

Introduction to semiconductor materials

Student Learning Outcomes

- Upon completion of viewing this presentation, you should be able to:
 - Define conductor, insulator and semiconductor, and state the resistance or conductance of each.
 - Name at least three semiconductor materials and state the most widely used.
 - Name the basic structure of material and explain how it is formed with atoms.
 - Define doping and name the two types of semiconductor material formed with doping.
 - Name the current carriers in N and P-type material.
 - Explain how current flows in semiconductor material.

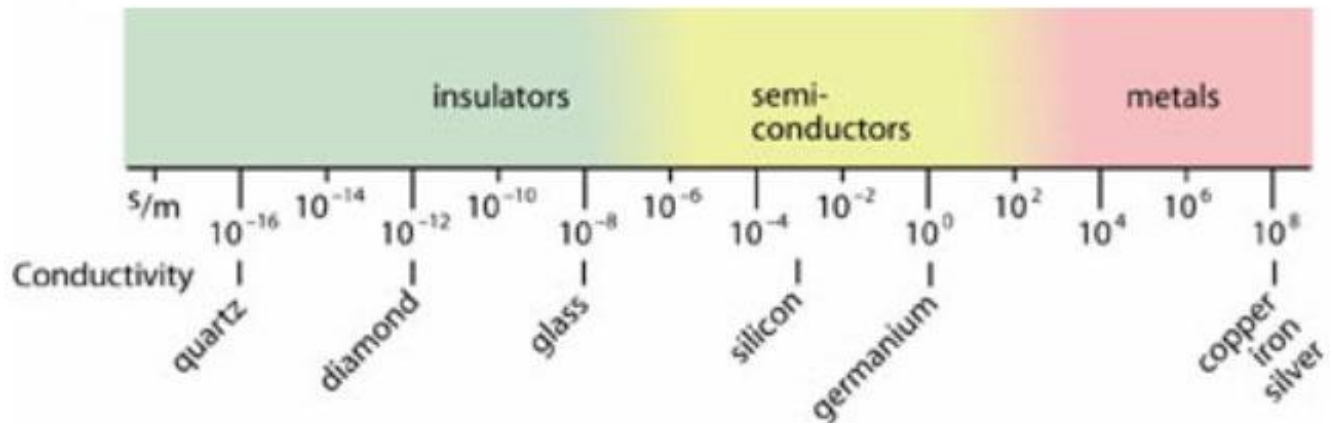
Electronic Materials

- The goal of electronic materials is to generate and control the flow of an electrical current.
- Electronic materials include:
 1. Conductors: have low resistance which allows electrical current flow
 2. Insulators: have high resistance which suppresses electrical current flow
 3. Semiconductors: can allow or suppress electrical current flow

What is a Semiconductor?

- Low resistivity \Rightarrow “conductor”
- High resistivity \Rightarrow “insulator”
- Intermediate resistivity \Rightarrow “semiconductor”

The conductivity (and at the same time the resistivity) of semiconductors lie between that of conductors and insulators.



