Paper: DSE2BT (Digital & Analog Circuits & Instrumentation)

Topic: Semiconductor Diodes (Part-1)

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by

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Introduction

- Electronics is a branch of science and engineering which deals with the theory and applications of a class of devices in which electrons are transported through a vacuum, gas or semiconductor.
- The motion of electrons in such devices, called electron devices, is generally controlled by electric fields. Diodes, triodes, transistors etc. are examples of electron devices.

- Applications of electronics are now endless. Some of the very common examples are: Radio, TV, Mobiles, Computers, VCRs, Microwave ovens, digital watches comes under home-uses; Round-the-globe communication systems, sophisticated instruments in the field of experimental science, engineering, medical science etc.

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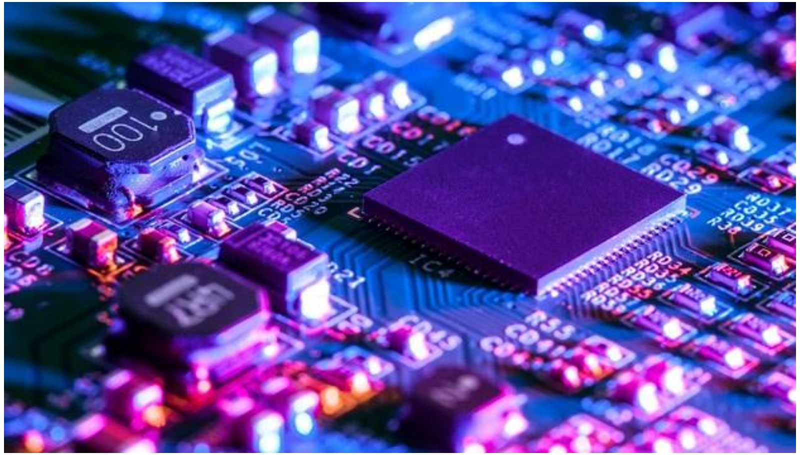
Introduction

❖ Electronics has inroads into many fields of science and engineering and has profoundly influenced our lives. Electronics has improved our living standards, but at the same time we are at the peril of deadly weapons that would not have existed without the progress of electronics.



❖ The modern day electronics is almost fully based on semiconductor technology.

❑ Semiconductor has revolutionized the electronics industry. It has reduced the size of the devices by orders of magnitude.

❑ Semiconductor devices have several other advantages over vacuum devices. Some of them are low power consumption, longer lifetime, low noise, low heating and comparatively cheaper.

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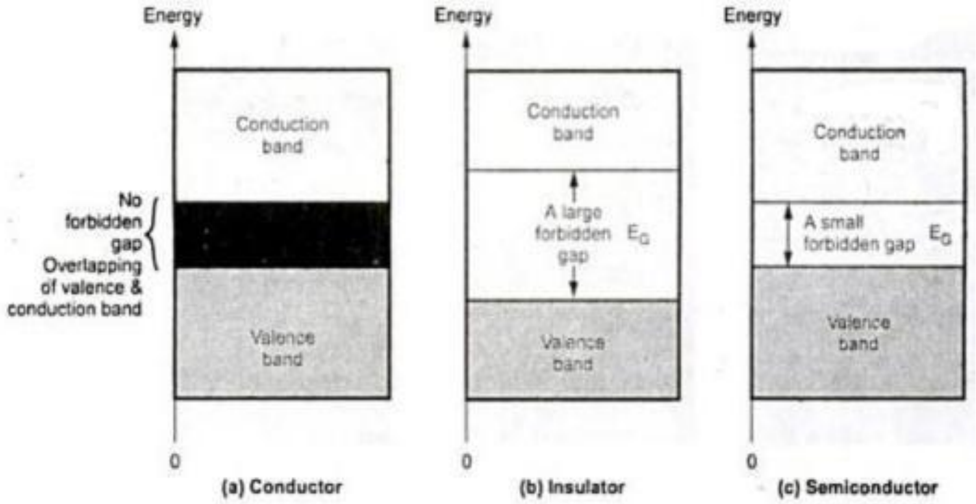
Classification of Materials - Band Structure

❑ We can classify solid crystalline materials into metals, insulators and semiconductors on the basis of band structure.

