Semiconductor Diodes & Transistors

Electronic Devices

The devices whose action is based on the controlled flow of electrons through it is called an electronic devices. Electronic devices sire the building blocks of all the electronic circuits.
The electronic devices are two types:

1. **Vacuum tubes:** Vacuum diodes (cathode, anode) triode (three electrodes) and pentode (five electrodes) etc.
2. **Solid state electronic devices:** The semiconductors are the basic materials for designing the solid state electronic devices such as junction diode (2-electrodes), transistor (3-electrodes) and integrated circuits (IC).
   The solid state devices are better than vacuum tubes because vacuum tubes are bulky, consume high power and voltage (≈100 V), low life and low reliability while solid state devices are small in size, consume low power and low voltage, long life and high reliability.

Energy levels and energy bands

(a) Energy Levels in Atoms: In an atom electrons revolve around the nucleus in almost circular orbits of different radii representing shells and subshells. Energy of electrons in each subshell is definite. These definite energy values, are called energy levels of the atoms. Hence, each electrons will have a different energy levels.
They are represented by straight lines drawn parallel to each other at distances proportional to the energy they represent.

(b) Energy Bands in Solids (Crystals): In a crystal, atoms are packed very closely. A crystal of volume 1 c.c. has about 10^{23} closely packed atoms. The energy levels (values) of electrons in outer shells are influenced in the presence of nuclei of other atoms. Due to interatomic interaction, the different energy levels with continuous energy variation form is called energy band.

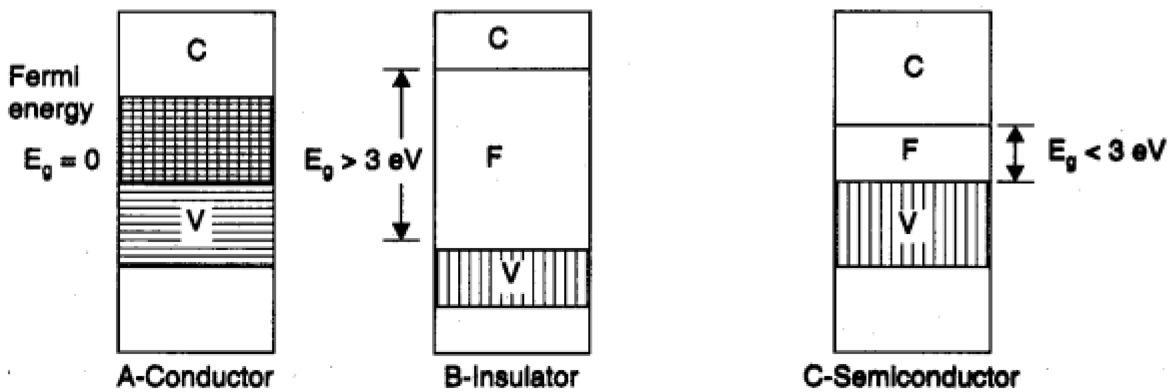
Different types of energy bands

1. **Conduction Band (C):** The topmost partially filled band, is called Conduction band. It is so called because by accommodating more electrons in itself, the band provides mobility to electrons and helps in conduction.
2. **Valence Band (V):** The energy band which includes the energy levels of the valence electrons is called the valence band. It is lower most completely filled band.

3. **Forbidden Band (F):** The band separating a valence band and conduction band, is called Forbidden band. The difference in the extreme energy levels of the forbidden band, is called energy gap (E_g).

Conductors, insulators and semiconductors

1. **Conductors:** In case of conductors, the partially filled conduction band (C) and the valence band (V) overlap. Electrons of valence band move freely in partially filled conduction band.
   Free electrons are available for movement even when small electric field is applied. Electric current flows.
2. **Insulators:** In case of insulators, the empty conduction band (C) and the valence band (V) have an energy gap (E) of about 6 eV Due to large energy gap, no electrons jumped from valence band to empty conduction band. Valence band remains completely filled.



Energy bands.

