VOLUME-15 Part B and C

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VI. Electronics

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1. Semiconductor

1.1 Introduction

Certain substance like germanium, silicon, carbon etc. are neither good conductors like copper nor insulators like glass. In other words, the resistivity of these materials lies in between conductors and insulators. Such substances are classified as semiconductors. Semiconductors have some useful properties and are being extensively used in electronic circuits. For instance, transistor– a semiconductor device is fast replacing bulky vacuum tubes in almost all applications. Transistors are only one of the family of semiconductor devices; many other semiconductor devices are becoming increasingly popular.

It is not easy to define a semiconductor if we want to take into account all its physical characteristics. However, generally, a semiconductor is defined on the basis of electrical conductivity as under:

A **semiconductor** is a substance which has resistivity (10^{-4} to 0.5 Ωm) in between conductors and insulator e.g. germanium, silicon, selenium, carbon etc. The reader may wonder, when a semiconductor is neither a good conductor nor an insulator, then why not to classify it as a resistance material? The answer shall be readily available if we study the following table:

S. No.	**Substance**	**Nature**	**Resistivity**
1	Copper	Good conductor	$1.7\times10^{-8}\ \Omega m$
2	Germanium	Semiconductor	$0.6\ \Omega m$
3	Glass	Insulator	$9\times10^{11}\ \Omega m$
4	Nichrome	Resistance material	$10^{-4}\ \Omega m$

Comparing the resistivities of above materials, it is apparent that the resistivity of germanium (semiconductor) is quite high as compared to copper (conductor) but it is quite low when compared with glass (insulator). This shows that resistivity of a semiconductor lies in between conductors and insulators. However, it will be wrong to consider the semiconductor as a resistance material. For example, nichrome, which is one of the highest resistance material, has resistance much lower than germanium. This shows that electrically germanium cannot be regarded as a conductor or insulator of a resistance material. This gave such substances like germanium the name of semiconductors.

It is interesting to note that it is not the resistivity along that decides whether a substance is semiconductor or not. For example, it is just possible to prepare an alloy whose resistivity falls within the range of semiconductors but the alloy cannot be regarded as a semiconductor. In fact, semiconductors have a number of peculiar properties which distinguish them from conductors, insulators and resistance materials.

Properties of semiconductors

(i) The resistivity of a semiconductor is less than an insulator but more than a conductor.

(ii) Semiconductors have negative temperature co efficient of resistance i.e. the resistance of a semiconductor decreases with the increases in temperature and vice versa. For example, germanium is actually an insulator at low temperatures but it becomes a good conductor at high temperatures.

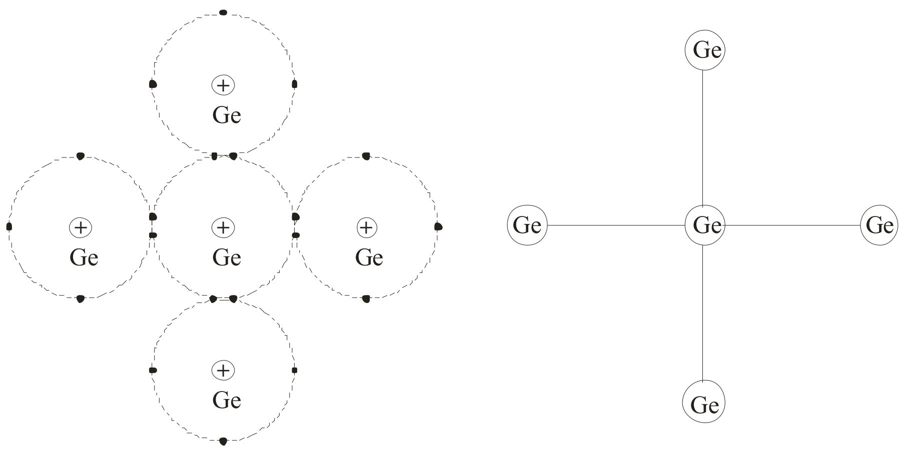
(iii) When a suitable metallic impurity (e.g. arsenic. Gallium etc.) is added to a semiconductors, its current conducting properties change appreciably. This property is most important and is discussed later in detail.

1.2 Bonds in Semiconductors

The atoms of every element are held together by the bonding action of valence electros. This bonding is due to the fact that it is the tendency of each atom to complete its last orbit by acquiring 8 electrons in it. However, in most of the substances, the last orbit is incomplete i.e. the last orbit does not have 8 electrons. This makes the atom active to enter into bargain with other atoms to acquire 8 electrons in the last orbit. To do so, the atom may lose, gain or share valence electrons with other atoms. In semiconductors, bonds are formed by sharing of valence electrons. Such bonds are called co-valent bonds. In the formation of co-valent bond, each atom contributes equal number of valence electrons and the contributed electrons are shared by the atoms engaged in the formation of the bond.