Electronic Devices

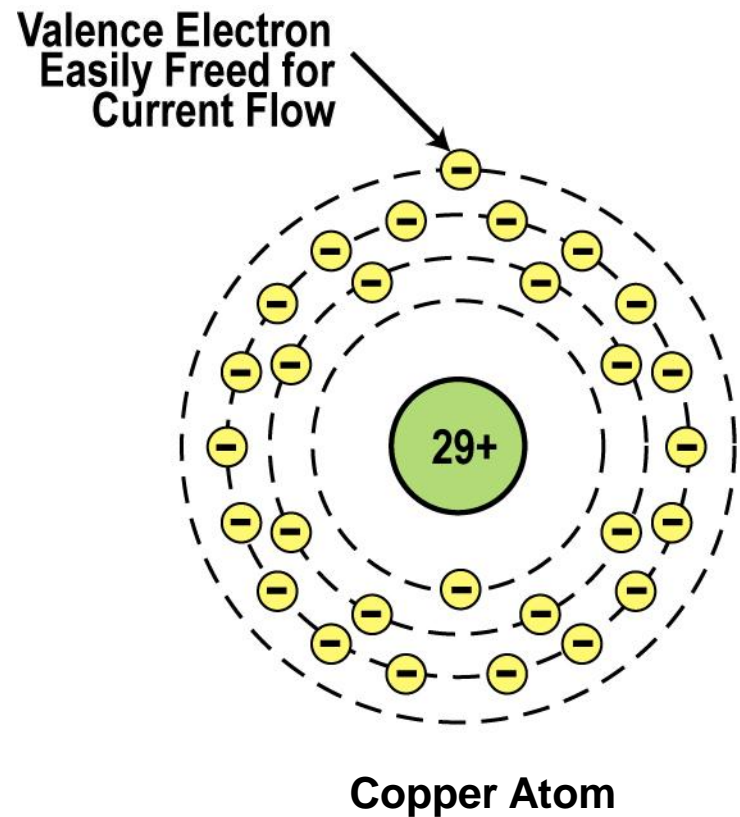
- Most electronic devices are made out of semiconductors, insulators, and conductors.
- Semiconductors
 - Old Days – Germanium (Ge)
 - Now – Silicon (Si)
 - Now – Gallium Arsenide (GaAs) used for high speed and optical devices.
 - New – Silicon Carbide (SiC) – High voltage Schottky diodes.

Conductors

- Good conductors have low resistance so electrons flow through them with ease.
- **Best** element conductors include:
 - Copper, silver, gold, aluminum, & nickel
- Good conductors can also be liquid:
 - Salt water

Conductor Atomic Structure

- The atomic structure of good conductors usually includes only one electron in their outer shell.
 - It is called a valence electron.
 - It is easily striped from the atom, producing current flow.



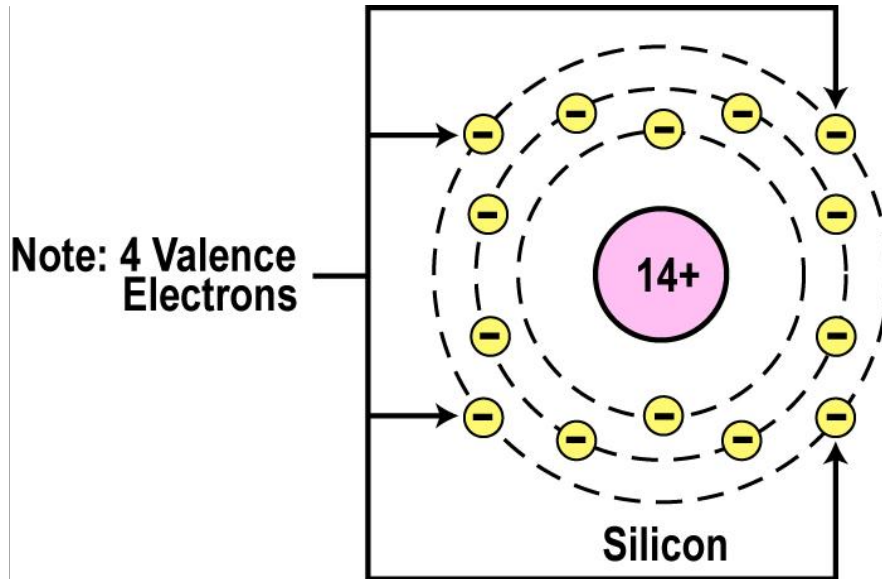
Insulators

- Insulators have a high resistance so current does not flow in them.
- Good insulators include:
 - Glass, ceramic, plastics, & wood
- Most insulators are compounds of several elements.
- The atoms are tightly bound to one another so electrons are difficult to strip away for current flow.

