Concept of Semiconductor

Semiconductor Material:

We are familiar with conducting and insulating materials. Conducting materials (such as silver, copper, aluminium etc.) are good conductors of electricity and are characterized by a large electrical conductivity and small electrical resistivity. Insulating materials (such as porcelain, glass, quartz, rubber, bakelite etc.) are characterized by poor electrical conductivity and are used to block current from flowing where it is not to pass. There is another group of materials (such as germanium, silicon, boron, selenium) which are neither good conductors nor good insulators. At room temperature such materials have conductivities considerably lower than those of conductors and much higher than those of insulators. Such materials are called the semiconductors. The resistivity of various semiconductor materials lies in a very wide range from 10-4 to about 0.5 Ω-m whereas the resistivities of conductors and insulators are of the order of 10-8 Ω-m and 1012 Ω -m respectively. An even more important property of semiconductors is that their resistance depends largely on various factors and therefore, it can be controlled.

The resistance of conducting materials except that of carbon, increases with the increase in temperature and resistance of insulating materials remains almost constant up to a certain temperature after which it suddenly falls off and insulating materials start conducting. Semiconductors behave in somewhat different way. The resistance of semiconductors decreases with the increase in temperature, i.e., temperature coefficient of resistance of semiconductors is negative. Thus, the semiconductors behave like insulators at very low temperatures but act as conductors at high temperatures.

Elemental semiconductor material:

Electronic Configuration: The electronic configuration of these elements is indicated in Table 1.The given configurations show that these elements have four electrons in their valence shell, two of which are in s-orbital while the remaining two are in p-orbital. Hence these elements possess $s^2 p^2$ configuration in the valence shell.

Element	*Atomic Number*	*Electronic Configuration*
Carbon (C)	6	$1s^2\ 2s^2\ 2p^2$
Silicon (Si)	14	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$
Germanium (Ge)	32	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^2$
Tin (Sn)	50	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^6\ 4d^{10}\ 5s^2\ 5p^2$
Lead (Pb)	82	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^6\ 4d^{10}\ 4f^{14}\ 5s^2\ 5p^6\ 5d^{10}\ 6s^2\ 6p^2$

COMPOUND SEMICONDUCTOR MATERIALS:

Most of the compound semiconductor materials are formed from the combinations of group III and group V elements. A portion of the periodic table listing the more common semiconductors is given in Table 2. A list of some semiconductor materials is given in Table 3.

TABLE 2. A Portion of Periodic Table

III	*IV*	*V*
B	C	
Al	Si	P
Ga	Ge	As
In		Sb

TABLE 3. List of Some Semiconductor Materials

Elemental Semiconductors	Silicon Si
	Germanium Ge
Compound Semiconductors	Aluminium phosphide AIP
	Aluminium arsenide AIAs
	Gallium phosphide GaP
	Gallium arsenide GaAs
	Indium phosphide InP

Two element compounds are called the binary compounds where as three element compounds are called ternary compounds. The wide variety of electronic and optical properties of semiconductors enable greater flexibility in the design of electronic and optoelectronic functions.

Compounds are widely employed in high-speed devices and devices requiring the emission or absorption of light. The two element (binary) III-V compounds such as gallium nitride (GaN), gallium phosphide (GaP) and gallium arsenide (GaAs) are commonly used in light-emitting diodes (LEDs). Ternary compounds such as GaAsP and quarternary (four element) compounds like InGaAsP can be grown to give added flexibility.

ENERGY BANDS

Energy Levels of Isolated Atoms:

For an isolated atom, the electrons can have discrete energy levels. We now consider two identical atoms. When they are far apart, the allowed energy levels for a given principal quantum number (e.g., n = 1) consist of one doubly degenerate level, that is, both atoms have exactly the same energy. When they are brought closer, the doubly degenerate energy levels will split into two levels by the interaction between the atoms. As N isolated atoms are brought together to form a solid, the orbits of the outer electrons of different atoms overlap and interact with each other. This interaction, including those forces of attraction and repulsion between atoms, causes a shift in the energy levels, as in the case of two interacting atoms. However, instead of two levels, N separate but closely spaced levels are formed. When N is large, the result is an essentially continuous band of energy. This band of N levels can extend over a few eV depending on the inter-atomic spacing for the crystal.

