الكلية	الهندسة
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المادة باللغة الانجليزية	Electronic Devices and Circuit Theory
المادة باللغة العربية	مكونات و دوائر إلكترونية
المرحلة الدراسية	الثانية
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رقم المحاضرة	١
المصادر والمراجع	Electronic-Devices-and-Circuit-Theory-11th-Edition-Ebook

Lecture 1

Introduction

1.1 Semiconductors Materials: Ge, Si, GaAs

The construction of every individual solid-state electronic device or integrated circuit begins with a semiconductor material of highest quality.

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

Semiconductor materials can be categorized into two distinct classes.

- Single-crystal: semiconductors such as germanium (Ge) and silicon (Si) have a repetitive crystal structure.
- 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.

Some Facts:

- The first integrated circuit (IC) was developed by Jack Kilby while working at Texas Instruments in 1958.
- Today, the Intel ® Core i7 has 731 million transistors in a package.

- The first germanium diode was invented in 1939 and the first germanium transistor was in 1947.
- The fist silicon transistor was invented in 1954.

1.2 Covalent bonding (الرابطة التساهمية) and intrinsic material (المواد النقية)

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 Figure 1

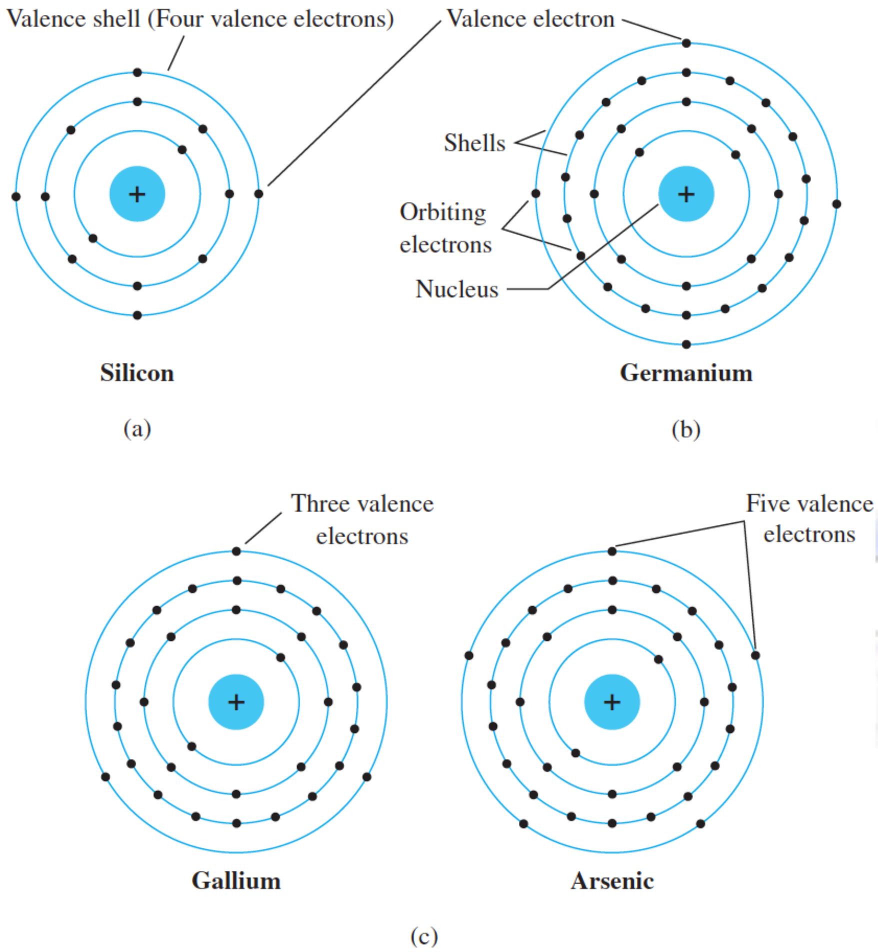

Figure 1: Atomic structure of (a) silicon; (b) germanium; and(c) gallium and arsenic.

As indicated in Figure 1, 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* (See Figure 2). 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.

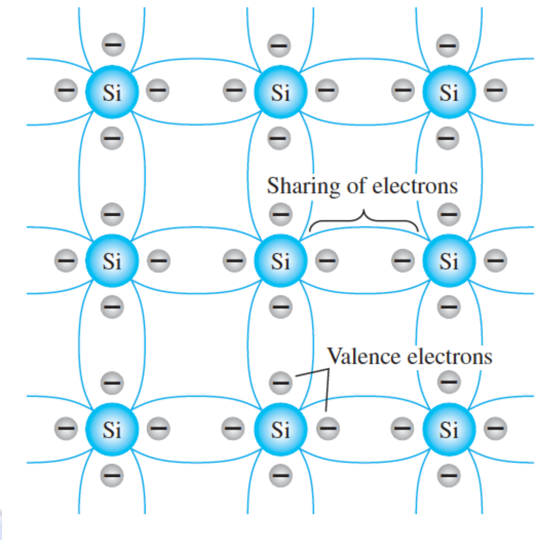

Figure 2: Covalent bonding of the silicon atom.

This bonding of atoms, strengthened by the sharing of electrons, is called covalent bonding.

