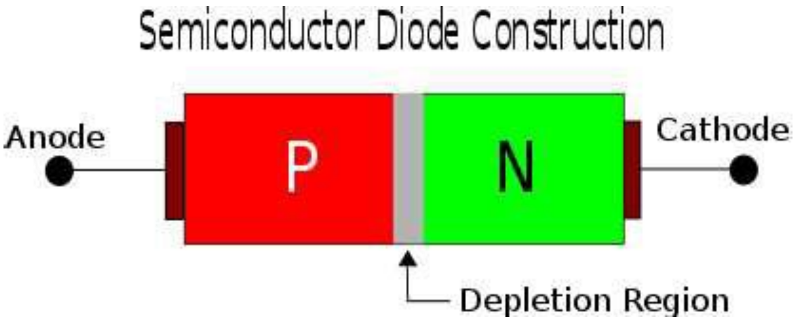
Al-Mustaqbal University
College of Engineering and Technologies
Medical Instrumentation Technique Engineering Department
Class: 2nd
Subject: Electronic Circuits
Lecturer: Dr. Rami Qays Malik
Lecture: 2- Semiconductors materials

Semiconductors materials



A- Rational

We will clarify the concept of Semiconductor Diodes general characteristics of three important semiconductor materials: Si, Ge.

B- Central Idea

1. definition of the Semiconductor Diodes
2. types of Semiconductor Diodes
3. basic operation and characteristics of a diode

C. Chapter objectives

After studying the:-general characteristics of important semiconductor materials: Si, Ge. the student will be able to

1- Understand conduction using electron and hole theory.

2- Be able to describe the difference between n - and p -type materials.

3- Develop a clear understanding of the basic operation and characteristics of a diode in the no-bias, forward-bias, and reverse-bias regions.

Email: rami.qays@uomus.edu.iq

1.2 SEMICONDUCTOR MATERIALS: Ge, Si

The construction of every discrete (individual) solid-state (hard crystal structure) electronic device or integrated circuit begins with a semiconductor material of the highest quality.

Semiconductors are a special class of elements having a conductivity between that of a good conductor and that of an insulator.

In general, semiconductor materials fall into one of two classes: single crystal and compound . Single-crystal semiconductors such as germanium (Ge) and silicon (Si) have a repetitive crystal structure, whereas compound semiconductors such as gallium arsenide (GaAs), cadmium sulfide (CdS), gallium nitride (GaN), and gallium arsenide phosphide (GaAsP) are constructed of two or more semiconductor materials of different atomic structures.

1.3 COVALENT BONDING AND INTRINSIC MATERIALS)

The fundamental components of an atom are the electron, proton, and neutron. In the lattice structure , neutrons and protons form the nucleus and electrons appear in fixed orbits around the nucleus. The Bohr model for the three materials is provided in Fig. 1.3 .

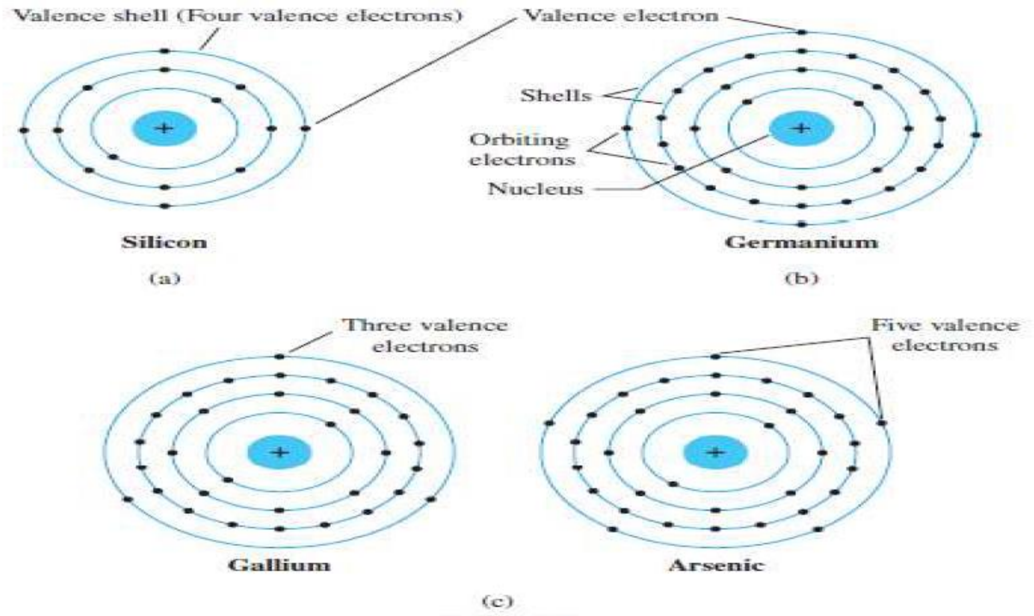


FIG. 1.3
Atomic structure of (a) silicon; (b) germanium; and (c) gallium and arsenic.

