

# Lec (01)

## Semiconductor Devices

### Objectives of the course:

The way a material **conducts** electrical current is important in **understanding** how **electronic devices operate**.

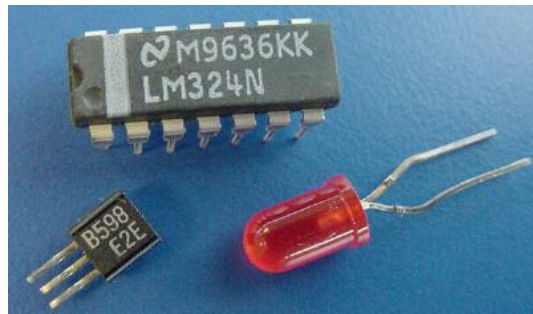
- **Understand** the basic structure of semiconductors and how they conduct current.
- **Describe** the properties of *n*-type and *p*-type semiconductors
- **Describe** how a *pn* junction is formed
- **Describe** the characteristics and biasing of a *pn* junction diode.

**Ref: Electronic Devices, Floyd, 9<sup>th</sup> edition**

{ 1 }

## Lecture (1): Introduction to Electronics

- **Materials used in electronics**
- **Current in semiconductors**
- ***N*-type and  
*P*-type semiconductors**
- **The *pn* junction**

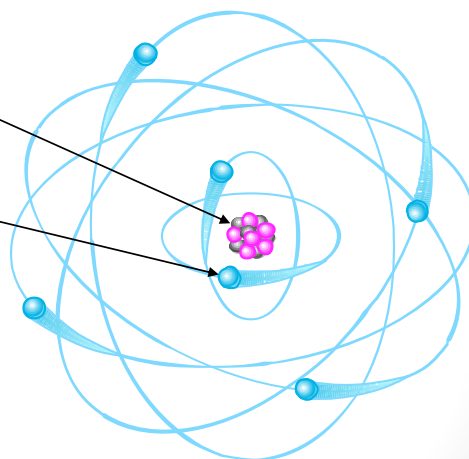


{ 2 }

## The Bohr atom

The Bohr atom is useful for visualizing atomic structure.

- The nucleus is **positively** charged and has the protons and neutrons.
- Electrons are **negatively** charged and in discrete shells.
- The atomic number is the number of protons and determines the particular element.
- In the neutral atom, the number of electrons is equal to the number of protons.



● Electron ● Proton ● Neutron

[ 3 ]

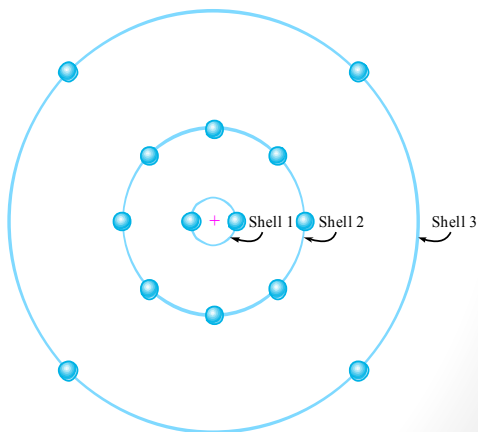
## The valence shell

The outer shell is called the *valence shell*. Electrons in this shell are involved in **chemical reactions** and they account for **electrical and thermal conductivity in metals**.

A neutral Si atom is shown. There are 4 electrons in the valence shell.

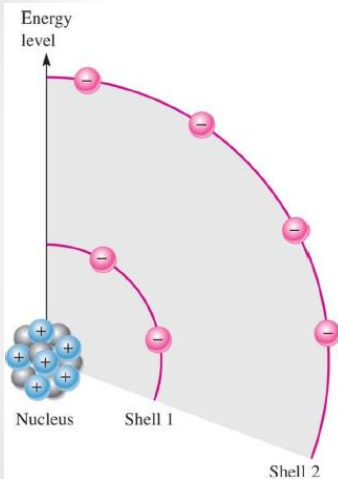
**Metals** have one, two or three electrons in the valence shell. The atom illustrated here is a sodium atom (Na), with only one electron in its outer shell.

**Non-metals** have either complete or nearly complete outer shells, so they make poor electrical conductors.



[ 4 ]

# The Atom Properties



Energy increases as the distance from the nucleus increases.

- Electrons with the **highest** energy levels exist in the outermost shell of an atom and are **loosely** bound to the atom.
- This outermost shell is known as the **valence shell** and electrons in the shell are called **valence electrons**.
- When an electron gains a certain amount of energy, it moves to an orbit farther from the nucleus.
- The process of losing an electron is called **ionization**.
- The escaped valence electron is called a **free electron**.

