3.10. INSULATORS, METALS AND SEMICONDUCTORS ON THE BASIS OF BAND GAP

(U.P. Tech. Tutorial Question Bank, First Semester (C.O.), 2003-04) (05 marks)

For any given material, the forbidden energy-gap may be large, small or non-existent. Thus, the difference between insulators, metals and semiconductors is largely concerned with the relative widths of the forbidden energy gaps. In this article, we shall discuss the electrical properties of insulators, metals and semiconductors on the basis of band gap or forbidden energy gap.

3.10.1. Insulators

(U.P. Tech Sem. Exam. 2005-06) (03 marks)

In case of insulators, there is generally no electron in the conduction band and the valence band is filled.* Figure 3.7(*a*) shows the energy band diagram of insulators. It may be observed from energy band diagram that there is a wide gap between valence and conduction bands (forbidden energy gap). It is generally 5 eV or more. Due to this wide gap, it is almost impossible for an electron to cross the gap to go from valence band to conduction band. At room temperature, the valence electrons of an insulator can not have so much energy that it is able to jump to the conduction band. Due to this fact, the insulators are not able to conduct electric current. This means that the insulators have very high resistivity or extremely low conductivity at room temperature. But an insulator may conduct if its temperature is very high or if a very high voltage is applied across it. This is also known as the **breakdown** of the insulators.

3.10.2. Metals or Conductors

(U.P.Tech., Sem. Exam., 2005-06) (03 marks)

Figure 3.7(*b*) shows the energy band diagram of metals. It may be observed that forbidden energy gap or energy gap between valence and conduction bands is zero. In fact, the valence and conduction bands overlap each other. In a metal, the valence band energies and conduction band energies are same. The orbits in the conduction band are very large. An electron in the conduction band experiences almost negligible nuclear attraction. Hence it is very easy for a valence band electron to become a conduction band electron. It means that a metal consists of a large number of free electrons without supplying any external energy. Because of this fact, a metal works as a very good conductor.

3.10.3. Semiconductors

Figure 3.7(*c*) shows the energy band diagram of a semiconductor. It may be observed that forbidden energy gap E_G is not very wide for semiconductors. It is 0.72 eV for germanium and 1.12 eV for silicon. At 0 K,** the semiconductors behave as insulators because there is no free electron to conduct in the conduction band. However, in semiconductor, an electron can be lifted from the valence band to the conduction band by imparting some amount of energy to it. This energy must be more than energy gap E_G. If the energy imparted to the electron is less than E_G, it cannot be lifted from valence band to conduction band since no permissible energy levels exist between the two bands. Room temperature provides the sufficient amount of energy to lift electrons from the valence band to the conduction band. Some electrons jump to conduction band. Hence at room temperature, semiconductors are able to conduct some electric current. If

DO YOU KNOW?

Another common semiconductor element is carbon (C), which is used mainly in the production of resistors.

* Valence band filled implies that all the permissible energy levels in this band are occupied by the electrons.

** At a temperature of absolute zero (–273°C).

temperature is further raised above room temperature, more and more valence electrons acquire energy and cross the energy to go to conduction band. Hence semiconductors have negative temperature coefficient of resistance.