   No electron movement takes place even when large electric field is applied. No electric current flows.
   An important example of insulator is diamond with energy gap of about 5.4 eV.

3. **Semiconductors:** In case of semiconductors, the partially filled conduction band (C) and the valence band (V) have an energy gap (E_g) of about leV . Due to small energy gap some electrons may gain sufficient thermal energy at ordinary room temperatures and enter the empty conduction band to make it partially filled.
   Electrons reaching conduction band, leave electron vacancy (hole) in valence band.
   Due to vacancy in valence band, some electron movement may take place when a moderate electric field is applied. A weak electric current flows.
   Common examples of semiconductors are Silicon (14) and Germanium (32) with energy gaps of about 1.2 eV and 0.73 eV respectively.

Intrinsic and extrinsic semiconductors

(a) Intrinsic Semiconductor: A pure semiconductor material, is called intrinsic semiconductor. Crystalline form of Germanium (Ge) and Silicon (S_i) are examples of intrinsic semiconductors. Concentration of holes (n_h) = concentration of electrons (n_e) in pure semiconductor.

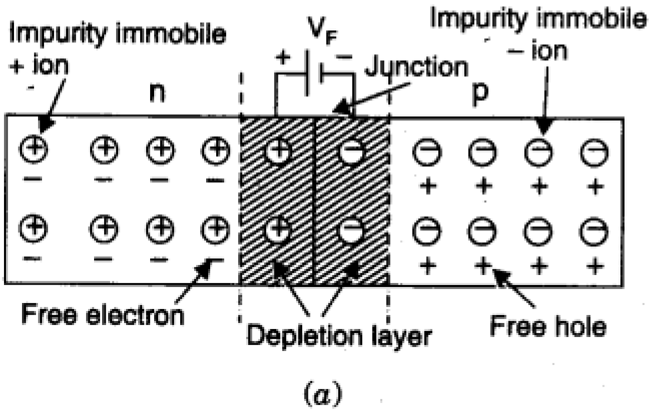
(b) Extrinsic Semiconductor: A semiconductor material made deliberately impure by adding suitable impurity atoms through doping, is called an extrinsic semiconductor.
It is of two types:

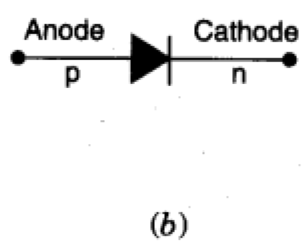
1. **N-type semiconductor:** The re-type semiconductor is obtained by adding a small quantity (one millionth part) of a pentavalent impurity like Phosphorus (15), Arsenic (33), Antimony (51) or Bismuth (83) to a pure semiconductor crystal. Generally Arsenic (As) is taken for this purpose. $N_e >> n_h$

2. **P-type semiconductor:** Ap-type semiconductor is obtained by adding a small quantity (one millionth part) of a trivalent impurity like Boron (5), Aluminium (13), Gallium (31), Indium (49) or Thalium (81) to a pure semiconductor crystal. Generally Indium (In) is taken for this purpose. $N_h >> ne$
The process of adding impurity deliberately, is called doping.

Semiconductor diode (Junction Diode)

(a) Preparation: When a p-type semiconductor crystal is grown over an n-type semiconductor crystal (or vice-versa), the common surface of the two types, is called a junction. The compound crystal forms a semi-conductor device, called junction diode





p-n junction diode
(*a*) Block diagram (*b*) Symbol.

(b) Description: Two important processes occur during the formation of a p-n junction. Diffusion and drift. Due to higher concentration of holes in p-section, holes diffuse from p-side to re-side and leaves befind an ionised negative charge which is immobile.

As the holes continue to diffuse, a layer of negative charge on the p-side of the junction is developed. Similarly, electrons diffuse due to its high concentration from re-side to p-side and leaves befind the positive charge which is immobile.

As the electrons continue to diffuse, a layer a positive on re-side developed. This space charge region on either side of the junction together is known as depletion layer. Due to diffusion, an electric field set-up directed from positive charge (re-side) to negative charge (p-side).

