Electronic devices-I

Semiconductor Devices is one of the important and easy units in class XII CBSE Physics syllabus. It is easy to understand and learn. Generally the questions asked are simple.

The unit carries 7 marks. In order to help you prepare this unit, I am starting a series of posts and plan to cover all the important parts in the unit shortly in subsequent posts.

To begin with the easy thing first, I posted Logic Gates as a part of the MLL (Minimum Level of Learning).

GET STARTED:
HAPPY LEARNING!

Difference between conductors, insulators and semiconductors

In conductors, valence and conduction bands overlap or the conduction band is partially filled i.e. there is no gap between VB and CB as shown below.

![Overlapping conduction band](image)

In an insulator the valence band is completely filled. The conduction band is empty and is separated from the conduction band by a large forbidden gap (> 3 eV) as shown below.

![Insulator](image)

In a semiconductor there is forbidden gap < 3 eV. At OK all energy levels are occupied and the material acts as an insulator. At room temperature (nearly 300 K), some of the electrons from the VB jump across the gap to the conduction band. This transition excites electrons to the conduction band leaving holes in the valence band. Both the both holes and electrons contribute to conduction.
DOPING:
Doping is the process of deliberate addition of a certain amount of impurity to a pure semiconductor to suitably modify its conduction properties to a desired level.

Need of doping:
1. Pure semiconductors at 0K act as insulators. At room temperatures (i.e., 300 K), they have a poor conduction. Doping helps to increase the number of available charge carriers in the semiconductor and hence improve the conduction to a desired level through controlled doping.
2. Conduction in a pure semiconductor improves rapidly with rise in temperature. (The behavior of pure semiconductor depends on temperature). Doping of the semiconductor helps to reduce this temperature dependence.

The charge carriers which contribute to conduction in a semiconductor are
(i) Electrons (ii) Holes

The two types of doped semiconductors are
(a) n-type semiconductor (dopant used: group 15 e.g., P, Sb, Bi)
(b) p-type semiconductor (dopant used: group 13 e.g., Al, In)

Energy Band diagrams of the two types of semiconductor are as under:

### DIFFERENCE BETWEEN P & N-TYPE SEMICONDUCTORS:

<table>
<thead>
<tr>
<th>n-type semiconductors</th>
<th>p-type semiconductors</th>
</tr>
</thead>
<tbody>
<tr>
<td>These are extrinsic semiconductors obtained by adding impurity atoms of group 15 to Ge or Si crystal.</td>
<td>These are extrinsic semiconductors obtained by adding impurity atoms of group 13 to Ge or Si crystal.</td>
</tr>
<tr>
<td>The impurity atoms added provide free electrons and are called donors.</td>
<td>The impurity atoms provide holes and are called acceptors.</td>
</tr>
<tr>
<td>The donor impurity level lies just below the conduction band.</td>
<td>The acceptor impurity level lies just above the valence band.</td>
</tr>
<tr>
<td>The electrons are majority charge carriers while holes are minority charge carriers.</td>
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</tr>
<tr>
<td>( i.e., n_e &gt; n_h )</td>
<td>( i.e., n_h &gt; n_e )</td>
</tr>
</tbody>
</table>

### DIFFERENCE BETWEEN INTRINSIC AND P-TYPE SEMICONDUCTOR:

<table>
<thead>
<tr>
<th>Intrinsic semiconductor</th>
<th>p-type semiconductor</th>
</tr>
</thead>
<tbody>
<tr>
<td>These are pure semiconductors from group 14 e.g., Ge; Si.</td>
<td>These are obtained by doping pure semiconductors with impurity from group 13 e.g., Al to Si.</td>
</tr>
<tr>
<td>The charge carriers are electrons in conduction band and an equal number of holes in valance band.</td>
<td>The charge carriers are majority holes provided by impurity atoms and the electron hole pairs formed by electrons jumping from valence band to conduction band.</td>
</tr>
<tr>
<td>In pure semiconductor ( n_e = n_h ). The temperature dependence of conductivity is high.</td>
<td>In p-type semiconductors ( n_h &gt; n_e ). The temperature dependence of conductivity is low.</td>
</tr>
</tbody>
</table>
FORMATION OF ‘DEPLETION LAYER’ AND ‘BARRIER POTENTIAL’ IN A P-N JUNCTION

A p-type semiconductor has excess of holes and n-type material has excess of electrons in it. As a result when a pn junction is formed; the free electrons from n-region and holes from p region drift towards the junction. Some of the electrons combine with holes. For every electron lost by n-region, we get an immobile positive donor ion in n-region and for every electron gained by p-region, we get an immobile negative acceptor ion. These ions oppose the further drift of the charge carriers from the two regions towards the junction. As a result we get a thin layer at the junction which is free of any charge carriers. This layer is known as Depletion layer. It is very thin and is of the order of a few microns only.

The accumulation of ions on the two sides of the junction develops a fictitious battery which opposes the further drift of charge carriers. This potential is called Barrier Potential. It is about 0.3 V for Ge and 0.7 V for Si.

Note: The width of depletion zone (i) decreases in forward bias (ii) increases in reverse bias (iii) decreases with increasing doping concentration.

DIFFERENCES BETWEEN FORWARD AND REVERSE BIASING IN THE JUNCTION DIODE:

(a) In forward biasing of the pn junction; the p-region is connected to positive terminal of battery and the n-region to the negative terminal of the battery. However in reverse biasing p-region is connected to negative and n-region to positive terminal of the battery as shown.