- Conductor: Uppermost energy band is partly filled - No forbidden gap. Ex- Cu, Ag, Fe etc.
- Insulator: Large forbidden Gap. Ex- Diamond, glass etc.
- Semiconductor: Small forbidden Gap (~ 1 - 2 eV). Ex- Si, Ge, GaAs etc.



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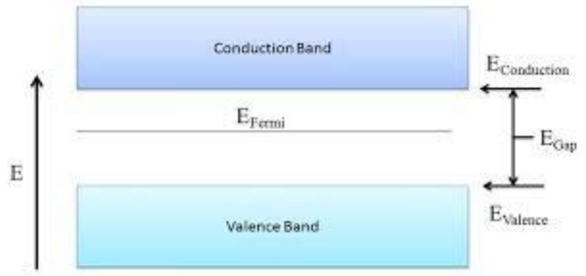
Basics of Semiconductors

- ❖ Semiconductors are a class of materials which have small but finite band-gap between the valence band and conduction band. Electrical conductivity of semiconductors lies between that of a metal and an insulator. Typical value of conductivity of semiconductors lies between 10^{-4} to 10^{5} s/m.
- ❖ Semiconductors have following additional properties:

(a) Negative temperature coefficient of resistance
(b) Upon irradiation by light, resistance changes
(c) Have high thermoelectric power of both signs
(d) When a suitable impurity is added, the conducting property changes



- ❑ The band gap of semiconductors lies in the range 0.2 to 2.5 eV. Due to this small band gap, electrons can be thermally excited from valence band to conduction band at ordinary (room) temperature in semiconductors.

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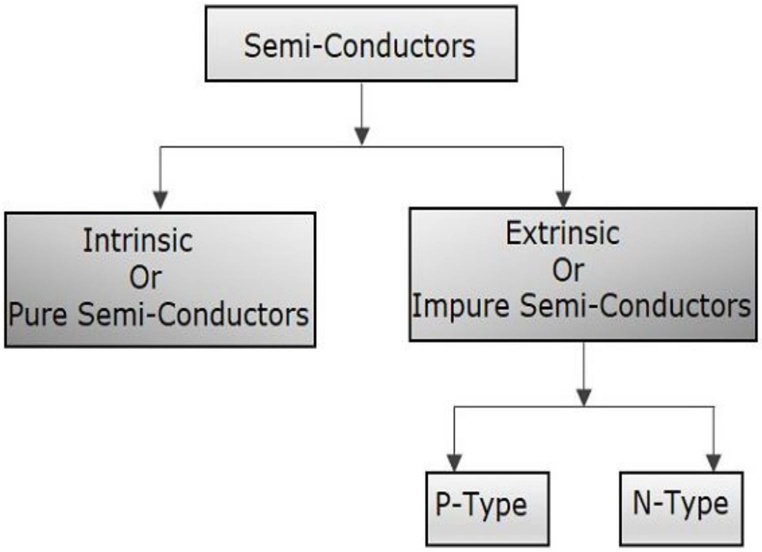
Basics of Semiconductors

- ❖ There are several elemental semiconductors like Ge and Si which are widely used in the semiconductor industry. Ge has a band gap of 0.67 eV while Si has 1.12 eV.
- ➢ Ge used to be the key material for the majority of early solid state devices. But, later on Si has replaced it because of better thermal stability and natural abundance.
- ❖ Compounds like GaAs, InP, InAs, CdS etc. also exhibit semiconducting properties.
- ❖ Alloys like $GaAs_xP_{1-x}$ is used in light-emitting diodes (LED), $In_{1-x}Ga_xAs$ in microwave and optoelectronic devices.
- ❑ Semiconductors can be broadly categorized In two types as shown in the right.