Semiconductors

- A material whose properties are such that it is not quite a conductor, not quite an insulator.
- Some Common S.M:
- elemental
 - carbon, silicon, and germanium
- Compound
 - GaAs - Gallium arsenide
 - AlAs - Aluminum arsenide

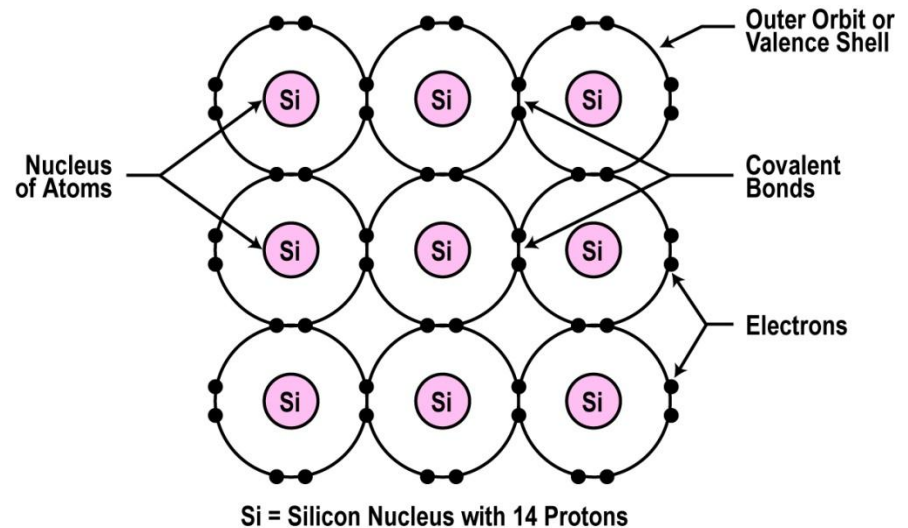
Semiconductor Valence Orbit



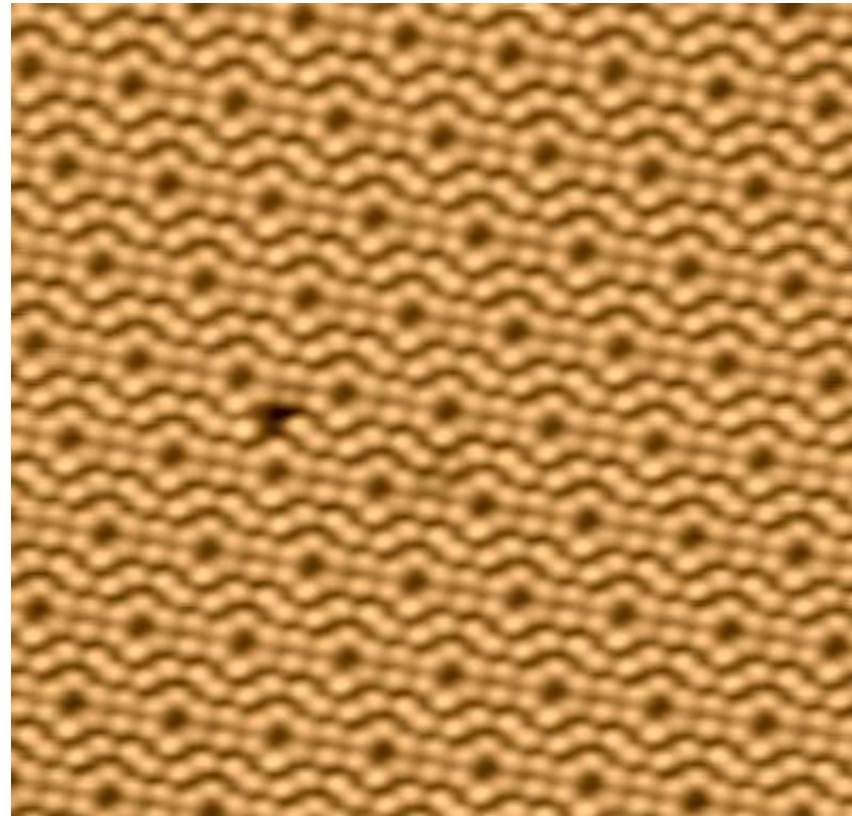
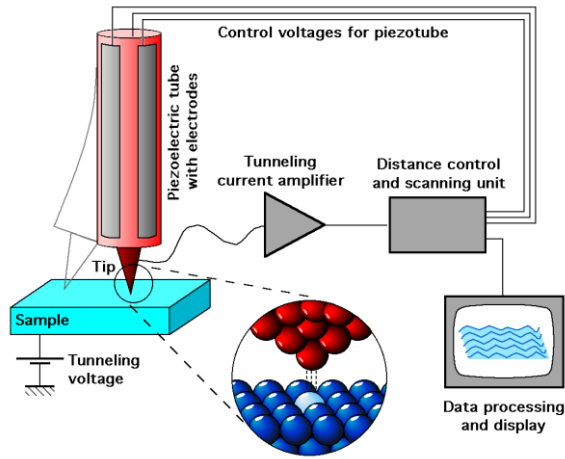
- The main characteristic of a semiconductor element is that it has four electrons in its outer or valence orbit.