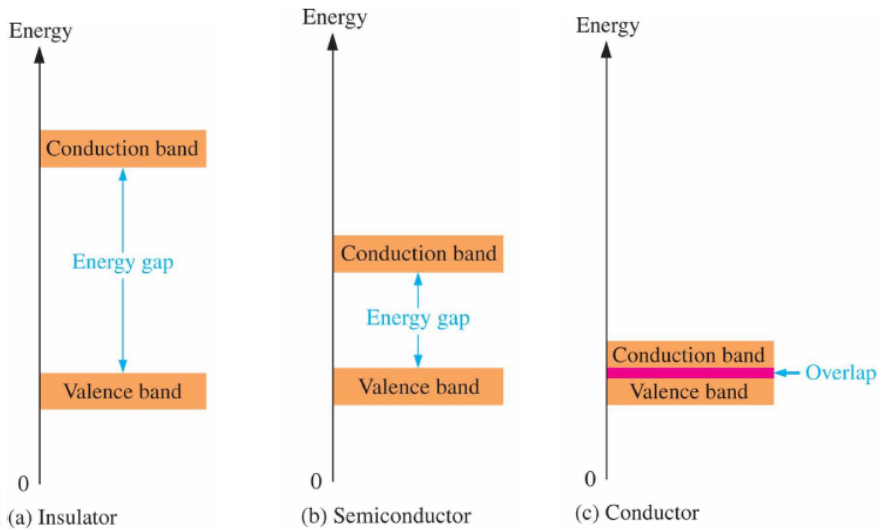
{ 5 }

## Insulators, Conductors, and Semiconductors

- **Insulators** is a material that does not conduct electrical current under normal conditions. Most insulators are **compounds** and have very high resistivities. Valence electrons are **tightly** bound to the atoms. Examples of insulators are rubber, plastics, glass, mica, and quartz.
- **Conductors** is a material that easily conducts electrical current. Most metals are good conductors. The best conductors are **single-element materials**, such as (Cu), (Ag), (Au), and (Al), which are characterized by atoms with only **one valence electron** very **loosely** bound to the atom.
- **Semiconductors** is a material that is between conductors and insulators in its ability to conduct electrical current. The single-element semiconductors are characterized by atoms with **four valence electrons**. Silicon is the most commonly used semiconductor.

{ 6 }

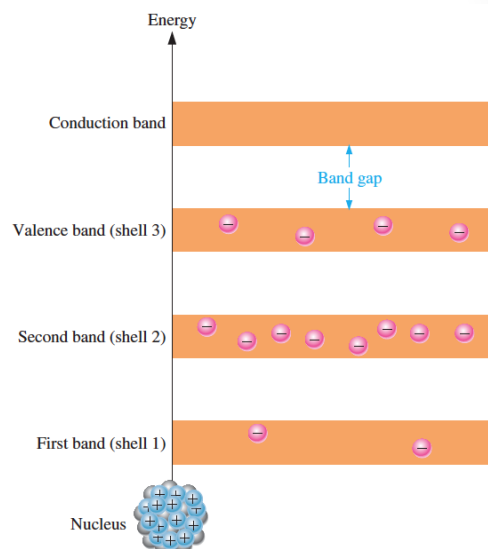
# Energy diagrams



{ 7 }

# Semiconductors

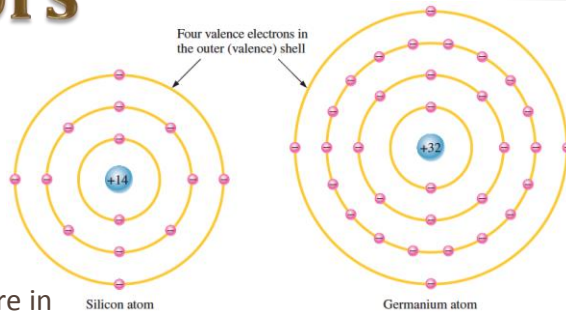
- Semiconductors are crystalline materials that are characterized by specific energy bands for electrons.
- Between the bands are gaps; these gaps represent energies that electrons cannot have.
- The last energy band is the **conduction band**, where electrons are mobile.
- The next to the last band is the **valence band**, which is the energy level associated with electrons involved in bonding.



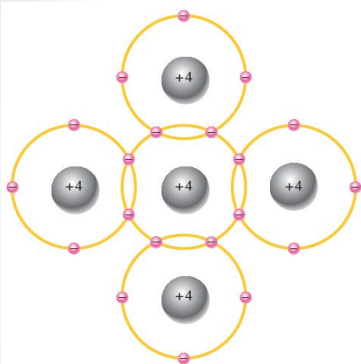
{ 8 }

# Semiconductors

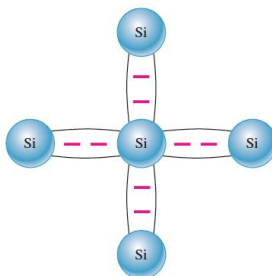
- Both the **silicon** and **germanium** atoms have four valence electrons.
- These atoms differ in that silicon has 14 protons in its nucleus and germanium has 32.
- The valence electrons in germanium are in the **fourth shell** while the ones in silicon are in the **third shell** closer to the nucleus.
- This means that the germanium valence electrons are at a higher energy level than those in silicon and therefore requires a small amount of additional energy to escape from the atom.
- This property makes germanium more unstable than silicon at high temperatures.