The actual band splitting in a semiconductor is much more complicated. In Figure 1 shows an

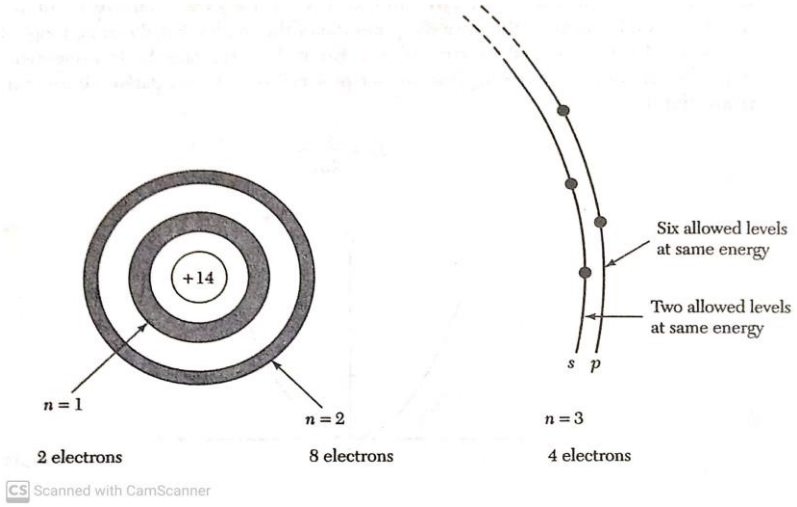

Fig.1: isolated silicon atom

isolated silicon atom that has 14 electrons. Of the 14 electrons, 10 occupy deeplying energy levels whose orbital radius is much smaller than the interatomic separation in the crystal. The four remaining valence electrons are relatively weakly bound and can be involved in chemical reactions. Therefore, we only need to consider the outer shell (the n = 3 level) for the valence electrons, since the two inner shells are completely full and tightly bound to the nucleus. The 3s subshell (i.e., for n = 3 and l = 0) has two allowed quantum states per atom. This subshell will contain two valence electrons at T = 0 K. The 3p subshell (i.e., n = 3, and l = 1) has six allowed quantum states per atom. This subshell will contain the remaining two valence electrons of an individual silicon atom.

Figure 2 is a schematic diagram of the formation of a silicon crystal from N isolated silicon atoms.

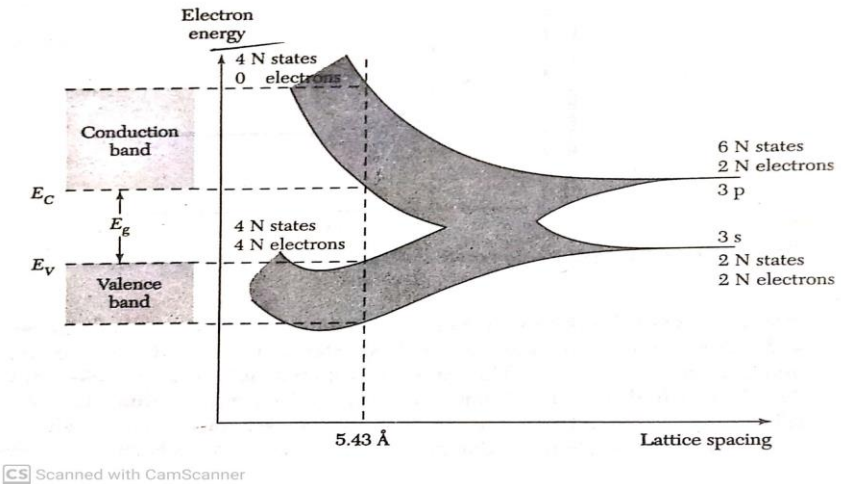

Fig. 2. Formation of energy bands

As the interatomic distance decreases, the 3s and 3p subshell of the N silicon atoms will interact and overlap. At the equilibrium interatomic distance, the bands will again split, with four quantum states per atom in the lower band and four quantum states per atom in the upper band. At a temperature of absolute zero, electrons occupy the lowest energy states, so that all states in the lower band (the valence band) will be full and all states in the upper band (the conduction band) will be empty. The bottom of the conduction band is called Ec, and the top of the valence band is called Ev. The bandgap energy Eg between the bottom of the conduction band and the top of the valence band (Ec-Ey) is the width of the forbidden energy gap, as shown on the far left of Fig. 2. Physically, Eg, is the energy required to break a bond in the semiconductor to free an electron to the conduction band and leave a hole in the valence band.