Due to this field, electrons drift from p-side to re-side and holes from re-side to p-side, making a drift current which is opposite to diffusion current. Initial, diffusion current is large and drift current is small, but when these current become equal, the p-n junction is formed.

The loss of electrons from re-region and gain of electrons in p-region causes a potential difference across the junction of the two region. It is called potential barrier. This potential barrier tends to prevent further flow of electrons from re-region to p-region.

$$V_F = 0.3 \text{ V for Ge}$$
$$V_F = 0.7 \text{ V for Si}$$

Biasing of junction

(a) Definition: Applying an external potential difference on the faces of a junction, is called biasing of the junction.
It is done by connecting the outer ends of the two sections of the junction diode to the positive and the negative terminals of a battery (source of potential difference).

(b) Type: It has two types:

(1) Forward biasing (2) Reverse biasing

1. **Forward Biasing:** When outer end of re-type section is connected to the negative terminal and that of p-type section is connected to the positive terminal, the biasing of junction is called forward biasing.
   The free majority charge carriers from each section are made to move forward towards the junction. IF forward bias potential is more than potential barrier, the charges from both sections cross the junction and a current flows through the junction and the circuit. It is called forward current. It is formed due crossing the junction by majority carriers. It is order of 10-3 A. The size of depletion layer decreases in forward biasing and hence resistance decreases.

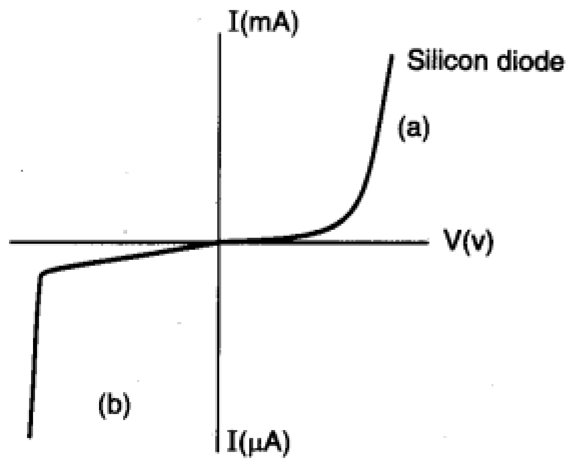
2. **Reverse Biasing:** When outer end of re-type section is connected to the positive terminal and that of p-type section is connected to the negative terminal, the biasing of junction is called reverse biasing.
   The free majority charge carrier from each section are made to move in reverse direction, away from the junction. The majority carrier charges do not cross the junction and no current flows through the junction due to flow of majority carriers. The minority carrier charge are made to move toward the junction due to reverse biasing. The minority carrier charge cross the junction and there is very small current order to micron across the junction. The size of depletion layer increases in reverse biasing and hence resistance increases.

Characteristics of a junction diode

(a) Definition: Graphs drawn between bias voltage and current of a junction diode, are called characteristics of the diode. They reveal the character (way of behaviour) of the junction diode.

(b) Type: These are of two types:

(1) Forward Bias Characteristic: This is obtained by plotting a graph between forward bias voltage and forward current. Junction resistance for forward bias is about 10 ohm.
(2) Reverse Bias Characteristic: This is obtained by plotting a graph between reverse bias voltage and reverse circuit current. Junction resistance for reverse bias is about 10,000 ohm.



V-I characteristics curve of a *p-n* junction diode
(*a*) in forward bias (*b*) in reverse bias.

Zener diode

A specially designed junction diode with a heavily doping to operate in the reverse breakdown region is called a zener diode.
(a) Principle: It works on phenomenon of Zener breakdown at reverse voltage, for

which large changes in diode current produce only a small change in diode voltage. This makes the zener diode to use as the voltage regulator.