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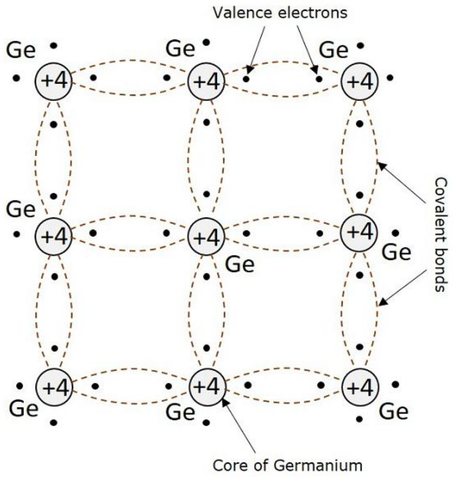
Intrinsic Semiconductors

- ❑ If the electrical conductivity of a semiconductor is entirely due to the carriers which are generated by the thermal excitation from valence band to the conduction band then it's called intrinsic or pure semiconductor.
- ❑ Properties of an intrinsic semiconductor:
  - ➢ The electrons and holes are solely created by thermal excitation.
  - ➢ The number of free electrons is equal to the number of holes.
  - ➢ The conduction capability is small at room temperature.
- ❑ Examples: Germanium and Silicon are two very important intrinsic semiconductors.
- ❖ The Two dimensional picture of Ge crystal is shown in the right. The four valence electrons of each Ge atom form covalent bonds with the nearest neighbour.



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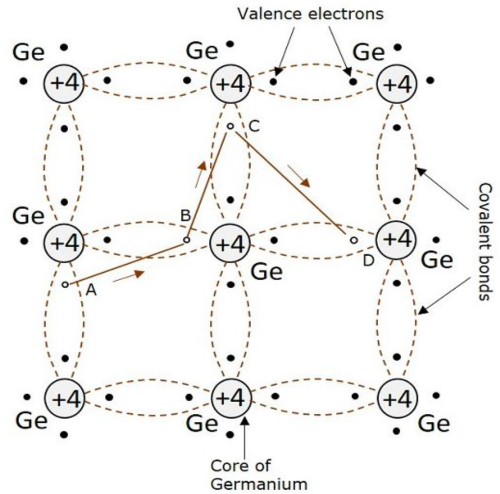
Intrinsic Semiconductors

- Since all the valence electrons bind one atom to another, they are not available for conduction in absence of thermal excitation. So, at absolute zero temperature (0 K), an intrinsic or pure semiconductor behaves like an insulator.
- At a finite temperature, some of the valence electrons get enough energy to break their covalent bonds and they become free to move in the crystal. The energy required to break the bond is the band gap energy; 0.67 eV for Ge.
- The vacancy in the bond caused by the free electron is called a hole.
- When a electron-hole pair is thermally created, a valence electron from a neighbouring atom can have sufficient thermal energy to jump into the position of the hole and reconstruct the covalent bond. The electron leaves a hole in its initial position. Thus the holes move in the direction opposite to that of electrons. The phenomenon is explained in the figure.



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Extrinsic Semiconductors

- **Doping:** The process of adding a small amount of impurities to a pure semiconductor is called doping. The impurities which are usually trivalent or pentavalent elements are called dopants. Free electrons and holes are generated by excitation from impurity atoms or dopants.
- **A semiconductor which has impurities is called doped or intrinsic semiconductor.** The electrical conductivity of an extrinsic semiconductor can be controlled by the amount of impurities doped.
- ➢ In Ge or Si, addition of a pentavalent (Group-V) impurity like P, Sb or As produces excess free electrons. Whereas, addition of trivalent (Group-III) impurity like In, B or Al creates extra holes.
- ❖ Depending upon the impurities added, an extrinsic semiconductor can either have excess electrons (n-type) or excess holes (p-type).

