes are termed as majority carriers and electrons as minority carriers.



(a)

N-type

(b)

Fig. 4.4 P-type semiconductor: (a) Formation of covalent bonds, and (b) Charged carriers.