Analog Electronics

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1st **semester**

Chapter One: Semiconductor Material

Lecture 1

Electronics

Electronics is the **branch of physics** that **deals with:**

1. The **emission and effects of electrons**
2. The **use of electronic devices**, i.e.,

Science of the motion of charges in a gas, vacuum, or semiconductor.

- An electronic building block packaged in a discrete form with two or more connecting leads or metallic pads.
- **Components** are connected together to create an electronic circuit with **a particular function**, e.g., an **amplifier, radio receiver,** or **oscillator**. Active components are sometimes called **devices**.
- **Composed** of **subsystems** or **electronic circuits**, which may **include amplifiers, signal sources**, **power supplies,** etc…, e.g.: Laptop, DVD players, iPods, mobile phones, PDAs (Personal Digital Assistants).

Atomic structure

- **All matter on earth is made of atoms** (**elements or a combination of elements**); all atoms **consist of** electrons, protons, and **neutrons except** ordinary hydrogen, which does not have a neutron.
- **An atom** is the smallest particle of an element that retains the characteristics of that element.
- **According to Bohr**, atoms have a planetary orbits structure that **consists of** a central nucleus **surrounded** by orbiting electrons (Figure 1). **The nucleus contains** protons and neutrons, similar to how planets orbit the sun in our solar system.
- **Each type of atom** has a certain number of electrons and protons that distinguish it from atoms of other elements.
- **Each electron** has its orbit that **corresponds** to different energy levels.
- In an atom, orbits are grouped into energy bands known as shells. Each shell has a fixed maximum number of electrons at allowed energy levels. The maximum number of electrons (N_e) that can exist in each shell can be calculated as, $N_e = 2n^2$ where **n** is the number of the shell.

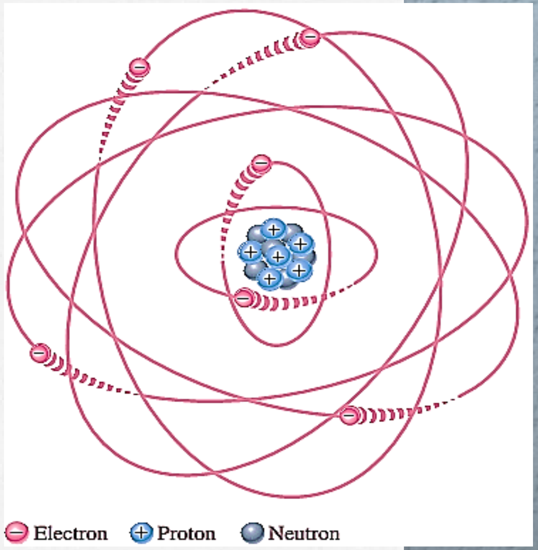


Figure (1)

- **Electrons** in orbits farther from the nucleus have higher energy and are less tightly bound to the atom than those closer to the nucleus.
- **Electrons** with the highest energy exist in the outermost shell of an atom and are relatively loosely bound to the atom.
- **This outermost shell is known** as **the valence shell,** and **electrons in this shell are** called **valence electrons**.
- **Valence electrons** contribute to chemical reactions and bonding within the structure of a material **and determine** its electrical properties.
- Maximum number of valence electrons **is 8**.
- An atom is **stable** if it has 8 valence electrons.
- The **number of valence electrons** determines the **ability** of a material to conduct current.

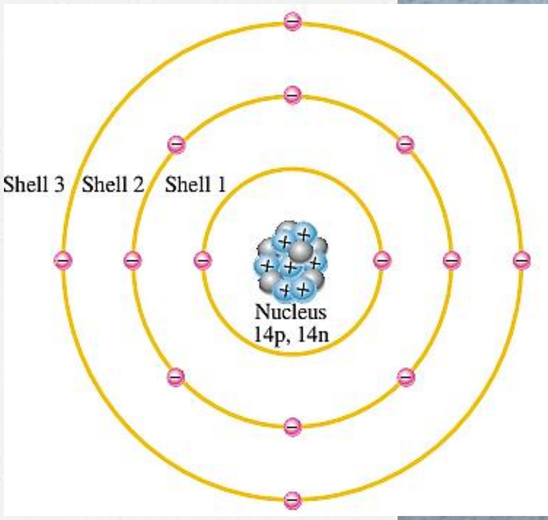


Figure 2: Illustration of the Bohr model of the silicon atom.

Materials Classification

(Insulators, Conductors, and Semiconductors)

In terms of their electrical properties, materials can be classified into three groups: conductors, semiconductors, and insulators.

