Al-Mustaqbal University College

Biomedical Engineering Department

Electronics

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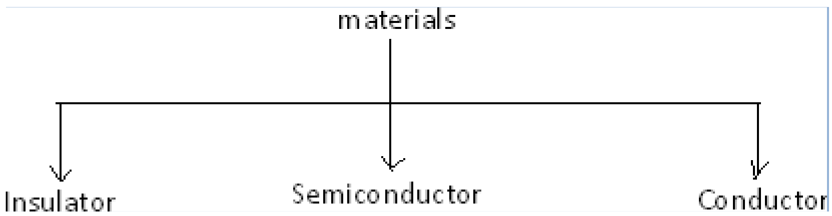
Third year T

LECTURE 1:

Semiconductor Materials and PN Junction Diode

INTRODUCTON

Based on the electrical conductivity all the materials in nature are classified as insulators, semiconductors, and conductors.



- The term conductor is applied to any material that will support a generous flow of charge when a voltage source of limited magnitude is applied across its terminals.
- An insulator is a material that offers a very low level of conductivity under pressure from an applied voltage source.
- A semiconductor, therefore, is a material that has a conductivity level somewhere between the extremes of an insulator and conductor.

Most of the electronic devices are made from semiconductor material because the energy levels of a semiconductor can be modified so that a material (e.g. silicon or germanium) that is normally an insulator will conduct electricity (see Fig. 1). Energy level structure of a semiconductor is quit complicated, requires a quantum mechanical treatment.

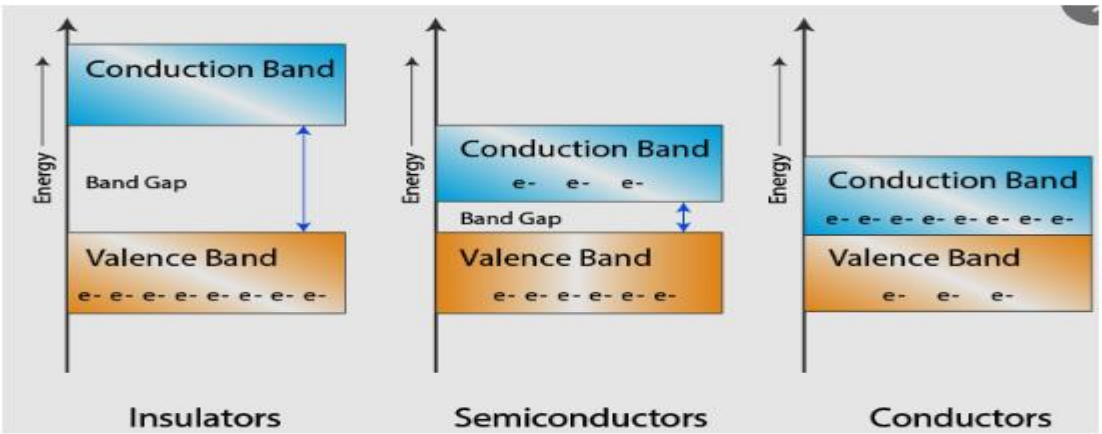


Fig. 1: Energy band gaps in materials.

EXTRINSIC SEMICONDUCTOR

Intrinsic semiconductor has very limited applications as they conduct very small amounts of current at room temperature. The current conduction capability of intrinsic semiconductor can be increased significantly by adding a small amounts impurity to the intrinsic semiconductor. By adding impurities it becomes impure or extrinsic semiconductor. This process of adding impurities is called as doping.

• ***Doping***: is a process where impurities are added to the semiconductor to lower its resistivity.

- ✓ Silicon has 4 electrons in its valence level.
- ✓ We add atoms which have a different number of valence shell electrons 3 or 5 to a piece of silicon to build P-Type or N-Type silicon structure, respectively.
- ✓ Phosphorous, Arsenic and Antimony have 5 valence electrons.
- ✓ Boron, Aluminum and Indium have 3 valence electrons.

N-Type Semiconductor:

Adding atoms which have 5 valence electrons makes the silicon more negative. The majority carriers are the excess electrons as shown in **Fig. 2**

P-Type Semiconductor:

Adding atoms which have 3 valence electrons makes the silicon more positive. The majority carriers are "holes" and the minority carriers are electrons as shown in **Fig. 2**. A hole is the lack of an electron in the valence shell.