As indicated in Fig. 1.3 , silicon has 14 orbiting electrons, germanium has 32 electrons, gallium has 31 electrons, and arsenic has 33 orbiting electrons (the same arsenic that is a very poisonous chemical agent). For germanium and silicon there are four electrons in the outermost shell, which are referred to as valence electrons . Gallium has three valence electrons and arsenic has five valence electrons. Atoms that have four valence electrons are called tetravalent , those with three are called trivalent , and those with five are called pentavalent . The term valence is used to indicate that the potential (ionization potential) required to remove any one of these electrons from the atomic structure is significantly lower than that required for any other electron in the structure.

Email: rami.qays@uomus.edu.iq

1.4 n -TYPE AND p -TYPE MATERIALS

A semiconductor material that has been subjected to the doping process is called an extrinsic material.

There are two extrinsic materials of immeasurable importance to semiconductor device fabrication: n -type and p -type materials. Each is described in some detail in the following subsections.

n -Type Material

An n -type material is created by introducing impurity elements that have five valence electrons (pentavalent), such as antimony, arsenic , and phosphorus The effect of such impurity elements is indicated in Fig. 1.7 (using antimony as the impurity in a silicon base). Note that the four covalent bonds are still present. There is, however, an additional fifth electron due to the impurity atom, which is unassociated with any particular covalent bond, This remaining electron, loose bound to its parent (antimony) atom,

Diffused impurities with five valence electrons are called donor atoms.

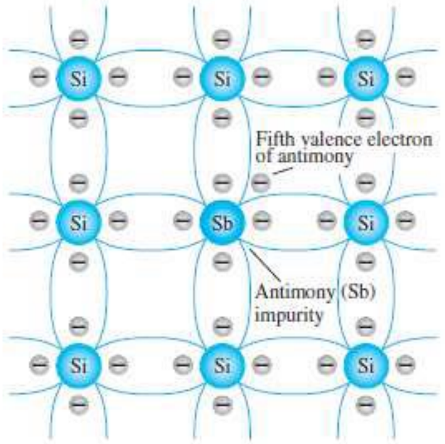


FIG. 1.7
Antimony impurity in n-type material

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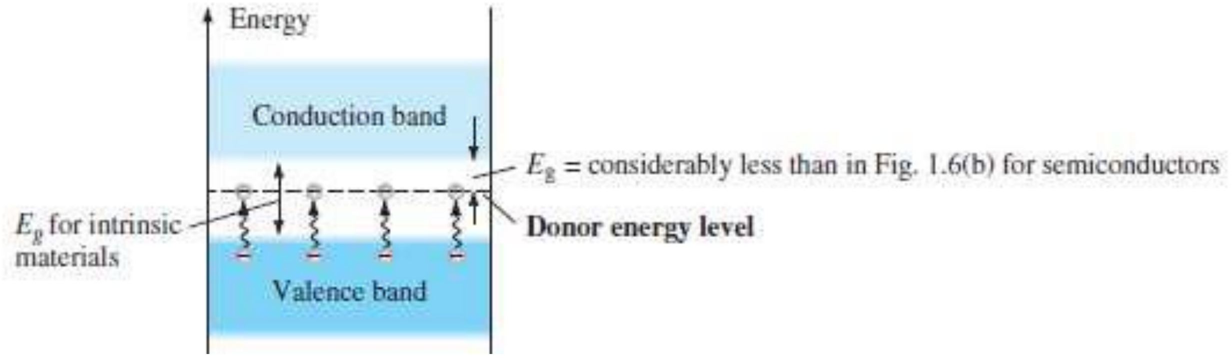
The effect of this doping process on the relative conductivity can best be described through the use of the energy-band diagram of Fig. 1.8 . Note that a discrete energy level (called the donor level) appears in the forbidden band with an Eg significantly less than that of the intrinsic material. Those free electrons due to the added impurity sit at this energy level and have less difficulty absorbing a sufficient measure of thermal energy to move into the conduction band at room temperature



p -Type Material

The p -type material is formed by doping a pure germanium or silicon crystal with impurity atoms having three valence electrons. The elements most frequently used for this purpose are boron , gallium , and indium . Each is a member of a subset group of elements in the Periodic Table of Elements referred to as Group III because each has three valence electrons. The effect of one of these elements, boron, on a base of silicon is indicated in Fig. 1.9. Note that there is now an insufficient number of electrons to complete the covalent bonds of the newly formed lattice. The resulting vacancy is called a hole and is represented by a small circle or a plus sign, indicating the absence of a negative charge. Since the resulting vacancy will readily accept a free electron:

The diffused impurities with three valence electrons are called acceptor atoms.