Insulators: An insulator is a material that **does not conduct electrical current under normal conditions.**

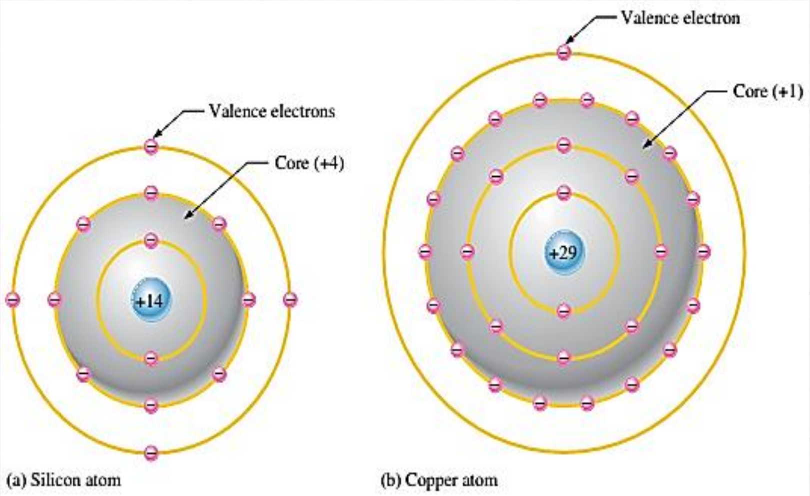
- **Valence electrons** are tightly bound to the atoms; therefore, an insulator has **very few free electrons**.
- **The energy gap** in an insulator is very wide ($\geq$ 6 eV). Valence electron requires a large electric field to gain enough energy to jump into the conduction band.
- Examples of insulators are rubber, plastics, glass, mica, and quartz.

- **Conductors:** A conductor is a material that easily conducts electrical current. Most **metals** are **good conductors**.
- The **best conductors** are (**with one valence electron**) e.g.: copper (Cu), silver (Ag), gold (Au), and aluminum (Al), which are characterized by atoms with only one valence electron very loosely bound to the atom.
- In a conductor, the valence band and the conductor band overlaps

($\leq$ 0.01 eV). Only a little energy or voltage is needed for the electron to jump into the conduction band.

- **Semiconductors:** A semiconductor is a material that is between conductors and insulators in its ability to conduct electrical current. A semiconductor in its pure (intrinsic) state is neither a good conductor nor a good insulator. Single-element semiconductors are silicon (Si), germanium (Ge), antimony (Sb), arsenic (As), astatine (At), boron (B), polonium (Po) and tellurium (Te).
- **Atoms with four valence electrons** characterize these semiconductors. Compound semiconductors such as gallium arsenide, indium phosphide, gallium nitride, silicon carbide, and silicon germanium are also commonly used. **Silicon** is the most commonly used semiconductor.

- **Silicon** is a semiconductor, and Copper is a conductor. **Bohr diagrams** of the silicon atom and the Copper atom are shown in following **Figure 3.**
- A **Silicon atom has 4 electrons** in its valence ring. This makes it a semiconductor.
- A **Copper atom has only 1 electron** in its valence ring. This makes it a good conductor.



- Figure 3: Diagrams of the silicon and copper atoms.

Silicon and Germanium

The atomic structures of silicon and germanium are compared in **Figure 4**,

Both silicon and germanium **have the characteristic four valence electrons**.

The valence electrons in **germanium** are in the **fourth shell** while those in **silicon** are in the **third shell**, closer to the nucleus.

This **means** the **germanium** valence electrons are at **higher energy levels** than those in silicon.

Therefore, requires a **smaller amount** of additional energy **to escape from the atom**. This property makes germanium more unstable at high temperatures, resulting in excessive reverse current. **This is why silicon is a more widely used semiconductive material.**

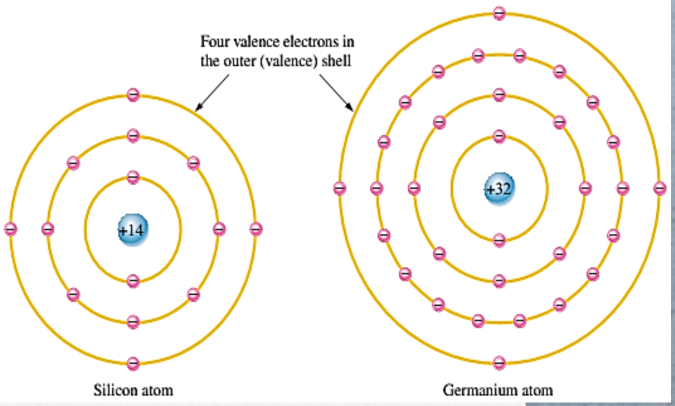


Figure 4