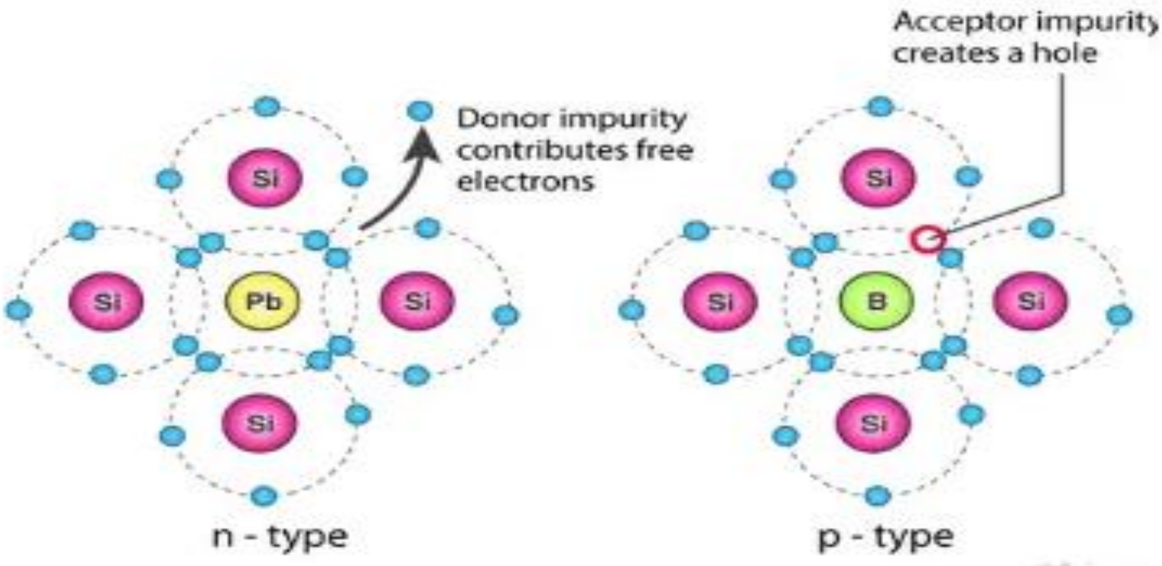


Fig. 2: N-Type & P-Type Semiconductor

The PN Junction:

When we take a block of silicon and dope part of it with a trivalent impurity and the other part with a pentavalent impurity, a boundary called the pn junction is formed between the resulting p-type and n-type portions. The pn junction is the basis for diodes, certain transistors, solar cells, and other devices.

If a piece of intrinsic silicon is doped so that part is n-type and the other part is p-type, a pn junction forms at the boundary between the two regions and a diode is created,

The p region has many holes (majority carriers) from the impurity atoms and only a few thermally generated free electrons (minority carriers). The n region has many free electrons (majority carriers) from the impurity atoms and only a few thermally generated holes (minority carriers).