The resulting p -type material is electrically neutral, for the same reasons described for the n -type material.

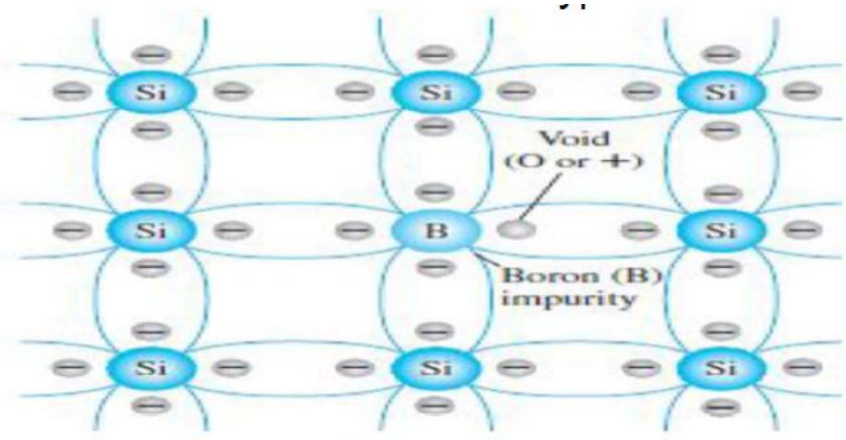


FIG. 1.9
Boron impurity in p-type material.

Electron versus Hole Flow

The effect of the hole on conduction is shown in Fig. 1.10 . If a valence electron acquires sufficient kinetic energy to break its covalent bond and fills the void created by a hole, then a vacancy, or hole, will be created in the covalent bond that released the electron. There is, therefore, a transfer of holes to the left and electrons to the right, as shown in Fig. 1.10 . The direction to be used in this text is that of conventional flow , which is indicated by the direction of hole flow

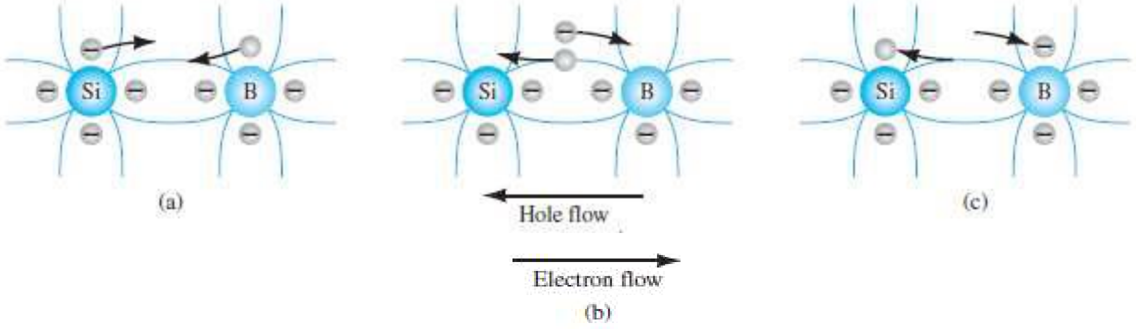
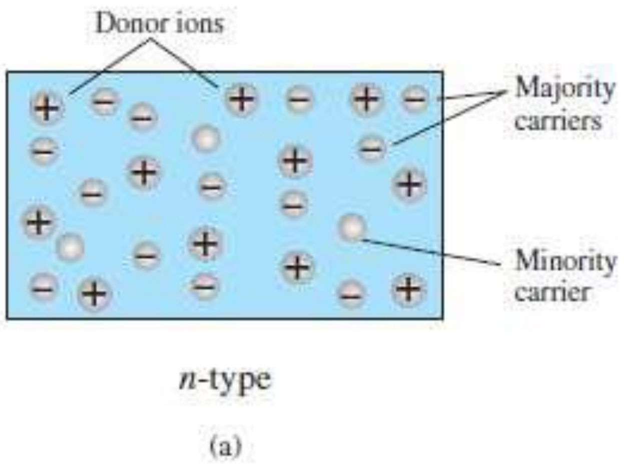


