AL-Mustaqbal University College
Department of Medical Physics
The Second Stage
Semiconductors
Dr. Rusul Abdul Ameer

كلية المستقبل الجامعة
قسم الفيزياء الطبية
المرحلة الثانية
أشباه موصلات

Lecture .1

Introduction

Semiconductors are known as insulating materials at low temperatures, but they have a certain amount of electrical conductivity at high temperatures. If the valence band is completely filled with electrons, and in order for the electron to cross the relatively small energy gap to reach the conduction band, it needs thermal energy (K_BT) and so on thermal energy plays an important role in helping the electrons cross the energy gap.

Electrical conduction requires the transfer of an electron from a valence bundle filled with electrons to an empty conduction bundle of electrons through the prohibited gap between them, meaning that the electron must gain energy in order to be able to move from one bundle to another, and this energy (Eg) is called the energy gap. As for semiconducting materials, the main difference between them and insulating materials lies in the value of the energy gap, which is much less than the value of the energy gap in the insulating materials.

The electrical conductivity in insulating materials is very low, because the energy gap is large, which makes the number of electrons transferred to the conduction beam few at normal temperatures or even at high temperatures, as the value of the energy gap in many insulating materials ranges between eV (10-3).). As for the electrical conductivity in semiconductor materials, it is somewhat moderate at high temperatures, but at low temperatures the electrical conductivity is very little, because the conduction band is empty at absolute zero temperature and as temperatures rise, a large number of electrons move to the conduction band and rise The value of the electrical conductivity to a large extent.

Semiconductors are employed in the manufacture of various kinds of electronic devices, including diodes, transistors, and integrated circuits. Such devices have found wide application because of their compactness, reliability, power efficiency, and low cost. As discrete components, they have found use in power devices, optical sensors, and light emitters, including solid-state lasers. They have a wide range of current- and voltage-handling capabilities and, more important, lend themselves to integration into complex but readily manufacturable microelectronic circuits. They are, and will be in the foreseeable future, the key elements for the majority of electronic systems, serving communications, signal processing, computing, and control applications in both the consumer and industrial markets.