Crystal Lattice Structure

- The unique capability of semiconductor atoms is their ability to link together to form a physical structure called a crystal lattice.
- The atoms link together with one another sharing their outer electrons.
- These links are called covalent bonds.



2D Crystal Lattice Structure



الإلكترونات داخل الذرات
Electrons in atoms

بالرسم الكرتوني : الإلكترونات
تدور في مسارات محددة

في الحقيقة : الإلكترونات
تتحرك بمسارات غير معلومة
بالتضيق ولكنها داخل سحابه
محددة الشكل

STM Topographic Image of Si (111) surface

Semiconductors can be Insulators

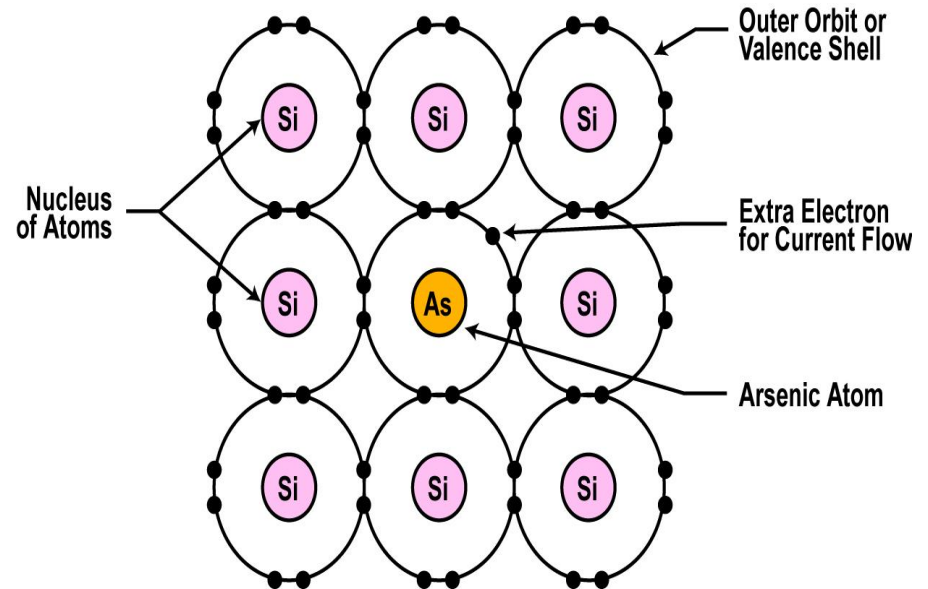
- If the material is pure semiconductor material like silicon, the crystal lattice structure forms an excellent insulator since all the atoms are bound to one another and are not free for current flow.
- Good insulating semiconductor material is referred to as intrinsic.
- Since the outer valence electrons of each atom are tightly bound together with one another, the electrons are difficult to dislodge for current flow.
- Silicon in this form is a great insulator.
- Semiconductor material is often used as an insulator.