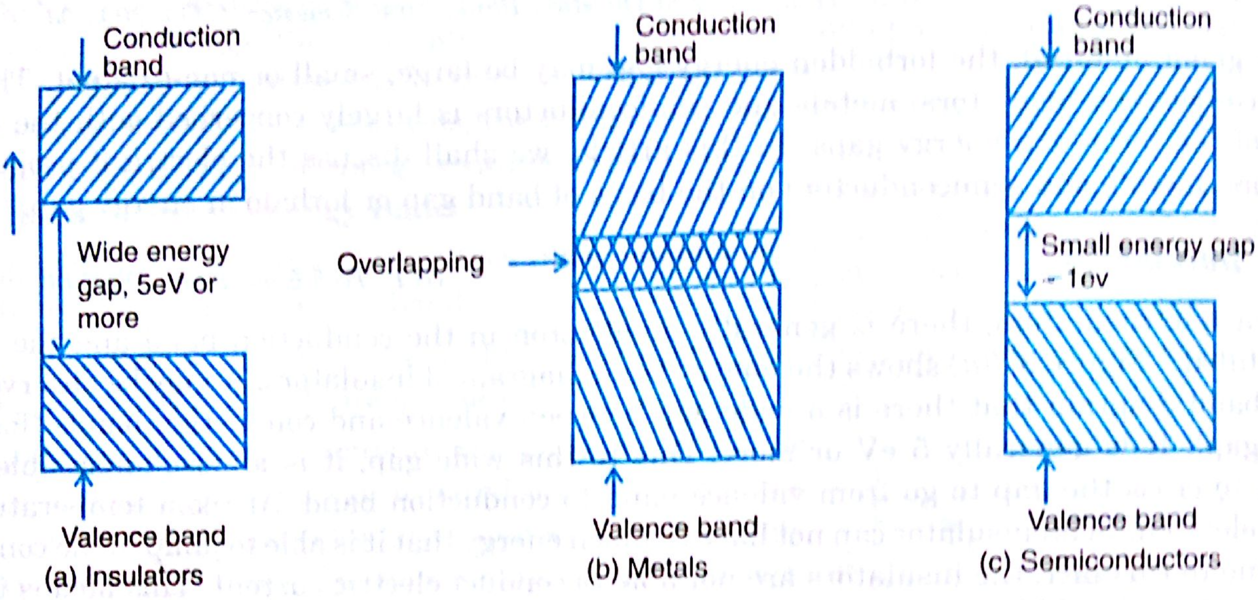

Fig. 3.6. Energy band diagram

3.10.3.1. Why Silicon is More Widely used Semiconductor Material?

As a matter of fact, the valence electrons in germanium are in the fourth shell while those in silicon are in the third shell, *i.e.*, closer to nucleus. This means that the germanium valence electrons are at higher energy levels than those in silicon. Hence, the germanium valence electrons will need smaller amount of additional energy to escape from the atom. Because of this reason, the germanium produces more number of electron hole pairs than silicon. Hence, the leakage current (reverse saturation current) is more in germanium than that in silicon. This property makes germanium more unstable at high temperatures. Therefore, silicon is more widely used material than germanium.

3.10.3.2. Elemental and Compound Semiconductors

Table 3.2 shows a portion of the periodic table in which the more common semiconductors are found. Silicon and germanium are in group IV and are the elemental semiconductors. But, the gallium arsenide (GaAs) is a group III-V compound semiconductor.

Table 3.2: A portion of Periodic Table

S.No.	Group III	Group IV	Group V
1.	B (Borium)	C (Carbon)	
2.	Al (Aluminium)	Si (Silicon)	P (Phosphorus)
3.	Ga (Gallium)	Ge (Germanium)	As (Arsenic)

3.11. COMPARISON OF CONDUCTORS, INSULATORS AND SEMICONDUCTORS

(U.P. Tech. Sem. Exam. 2002-03) (03 marks)

Table 3.3: Comparison of Metals (Conductors), Insulators and Semiconductors

Sr. No.	Parameter of comparison	Conductors (Metals)	Insulators	(Semiconductors
1.	Conductivity	Very high	Very low	Moderate
2.	Resistivity	Very low	Very high	Moderate
3.	Forbidden gap	No forbidden gap	Large gap ($E_G \cong 5$ eV)	Medium (E_G = 1 to 2 eV)
4.	Temperature coefficient of resistance	Positive	Negative	Negative
5.	Effect of temperature on resistance	R increases as T increases	R decreases as T increases	R decreases as T increases
6.	Number of electrons available for conduction	Very large	Very small	Moderate
7.	Conductivity at room temperature	Very good	Poor	Moderate
8.	Examples	Aluminium, copper	Paper, Mica, Glass	Silicon, Germanium
9.	Applications	As conductors, wires, bus bars.	Capacitors, insulation for wires	Semiconductor devices