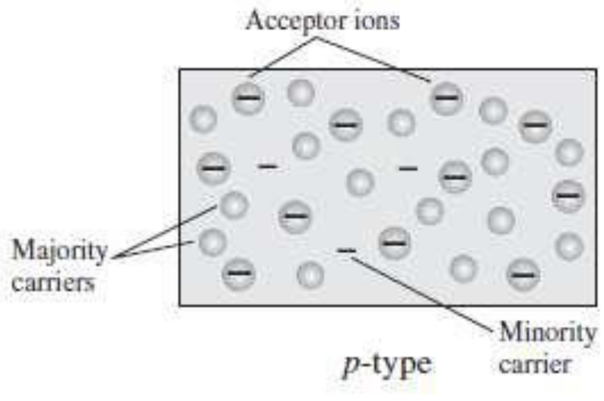
FIG. 1.10
Electron versus hole flow.

Majority and Minority Carriers

In an n-type material (Fig. 1.11a) the electron is called the majority carrier and the hole the minority carrier.



In a p-type material the hole is the majority carrier and the electron is the minority carrier. For the p -type material the number of holes far outweighs the number of electrons,



(b)

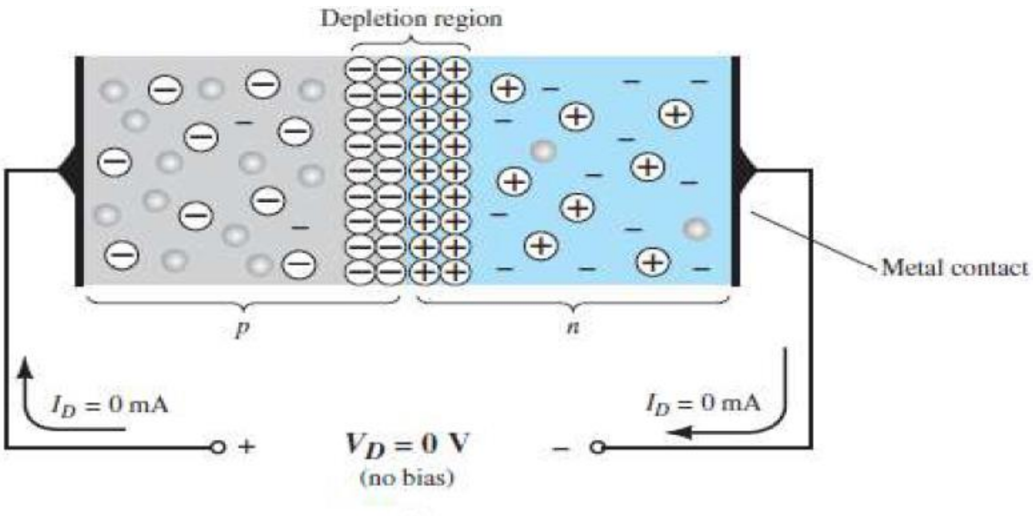
1.6 SEMICONDUCTOR DIODE

Now that both n - and p -type materials are available, we can construct our first solid-state electronic device: The semiconductor diode, is created by simply joining an n -type and a p -type material together

No Applied Bias (V_0 V)

At the instant the two materials are the electrons and the holes in the region of the junction will combine, resulting in a lack of free carriers in the region near the junction, as shown in Fig. 1.12a . Note in Fig. 1.12a that the only particles displayed in this region are the positive and the negative ions remaining once the free carriers have been absorbed.

This region of uncovered positive and negative ions is called the depletion region due to the depletion of free carriers in the region.



(a)

Under no-bias conditions, any minority carriers (holes) in the n -type material that find themselves within the depletion region for any reason whatsoever will pass quickly into the p -type material. The closer the minority carrier is to the junction, the greater is the attraction for the layer of negative ions and the less is the opposition offered by the positive ions in the depletion region of the n -type material. We will conclude, therefore, for future discussions, that any minority carriers of the n -type material that find themselves in the depletion region will pass directly into the p -type material. This carrier flow is indicated at the top of Fig. 1.12c for the minority carriers of each material. In the absence of an applied bias across a semiconductor diode, the net flow of charge in one direction is zero.