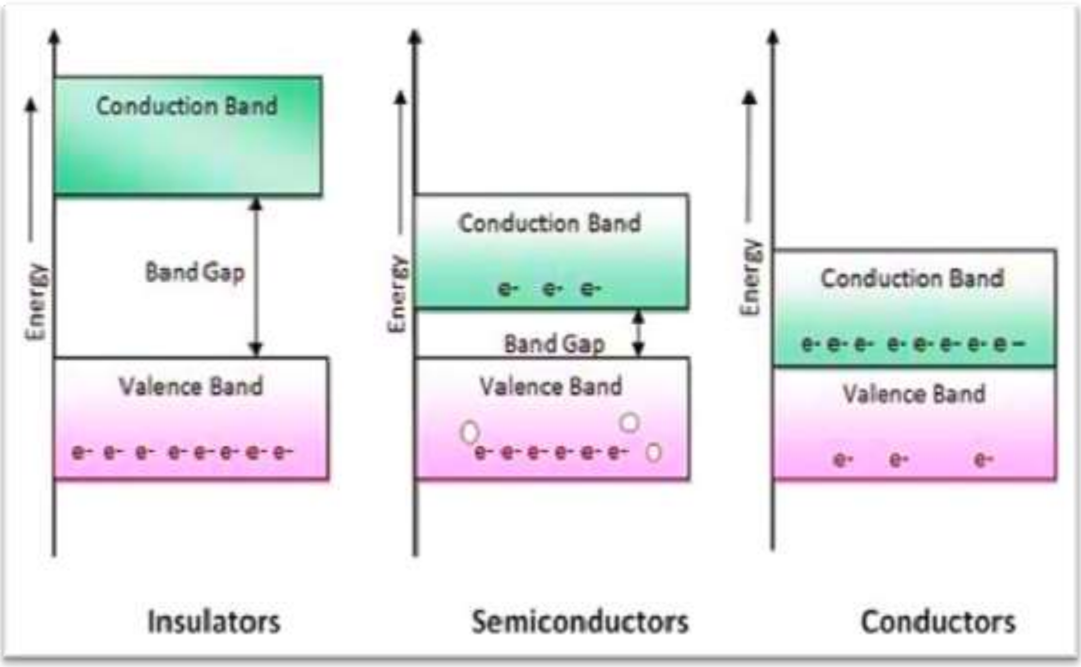


Fig (1) : Energy Band diagram for solid state material

General properties of semiconducting materials:

1. It has a resistance with a negative thermal coefficient.
2. Its resistance is a resistance between $(10^{-5}-10^{4})$ Ω .m .
3. The capacity for heat energy that this material can produce is very high.
4. Semiconducting materials have two types of charge carriers, holes and electrons.
5. The semiconductor materials are very sensitive to light.
6. The resistance (and conductivity) can be controlled by adding trivalent or pentavalent impurities

Semiconductor materials

1. Semiconductor materials come from different groups in the periodic table, yet share certain similarities.
2. The properties of the semiconductor material are related to their atomic characteristics and change from group to group.
3. Researchers and designers take advantage of these differences to improve the design and choose the optimal material for a PV application.

The atoms in a semiconductor are materials from either group IV of the periodic table, or from a combination of group III and group V (called III-V semiconductors), or of combinations from group II and group VI (called II-VI semiconductors). Because different semiconductors are made up of elements from different groups in the periodic table, properties vary between semiconductors. Silicon, which is a group IV, is the most commonly used semiconductor material as it forms the basis for integrated circuit (IC) chips and is the most mature technology and most solar cells are also silicon based. A full periodic table is given in the page Periodic Table.