Although the covalent bond will result in a stronger bond between the valence electrons and their parent atom, it is still possible for the valence electrons to absorb sufficient kinetic energy from external natural causes to break the covalent bond and assume the “free” state. The term *free* is applied to any electron that has separated from the fixed lattice structure and is very sensitive to any applied electric fields such as established by voltage sources or any difference in potential. *The external causes include effects such as light energy in the form of photons and thermal energy (heat) from the surrounding medium.*

The free electrons in a material due only to external causes are referred to as *intrinsic carriers*. Table 1.1 compares the number of intrinsic carriers per cubic centimeter (abbreviated n_i) for Ge, Si, and GaAs. It is interesting to note that Ge has the highest number and GaAs the lowest. In fact, Ge has more than twice the number as GaAs. The number of carriers in the intrinsic form is important, but other characteristics of the material are more significant in determining its use in the field. One such factor is the *relative mobility* (μ_n) of the free carriers in the material, that is, the ability of the free carriers to move throughout the material. Table 1.2 clearly reveals that the free carriers in GaAs have more than five times the mobility of free carriers in Si, a factor that results in response times using GaAs electronic devices that can be up to five times those of the same devices made from Si. Note also that free carriers in Ge have more than twice the mobility of electrons in Si, a factor that results in the continued use of Ge in high-speed radio frequency applications.

TABLE 1.1

Intrinsic Carriers n_i

Semiconductor	Intrinsic Carriers (per cubic centimeter)
GaAs	1.7×10^6
Si	1.5×10^{10}
Ge	2.5×10^{13}

TABLE 1.2

Relative Mobility Factor μ_n

Semiconductor	μ_n ($cm^2/V{\cdot}s$)
Si	1500
Ge	3900
GaAs	8500

1.3 ENERGY LEVELS

The farther an electron is from the nucleus, the higher is the energy state, and any electron that has left its parent atom has a higher energy state than any electron in the atomic structure.

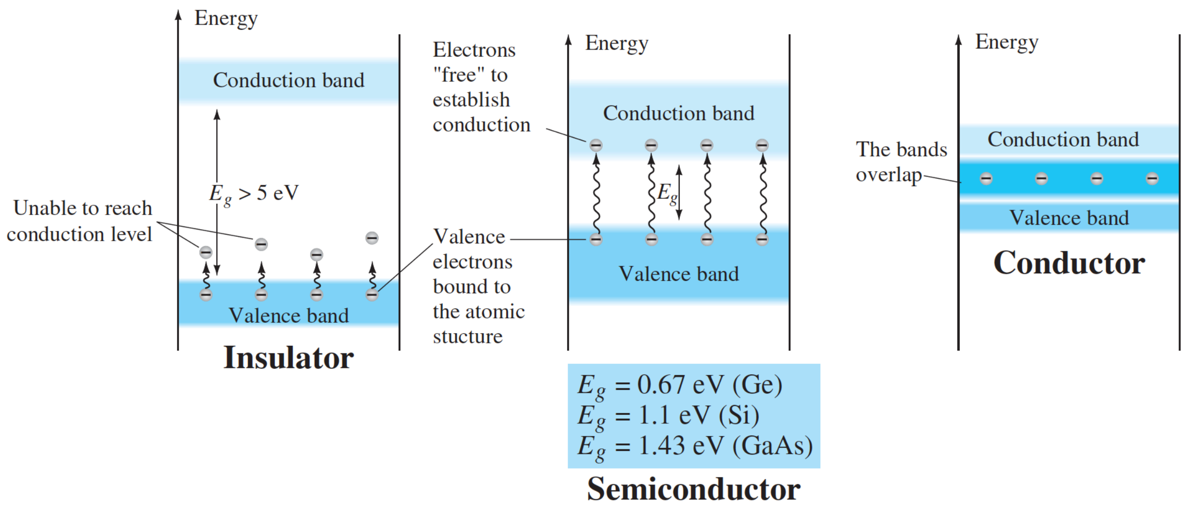

Figure 3:Energy levels: (a) discrete levels in isolated atomic structures; (b) conduction and valence bands of an insulator

An electron in the valence band of silicon must absorb more energy than one in the valence band of germanium to become a free carrier. Similarly, an electron in the valence band of gallium arsenide must gain more energy than one in silicon or germanium to enter the conduction band (See Figure 3).

This difference in energy gap requirements reveals the sensitivity of each type of

semiconductor to changes in temperature. For instance, as the temperature of a Ge sample increases, the number of electrons that can pick up thermal energy and enter the conduction band will increase quite rapidly because the energy gap is quite small. However, the number of electrons entering the conduction band for Si or GaAs would be a great deal less. This sensitivity to changes in energy level can have positive and negative effects. The design of photodetectors sensitive to light and security systems sensitive to heat would appear to be an excellent area of application for Ge devices. However, for transistor networks, where stability is a high priority, this sensitivity to temperature or light can be a detrimental factor.

Before we leave this subject, it is important to underscore the importance of understanding the units used for a quantity. In Fig. 1.6 the units of measurement are electron volts (eV). The unit of measure is appropriate because W (energy) = QV (as derived from the defining equation for voltage: V = W / Q). Substituting the charge of one electron and a potential difference of 1 V results in an energy level referred to as one electron volt . That is,

$$\begin{aligned} W &= QV \\ &= (1.6 \times 10^{-19}\,\text{C})(1\,\text{V}) \\ &= 1.6 \times 10^{-19}\,\text{J} \end{aligned}$$

and

$$\boxed{1\,\text{eV} = 1.6 \times 10^{-19}\,\text{J}}$$