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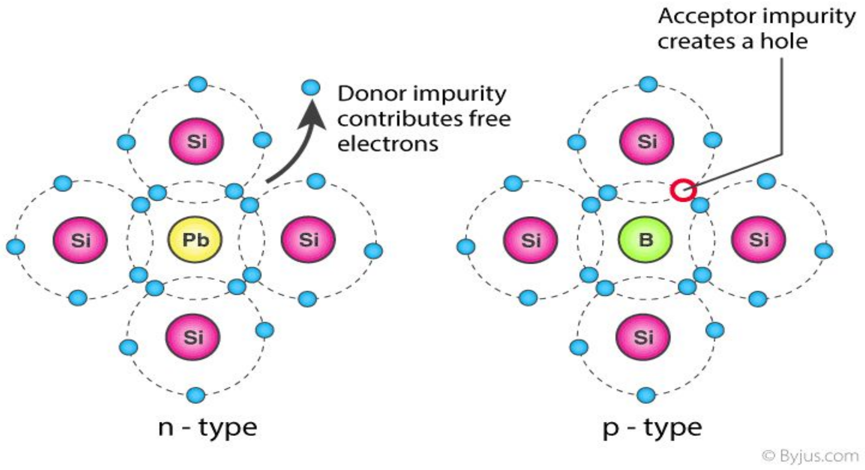
Extrinsic Semiconductors

- There are two types of extrinsic semiconductors: n-type and p-type

- n-type semiconductor: When a pentavalent impurity is added to tetravalent pure semiconductor like Ge or Si, there is excess of electrons in the material. Such impurity is called **donor** as it donates one electron to the conduction band. Here, electrons are majority carriers and holes are minority carriers.
- p-type semiconductor: When a trivalent impurity is added to tetra-valent pure semiconductor like Ge or Si, there is excess of holes in the material. Such impurities are called **acceptor** as it accepts electron from the semiconduc tor. Here, holes are the majority carriers and electrons are minority carriers.



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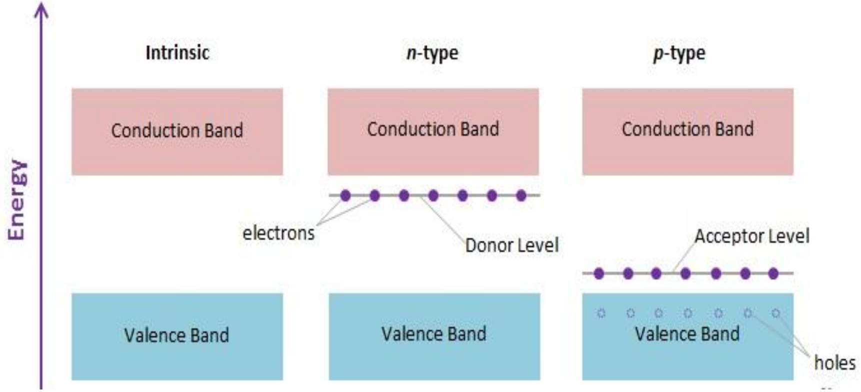
Band diagrams of n-type and p-type Semiconductors

❖ Here we compare energy band diagrams of n-type and p-type semiconductors with that for intrinsic semiconductors.

- n-type semiconductor: When donor impurities are added, an allowable energy level corresponding to the loosely bound valence electron of the donor is introduced iust below the conduction band. For doped Ge and Si, the donor level is about 0.01 and 0.05 eV respectively. At room temperature, most of the donors are ionized as the extra electrons are excited to the conduction band.



- p-type semiconductor: The unfilled energy level produced by the introduction of acceptor impurities lies just above the valence band. This allowable energy level is called acceptor level. Since a very small amount of energy is required by an electron to leave the valence band and occupy acceptor level, the acceptors are fully ionized at room temperature.

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