Reverse-Bias Condition (V D 0 V)

If an external potential of V volts is applied across the p n junction such that

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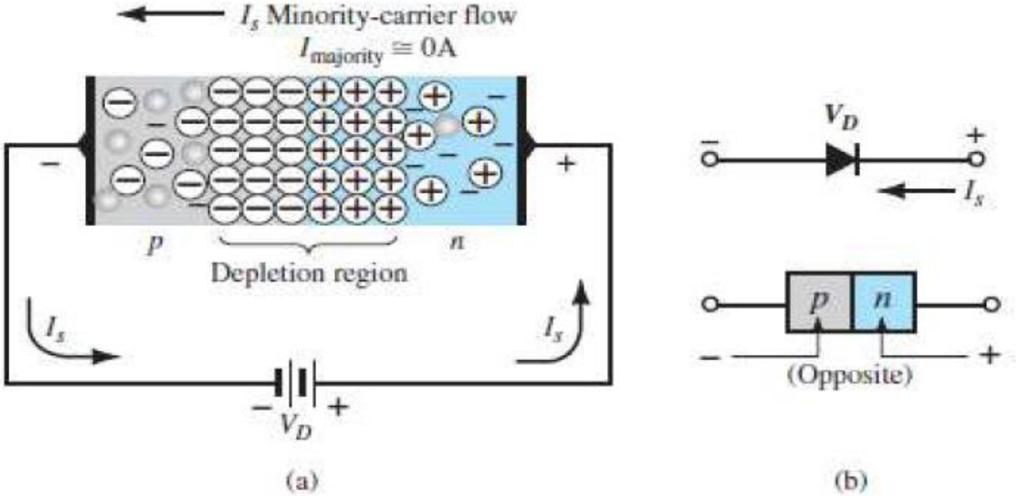
the positive terminal is connected to the n -type material and the negative terminal is connected to the p -type material as shown in Fig. 1.13 , the number of uncovered positive ions in the depletion region of the n -type material will increase due to the large number of free electrons drawn to the positive potential of the applied voltage. For similar reasons, the number of uncovered negative ions will increase in the p -type material. The net effect, therefore, is a widening of the depletion region. This widening of the depletion region will establish too great a barrier for the majority carriers to overcome, effectively reducing the majority carrier flow to zero, as shown in Fig. 1.13a

The current that exists under reverse-bias conditions is called the reverse saturation current and is represented by Is



(a) (b)

Forward-Bias Condition (V D + 0 V)

A forward-bias or condition is established by applying the positive potential to the p -type material and the negative potential to the n -type material as

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shown in Fig. 1.14 . The application of a forward-bias potential V D will electrons in the n -type material and holes in the p -type material to recombine with the ions near the boundary and reduce the width of the depletion region as shown in Fig. 1.14a . The resulting minority-carrier flow of electrons from the p -type material to the n -type material (and of holes from the n -type material to the p -type material) has not changed in magnitude (since the conduction level is controlled primarily by the limited number of impurities in the material), but the reduction in the width of the depletion region has resulted in a heavy majority flow across the junction

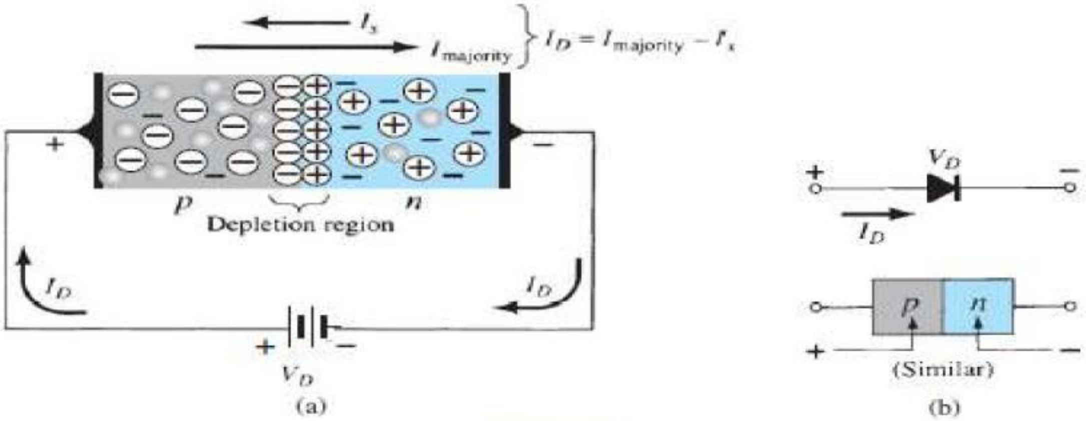

FIG. 1.14

Forward-biased p–n junction: (a) internal distribution of charge under forward-bias conditions; (b) forward-bias polarity and direction of resulting current.