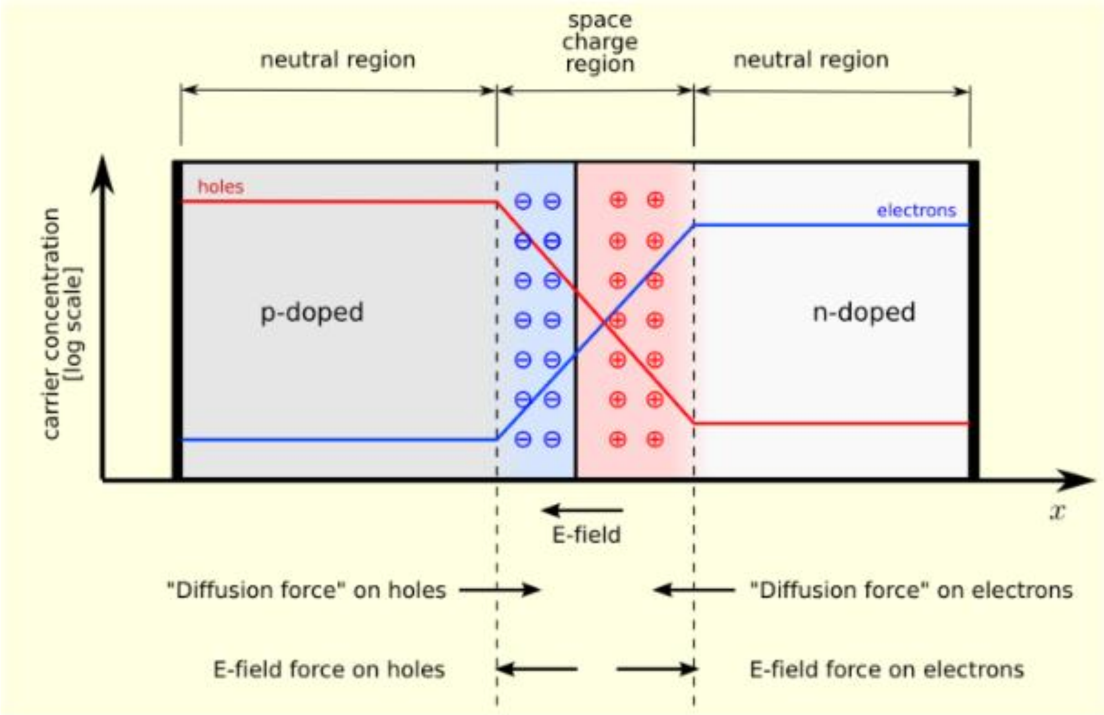


Fig.3 PN Junction

The Depletion Region

The free electrons in the n region are randomly drifting in all directions. At the instant of the pn junction formation, the free electrons near the junction in the n region begin to diffuse across the junction into the p region where they combine with holes near the junction,

Before the pn junction is formed, recall that there are as many electrons as protons in the n-type material, making the material neutral in terms of net charge. The same is true for the p-type material.
When the pn junction is formed, the n region loses free electrons as they diffuse across the junction. This creates a layer of positive charges near the junction.
As the electrons move across the junction, the p region loses holes as the electrons and holes combine. This creates a layer of negative charges near the junction.
These two layers of positive and negative charges form the depletion region, The term depletion refers to the fact that the region near the pn junction is depleted of charge carriers (electrons and holes) due to diffusion across the junction. The depletion region is formed very quickly and is very thin compared to the n region and p region.

Barrier Potential

The potential barrier in the PN-junction diode is the barrier in which the charge requires additional force for crossing the region. In other words, the barrier in which the charge carrier stopped by the obstructive force is known as the potential barrier

How It gets established?

When the P and N-type semiconductor material are placed together, the gradient of very large density charge carriers is created on both the P and N side region. The free electrons from N-side cross the region and start combining with the holes, leaving behind the immobile positive donor ions. Similarly, the holes of the P-region combine with the electrons of the N-region and leaving behind the negative acceptor ions.

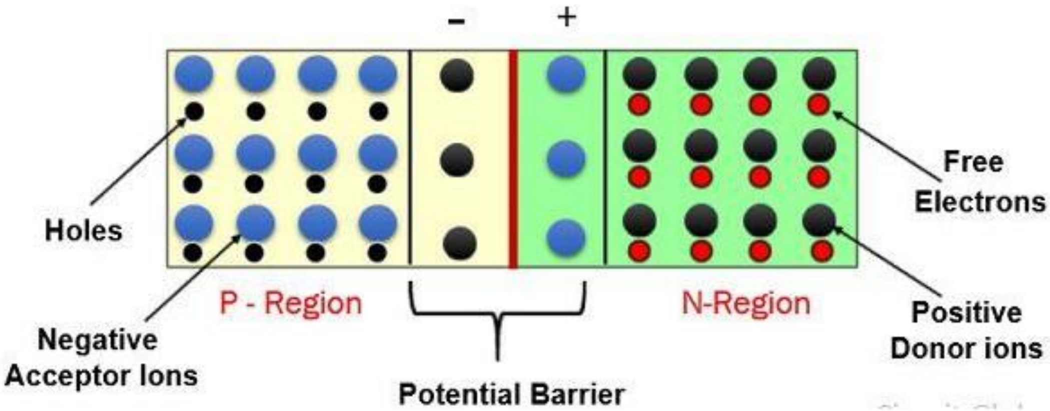


Fig.4 Barrier Potential

The Diode Symbol

The lead attached to the n-type semiconductor is called the cathode. Thus, the cathode is the negative side of the diode. The positive side of the diode that is, the lead attached to the p-type semiconductor is called the anode.
When a voltage source is connected to a diode such that the positive side of the voltage source is on the anode and the negative side is on the cathode, the diode becomes a conductor and allows current to flow. Voltage connected to the diode in this direction is called forward bias.

But if you reverse the voltage direction, applying the positive side to the cathode and the negative side to the anode, current doesn't flow. In effect, the diode becomes an insulator. Voltage connected to the diode in this direction is called reverse bias.