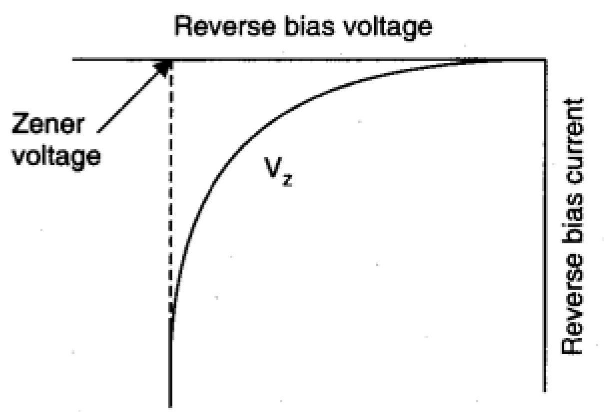
(b) Zener Breakdown: When the junction diode is reverse biased, free charge carriers are attracted away, (in reverse direction) from junction. As the charges do not cross the junction, no current flows in external circuit.

As bias voltage is increased, covalent bonds between atoms break, setting more electrons and holes free in each section. The free holes in n-type section and free electrons in p-type section, are called minority carriers.
The reverse bias makes these minority carriers move towards junction and cross it. Thus a current flows through junction and in opposite direction. The current is very small.

At a certain reverse bias voltage, a breakdown takes place and the current rises suddenly. The breakdown is called Zener breakdown and the voltage is called Zener voltage (V_z).

When the reverse bias voltage V = Vz, then the electric field strength is high enough to pull valence electrons from the host atoms on the p-side which are accelerated to n-side These electrons account fer high current observed at the breakdown.

The emission of electrons from the host atoms due to high electric field is known as internal field emission or field Ionisation. The situation is shown in Fig. 10.04. There is a large change in diode current for a small change in diode voltage.



Semiconductor triode (junction triode) or transistor

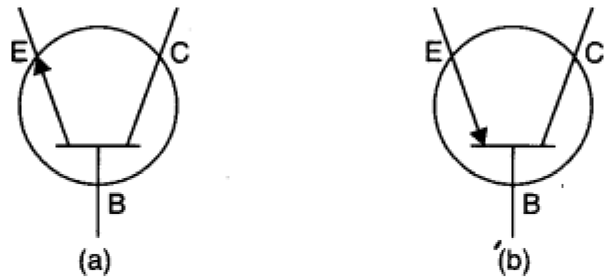
Introduction. When a thin layer of one type lightly doped semiconductor is grown between two comparatively broad sections of other type heavily doped semiconductor, the arrangement forms a semiconductor device called Junction Triode or Transistor. There are two types of transistors

1. n-p-n transistor
2. p-n-p transistor.

n-p-n transistor. It is formed by growing a thin layer of p-type semiconductor over n-type semiconductor crystal. Then a thicker layer of n-type is grown over p-type thin layer. The first thick layer section is called Emitter (E), the second thin layer is called Base (B), the third layer is called Collector (C) Emitter, base and collector from the three important terminals, hence the name 'triode'.

The level of doping is more in emitter than in collector. But collector section is larger than emitter section. The thin base layer is lightly doped.
The symbol of an n-p-n transistor is given in is the symbol of a p-n-p transistor. Arrow in emitter represents direction of flow of positive charge in the emitter.

Symbols



Transistor symbols (a) n-p-n (b) p-n-p.

Characteristic of a transistor

(a) Definition: Graphs drawn between bias voltage and current in the circuit, are called characteristics of the transistor. They reveal the character (way of behaviour) of the transistor.

(b) Types: These are of two types:

1. **Input Characteristics:** In common base circuit, these are obtained by plotting graphs between emitter voltage (V_e) and emitter current (I_e) for different constant collector voltage (V_c).
   In common emitter circuit, these are obtained by plotting graphs between base voltage (V_b) and base current (I_b) for different constant collector voltage (V_c).

2. **Output Characteristics:** In common base circuit, these are obtained by plotting graphs between collector voltage (V_c) and collector current (I_c) for different constant emitter current (I_e).
   In common emitter circuit, these are obtained by plotting graphs between collector voltage (V_c) and collector current (I_c) for different constant base current (I_b).