Figure (1) shows the co-valent bonds among germanium atoms. A germanium atom has 4 valence electrons. It is the tendency of each germanium atom to have 8 electrons in the orbit. To do so, each germanium atom positions itself between four other germanium atoms as shown in

Fig.1 (a). Each neighbouring atom shares one valence electron with the central atom. In this business of sharing, the central atom completes its last orbit by having 8 electrons revolving around the nucleus. In this way, the central atom sets up co-valent bonds. Fig. 1 (b) shows the bonding diagram.



[a] Covalent Bonds Among Ge ATOMS   [b] Bonding Diagram

Figure 1

The following points may be noted regarding the co-valent bonds:

(i) Covalent bonds are formed by sharing of valence electrons.

(ii) In the formation of covalent bond, each valence of an adjacent atom. In other words, valence electrons are associated with particular atoms. For this reason, valence electrons in a semiconductor are not free.

1.3 Crystals

A substance in which the atoms or molecules are arranged in an orderly pattern is known as a crystal. All semi-conductors have crystalline structure. For example, referring to Figure (1), it is clear that each atom is surrounded by neighbouring atoms in a repetitive manner. Therefore, a piece of germanium is generally called germanium crystal.

1.4 Commonly Used Semiconductors

There are many semiconductors available, but very few of them have a practical application in electronics. The two most frequently used materials are germanium (Ge) and silicon (Si). It is because the energy required to break their co-valent bonds (i.e. energy required to release an electron from their valence bands) is very small, being about 0.7 eV for germanium and about 1.1 eV for silicon. Therefore, we shall discuss these two semiconductors in detail.

(i) Germanium: Germanium has become the model substance among the semiconductors; the main reason being that it can be purified relatively well and crystallized easily. Germanium is an earth element and was discovered in 1886. It is recovered from the ash of certain coals or from the flue dust of zinc smelters. Generally, record germanium is in the form of germanium dioxide powder which is then reduced to pure germanium

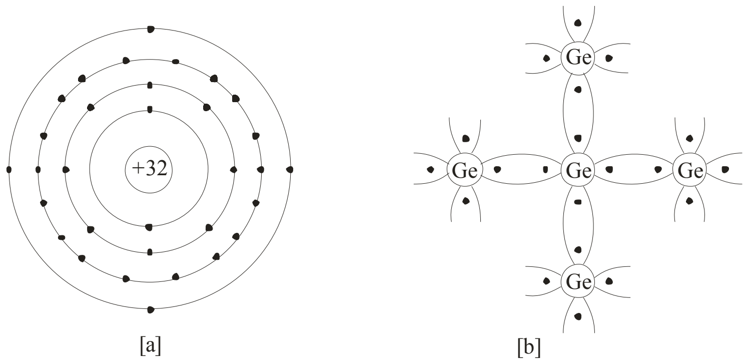


Figure 2

The atomic number of germanium is 32. Therefore, it has 32 protons and 32 electrons. Two electrons are in the first orbit, eight electrons in the second, eighteen electrons in the third and four electrons in the outer or valence orbit [See Fig. 2 (a)]. It is clear that germanium atom has four valence electrons i.e., it is a tetravalent element. Fig. 2 (b) shows how the various germanium atoms are held through co-valent bonds. As the atoms are arranged in an orderly pattern, therefore, germanium has crystalline structure.

(ii) Silicon: Silicon is an element in most of the common rocks. Actually, sand is silicon dioxide. The silicon compounds are chemically reduced to silicon which is 1000% pure for use as a semiconductor.

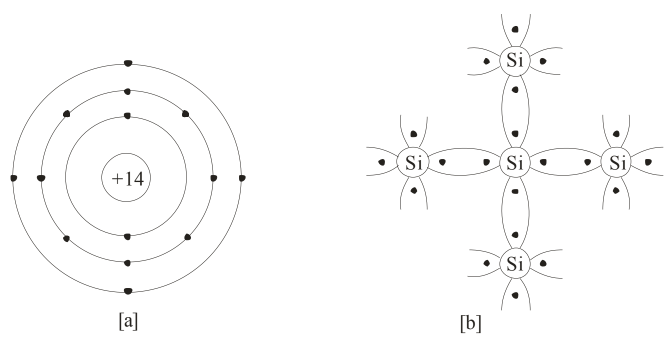


Figure 3

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