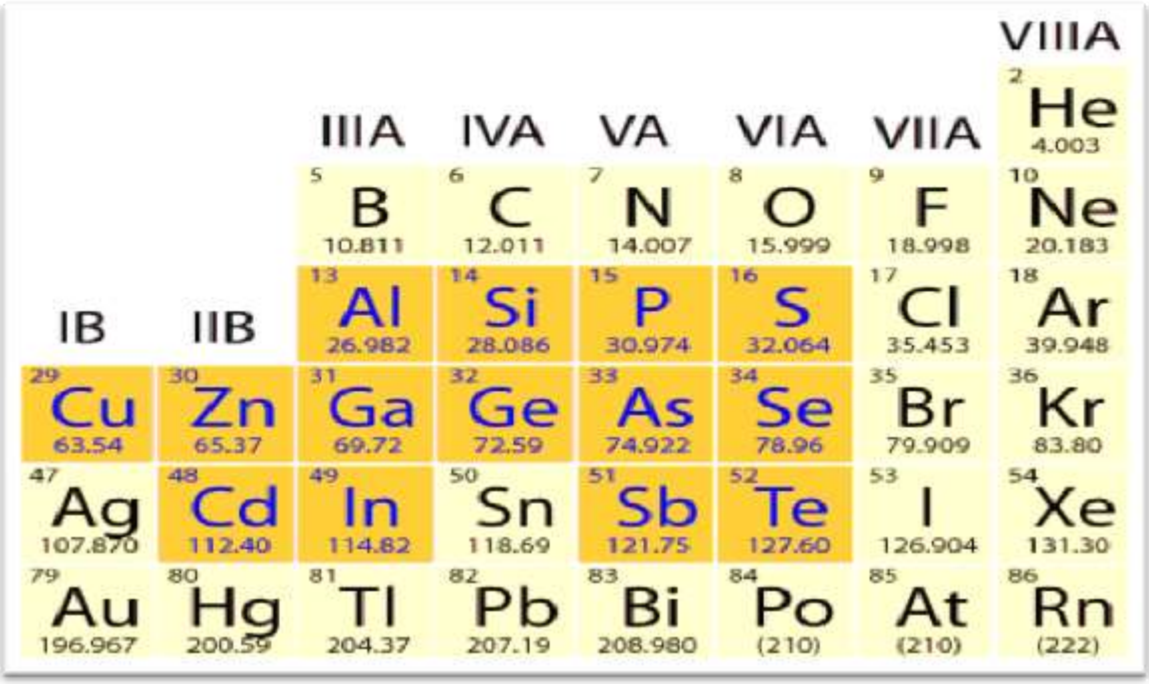
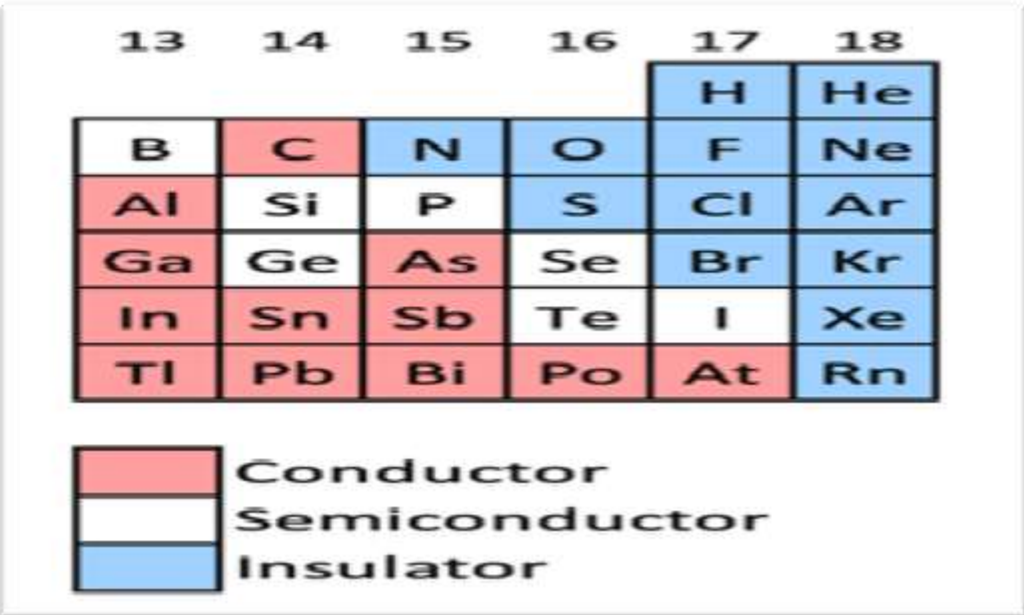


Fig (2) :A section from the periodic table. More common semiconductor materials are shown in blue. A semiconductor can be either of a single element, such as Si or Ge, a compound, such as GaAs, InP or CdTe, or an alloy, such as $Si_xGe_{(1-x)}$ or $Al_xGa_{(1-x)}As$, where x is the fraction of the particular element and ranges from 0 to 1.



Germanium Ge, whose energy gap value is (Eg = 0.72 eV), and silicon Si Eg = (1.1 eV), is one of the most important types of semiconductors that are used in electronic devices, as Si and Ge are two elements of the fourth group of the periodic table. The outer shell in the prime consists of electrons to be filled, and silicon has (14) electrons , while germanium has (32) electrons.

The electronic fabrication of the outer shell of silicon is $3\ P^2\ 3S^2$, meaning that the secondary shell of the third orbital P3 needs four electrons to fill it up to become $3P^6$.