Doping

- To make the semiconductor conduct electricity, other atoms called impurities must be added.
- “Impurities” are different elements.
- This process is called doping.

Semiconductors can be Conductors

- An impurity, or element like arsenic, has 5 valence electrons.
- Adding arsenic (doping) will allow four of the arsenic valence electrons to bond with the neighboring silicon atoms.
- The one electron left over for each arsenic atom becomes available to conduct current flow.

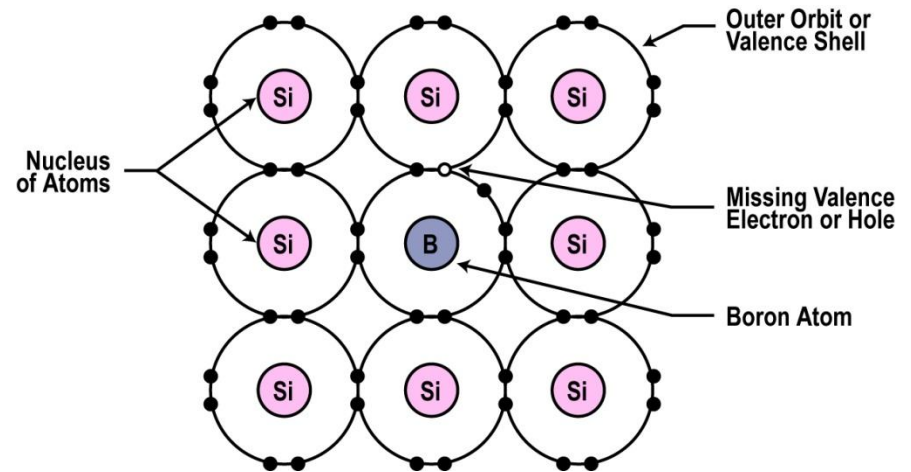


Resistance Effects of Doping

- If you use lots of arsenic atoms for doping, there will be lots of extra electrons so the resistance of the material will be low and current will flow freely.
- If you use only a few boron atoms, there will be fewer free electrons so the resistance will be high and less current will flow.
- By controlling the doping amount, virtually any resistance can be achieved.

Another Way to Dope

- You can also dope a semiconductor material with an atom such as boron that has only 3 valence electrons.
- The 3 electrons in the outer orbit do form covalent bonds with its neighboring semiconductor atoms as before. But one electron is missing from the bond.
- This place where a fourth electron should be is referred to as a hole.
- The hole assumes a positive charge so it can attract electrons from some other source.
- Holes become a type of current carrier like the electron to support current flow.