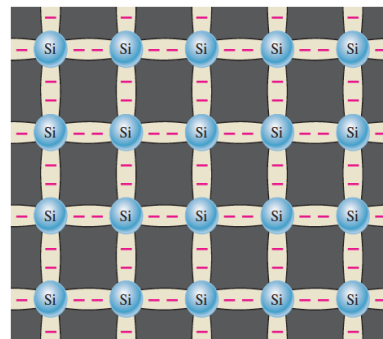
## Covalent bonds in a **intrinsic silicon crystal**



The center silicon atom shares an electron with each of the four surrounding silicon atoms, creating a covalent bond with each. The surrounding atoms are in turn bonded to other atoms, and so on.



**Bonding diagram.** The red negative signs represent the shared valence electrons.

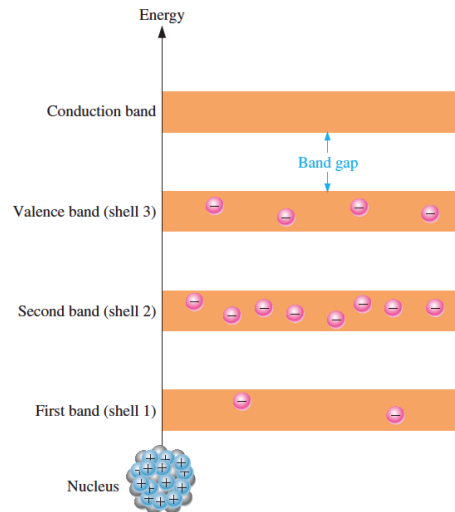


**Covalent bonds in a silicon crystal.**

Covalent bonding for germanium is similar because it also has four valence electrons.

## Current in semiconductors

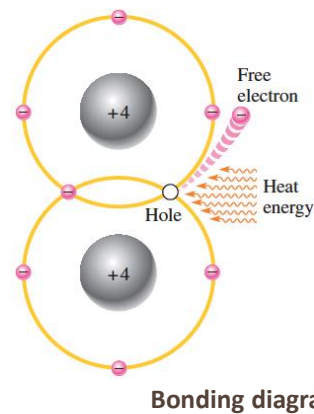
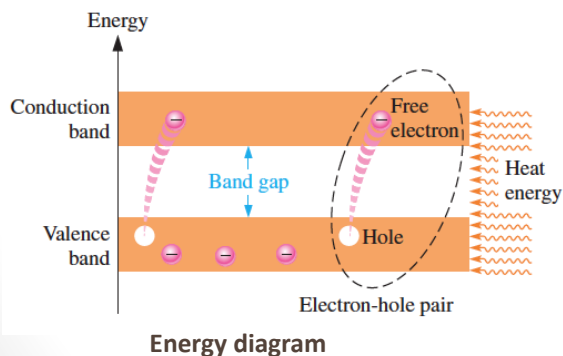
- Each shell around the nucleus corresponds to a certain energy band and is separated from adjacent shells by **band gaps**, in which **no electrons can exist**.
- The Figure shows the energy band diagram for an unexcited (no external energy such as heat) atom in a pure (**intrinsic**) silicon crystal.
- **This condition occurs only at a temperature of absolute 0 Kelvin.**



[ 11 ]

## Conduction Electrons and Holes

- An intrinsic (pure) silicon crystal at room temperature has sufficient heat (thermal) energy for some **valence electrons to jump the gap** from the valence band into the conduction band, becoming free electrons. **Free electrons are also called conduction electrons.**



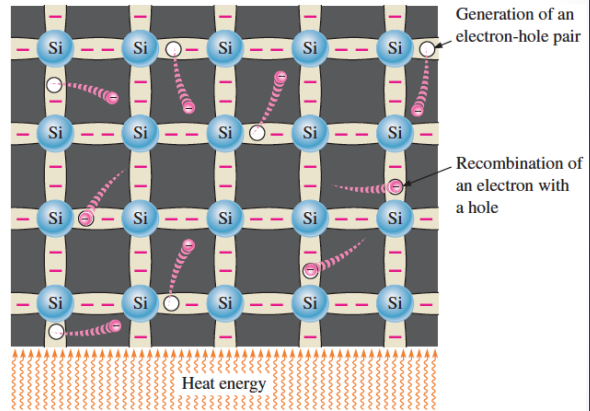
[ 12 ]

## Conduction Electrons and Holes

When an **electron jumps** to the conduction band, a **vacancy** is left in the valence band within the crystal.