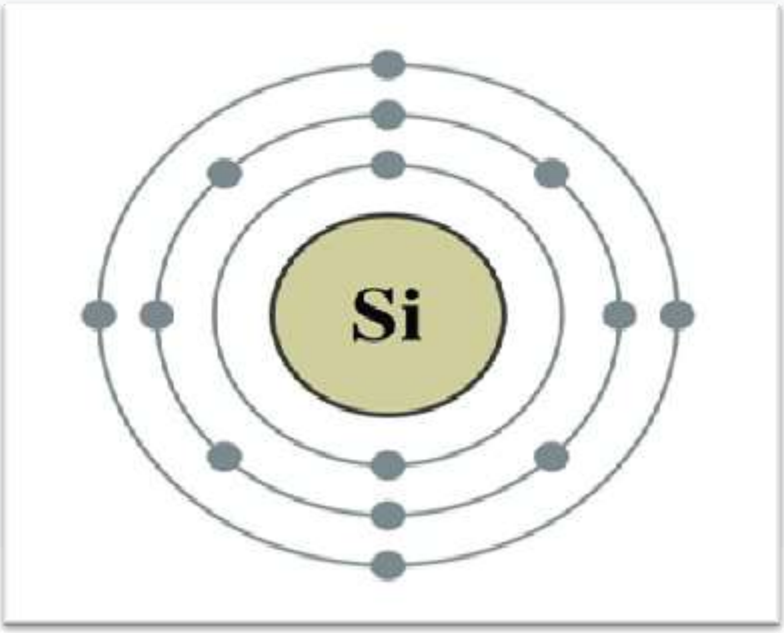
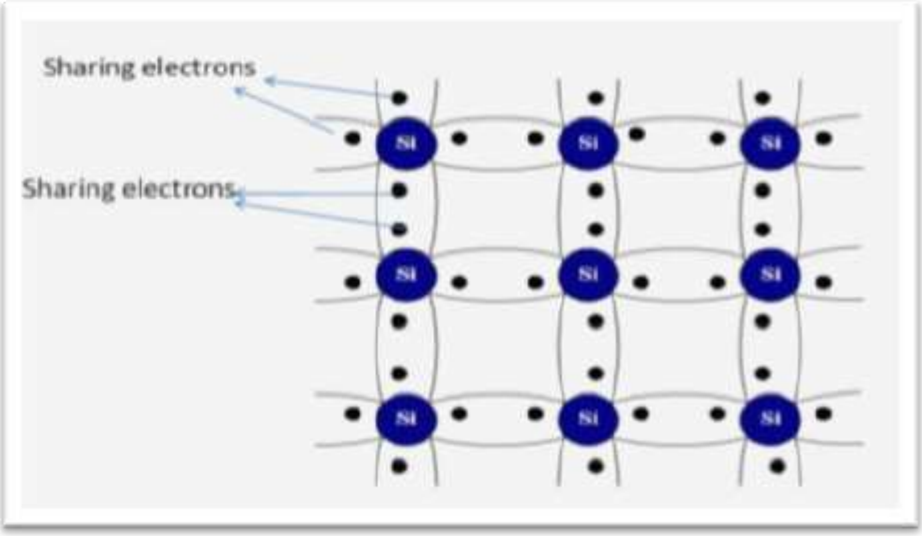


Fig (3) :The atomic structure of silicon

The bonds that bind silicon atoms in a silicon crystal are covalent bonds, as each silicon atom is surrounded by four atoms, and these four participate in filling the outer shell of the intermediate atom, with the contribution of an electron from each of them, as shown in Figure (4). Silicon is an insulator despite its quaternary equivalence. As the temperature rises, this thermal energy is sufficient to break the covalent bond by releasing one of the electrons of the covalent bond from its place, leaving a hole, as the resulting holes are of great importance in the process of electrical current transmission.



Fig(4) :A pure silicon crystal is where each silicon atom is attached to four other atoms.