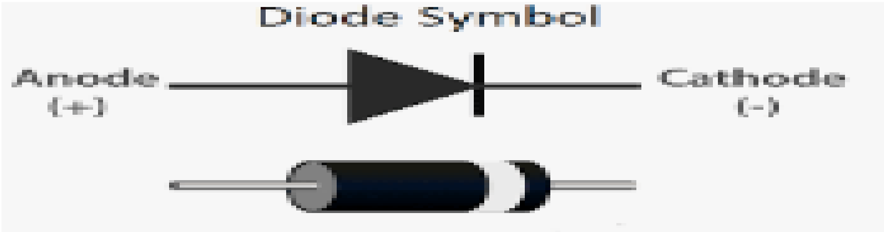


Fig. 5 The schematic symbol for the diode.

Types of diodes:

There are many types of diodes for many applications as:
1- Junction diode (ordinary type).
2- Light Emitting Diode (LED).
3- Photodiodes (absorbs light, gives current).
4- Schottky diode (high speed switch).
5- Tunnel diode
6-Veractor diode (varies with voltage).
7- Zener diode (special junction diode, use reversed biased)

Operation States of Diode

There are two important states for a *pn* junction, the reversed biased and forward biased state

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1- Forward Biased State

When V is large enough so that $E_{battery} > E$, then
(i) Holes are swept from the *p* to *n* regions, and

(ii) Electrons are swept from the *n* to *p* regions.

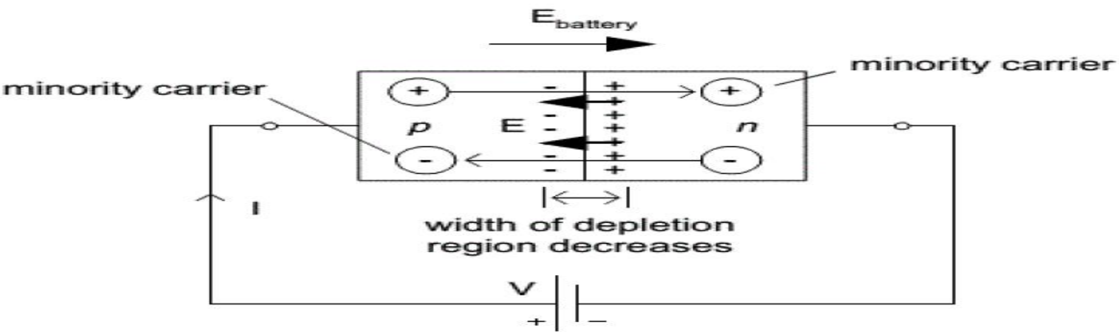

Fig. 6 Forward Biased State

2- Reversed biased state

The electric field produced by the battery E battery adds to this electric field of the space charge E in the depletion region. This increases the width of the depletion region. Consequently, the "majority carriers" cannot flow through the region: holes in the p material are opposed by E in the depletion region, as are electrons in the n material. Hence, little current flows (only the drift current IS) unless the junction breaks down. This occurs when Ebattery is strong enough to strip electrons from the covalent bonds of the atoms, which are then swept across the junction.

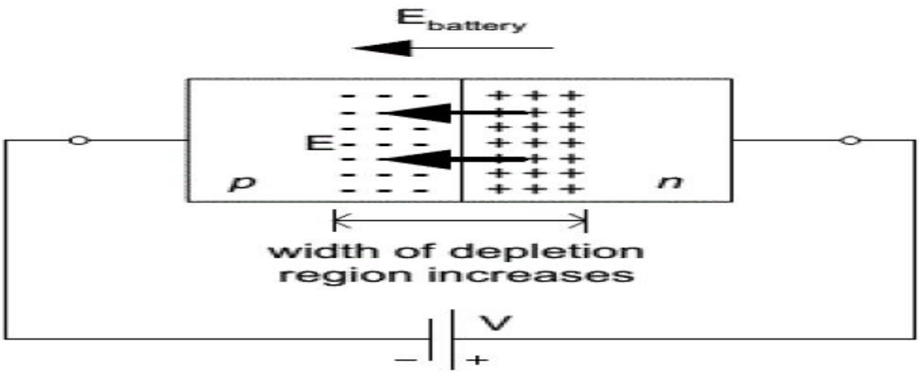

Fig. 7 Reversed biased state