This vacancy is called a **hole**. For every electron raised to the conduction band by external energy, there is one hole left in the valence band, creating what is called an **electron-hole pair**.

**Recombination** occurs when a conduction-band electron loses energy and falls back into a hole in the valence band.



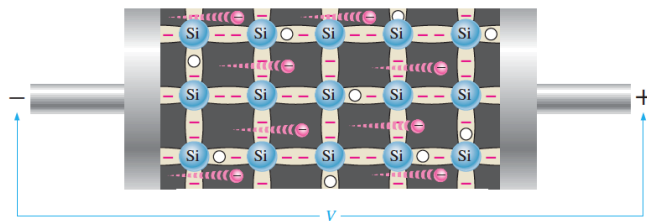
Electron-hole pairs in a silicon crystal.  
Free electrons are being generated continuously while some recombine with holes.

( 13 )

## Conduction Electrons and Holes

When a **voltage** is applied across a piece of intrinsic silicon, the thermally generated free electrons in the conduction band, which are free to move randomly in the crystal structure, are now easily attracted toward the positive end.

This movement of free electrons is one type of **current** in a semiconductive material and is called **electron current**.



Electron current in intrinsic silicon is produced by the movement of thermally generated free electrons.

( 14 )

# Conduction **Electrons** and **Holes**

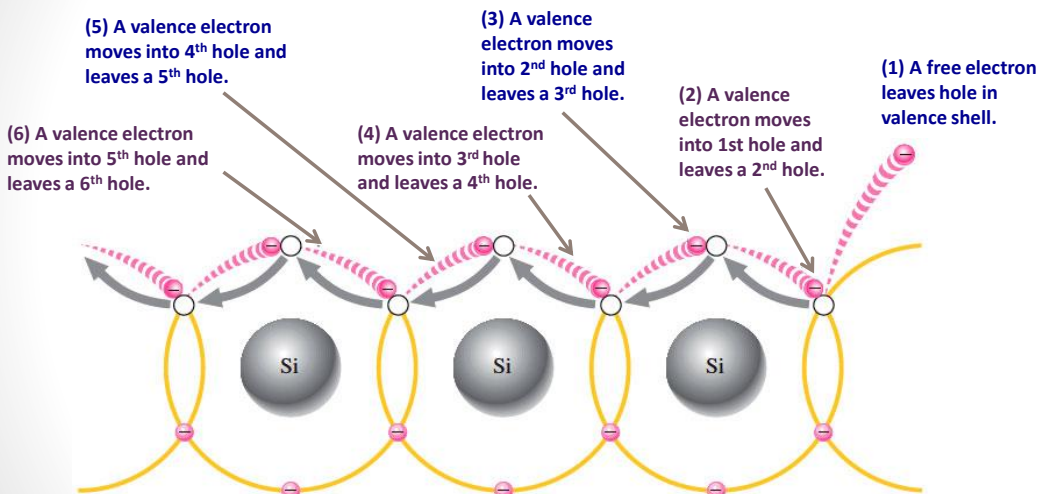
**Another type of current** occurs in the valence band, where the **holes** created by the free electrons exist.

Electrons remaining in the valence band are still attached to their atoms and are not free to move randomly in the crystal structure as are the free electrons. However, a valence electron can move into a nearby hole, thus leaving another hole where it came from.

Effectively the hole has moved from one place to another in the crystal structure, as illustrated in Figure.

Although current in the valence band is produced by valence electrons, it is called **hole current** to distinguish it from electron current in the conduction band.

## Holes Current



When a valence electron moves left to right to fill a hole while leaving another hole behind, the hole has effectively moved from right to left. Gray arrows indicate effective movement of a hole.



## Summary

- The electrons in the conduction band and the holes in the valence band are the **charge carriers**.
- Conduction in semiconductors is considered to be either the movement of free electrons in the conduction band or the movement of holes in the valence band, which is actually the movement of valence electrons to nearby atoms, creating hole current in the opposite direction.

**Current in the conduction band is by electrons; Current in the valence band is by holes.**

{ 17 }

## Questions

1. What is the basic difference between conductors and insulators?
2. How do semiconductors differ from conductors and insulators?
3. Why does a semiconductor have fewer free electrons than a conductor?
4. How are covalent bonds formed?
5. What is meant by the term intrinsic ?
6. Are free electrons in the valence band or in the conduction band?
7. Which electrons are responsible for electron current in silicon?
8. What is a hole?
9. At what energy level does hole current occur?

{ 18 }