Electron - hole

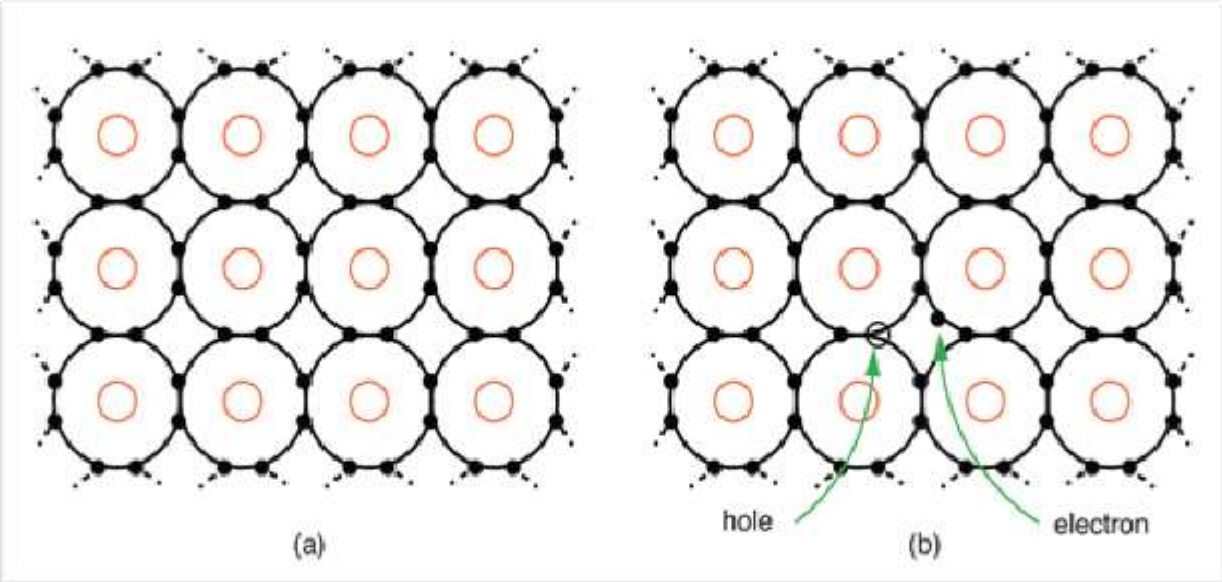
An electron hole is one of the two types of charge carriers that are responsible for creating electric current in semiconducting materials. A hole can be seen as the "opposite" of an electron. Unlike an electron which has a negative charge, holes have a positive charge that is equal in magnitude but opposite in polarity to the charge an electron has.

Holes can sometimes be confusing as they are not physical particles in the way that electrons are, rather they are the *absence* of an electron in an atom. Holes can move from atom to atom in semiconducting materials as electrons leave their positions.[2] An analogy may be helpful. Imagine people standing in a line, on a set of steps. If the person at the front of the line goes up one step, that person leaves a hole. As everyone steps up one step the available step (the hole) moves down the steps.

Holes are formed when electrons in atoms move out of the valence band (the outermost shell of the atom that is completely filled with electrons) into the conduction band (the area in an atom where electrons can escape easily), which happens everywhere in a semiconductor.

In order to encourage hole formation semiconductors are doped with certain elements. These semiconductors, where holes are the most prominent charge carrier, are known as p-type. When an element that has one less electron in its outer shell than silicon, such as boron, is added into a crystalline structure of silicon it replaces one of the silicon atoms in the crystalline structure. These holes readily accept free electrons and complement n-type semiconductors as the excess electrons of the n-type can be absorbed by the p-type. This property is integral to the p-n junction, a vital component in the operation of a diode and photovoltaic cells. Electrical conductivity is drastically increased with either the production of extra electrons or holes.

Both electrons and holes are vital to the creation of current in semiconductors. Under the influence of some external voltage, both electrons and holes can move through a semiconducting material. This process is known as applying a forward or reverse bias.



(a) An intrinsic semiconductor is an insulator having a complete electron shell. (b) However, thermal energy can create few electron-hole pairs resulting in weak conduction