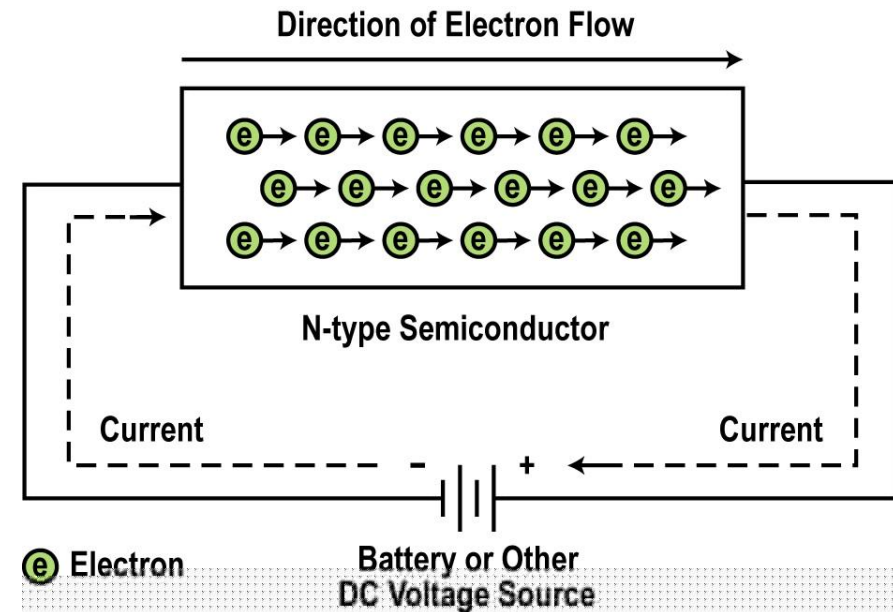


Types of Semiconductor Materials

- The silicon doped with extra electrons is called an “N type” semiconductor.
 - “N” is for negative, which is the charge of an electron.
- Silicon doped with material missing electrons that produce locations called holes is called “P type” semiconductor.
 - “P” is for positive, which is the charge of a hole.

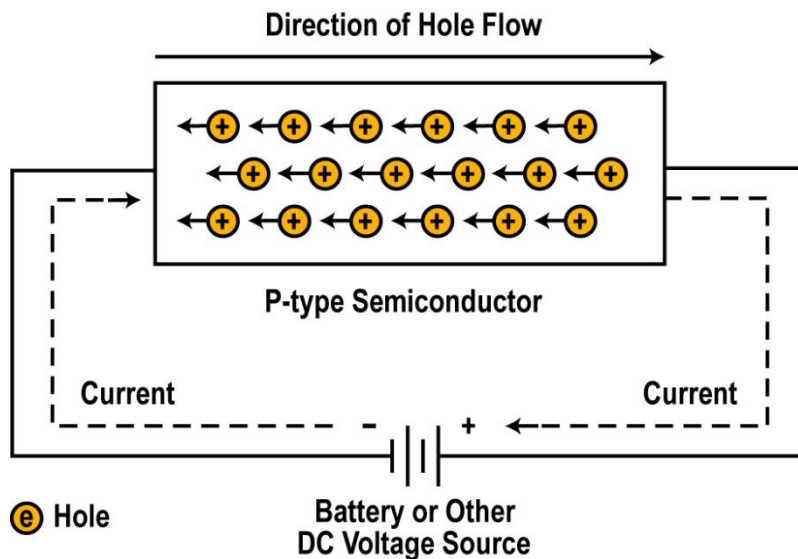
Current Flow in N-type Semiconductors

- The DC voltage source has a positive terminal that attracts the free electrons in the semiconductor and pulls them away from their atoms leaving the atoms charged positively.
- Electrons from the negative terminal of the supply enter the semiconductor material and are attracted by the positive charge of the atoms missing one of their electrons.



Current (electrons) flows from the positive terminal to the negative terminal.

Current Flow in P-type Semiconductors



- Electrons from the negative supply terminal are attracted to the positive holes and fill them.
- The positive terminal of the supply pulls the electrons from the holes leaving the holes to attract more electrons.
- Current (electrons) flows from the negative terminal to the positive terminal.
- Inside the semiconductor current flow is actually by the movement of the holes from positive to negative.

In Summary

- In its pure state, semiconductor material is an excellent insulator.
- The commonly used semiconductor material is silicon.
- Semiconductor materials can be doped with other atoms to add or subtract electrons.
- An N-type semiconductor material has extra electrons.
- A P-type semiconductor material has a shortage of electrons with vacancies called holes.
- The heavier the doping, the greater the conductivity or the lower the resistance.
- By controlling the doping of silicon the semiconductor material can be made as conductive as desired.

Terminology

donor: impurity atom that increases n

acceptor: impurity atom that increases p

N-type material: contains more electrons than holes

P-type material: contains more holes than electrons

majority carrier: the most abundant carrier

minority carrier: the least abundant carrier

intrinsic semiconductor: $n = p = n_i$

extrinsic semiconductor: doped semiconductor