(b) The forward biased p-n junction offers low resistance whereas the reverse biased junction offers high resistance.

(c) The current in forward biased p-n junction circuit is large (of the order of mA) whereas
that in reverse biased is low (of the order of mA).

(d) The characteristic V-I graphs for the FB and RB are as under.

EXPERIMENTAL STUDY OF V-I CHARACTERISTIC CURVE OF A PN JUNCTION: The circuit diagrams used to study the forward characteristic and reverse characteristic curves are as under:

![Circuit Diagrams](#)

**Fig. (a) Forward characteristics**  **Fig. (b) Reverse characteristics**

The potential dividers used in the circuits help to apply any desired potential difference (V) across the diodes.

By applying different voltages, corresponding values of current are recorded to get the forward and the reverse characteristics of the diode. The typical curves are as shown below.

![Characteristics Curves](#)
HALF WAVE RECTIFIER:

A rectifier is a device which converts A.C. to D.C.

Why rectification? The household supply is always A.C. due to low transmission losses. However for some specific applications only D.C is required (e.g., battery charging, operation of an amplifier, electroplating etc.). Hence the available A.C has to be changed to D.C. A p-n junction can be used to convert A.C. to D.C as it allows current to flow only from p to n but not in the opposite direction (Neglect a very weak reverse current).

The half-wave rectifier circuit shown uses a single p-n junction.

The a.c. voltage to be transformed is fed to the primary P1, P2 of a transformer. The desired voltage appears across the secondary.

Suppose in first half of ac cycle, P1 is -ve and P2 +ve. Due to mutual induction, S1 becomes +ve and S2 -ve. This makes the p-n junction forward biased and hence conducting. The current flows from X to Y in this half.

In second half of ac input cycle, P1 becomes +ve and P2 -ve. Hence the p-n junction becomes reverse biased and non-conducting. No current flows in this half. The output across R is DC but pulsating. The shape of input and output are as shown. A current flows only in one half of ac cycle, it is called a half wave rectifier. \[ V_{\text{output}} = \frac{1}{2} V_{\text{input}} \].
FULL WAVE RECTIFIER CIRCUIT

The circuit diagram used for a full wave rectifier using pn junction diodes is as under:

![Circuit Diagram](image)

*P1, P2: Primary coil
*S1, S2: Secondary coil
*D1, D2: pn-junction diodes
*R_L: Load resistance

WORKING PRINCIPLE OF FULL WAVE RECTIFIER: The full wave rectifier works on the principle that a pn-junction offers low resistance and conducts when forward biased i.e., the p side of the junction connected to positive terminal and n-side to the negative terminal. It (the pn-junction) offers very high resistance when it is reverse biased (p to negative and n to positive side) and hence does not conduct.

The shape of the ac input and the output waveforms is as shown below.

![Waveforms](image)

If the ac input has a frequency of 50 Hz then the full wave rectifier gives a frequency of 100 Hz.

WORKING OF A PHOTO-DIODE

A photo-diode transforms light energy to electrical energy. The material chosen is such that it is sensitive to incident radiations of desired frequency range.
A photo-diode is always operated in reverse bias. When light falls on it, the bonds between semiconductor atoms break up producing minority charge carriers. These charge carriers are separated by the junction field and made to flow across the junction producing reverse current. The value of reverse current depends on the intensity of incident radiations.

For detection of optical signals, the material should have a band gap of around 1.5 eV (1 to 1.8 eV).

![diagram.png](image)

**LIGHT EMITTING DIODE**

A light emitting diode converts electrical energy to light energy. It is a heavily doped *pn* junction diode operated in forward bias which emits light as it conducts. The semiconductor material chosen for fabrication of Light Emitting Diode is such that the energy band gap is equal to that of visible photon. When forward biased, the majority charge carriers drift across the junction and recombine. The recombination results in emission of photon of energy equal or slightly less than the band gap. The commonly used materials are Ga P (Green light); Ga As P for Red or Yellow light. The colour (wavelength) of light emitted depends on band gap and the intensity is controlled by the magnitude of current which is adjusted by changing variable resistance *R* shown in the diagram.

![diagram.png](image)

A light emitting diode is a diode fabricated using a material which emits light when current passes through the diode. Different materials are used to get light of different colours. The advantage of using LED over conventional lamps are

(i) High light emitting efficiency and hence lower power consumption.

(ii) Long life.
ZENER DIODE:

A zener diode is a specially fabricated semiconductor diode named after its inventor. It is fabricated by heavily doping both p-side and n-side of the junction. Due to heavy doping, the depletion region formed is very thin (< 10⁻⁶ m) and the electric field of the junction becomes very high (~ 5 × 10⁶ V/m) for a voltage as low as 5 V.

The characteristic curve of a typical pn junction is as shown.

(i) In reverse bias; only minority charge carriers i.e., holes in n-side and electrons in p-side contribute to conduction. As their number is small, so the current is almost independent of the applied voltage upto reverse breakdown voltage.

(ii) At a critical value i.e., reverse breakdown voltage, the applied voltage is large enough to break bonds producing more minority charge carriers which conduct causing a sudden increased in current.

Zener diode operates in reverse breakdown voltage.

ZENER DIODE AS A VOLTAGE REGULATOR: The circuit diagram shows the use of zener diode as a voltage regulator. If the input voltage increases; the value of current through the zener diode and the resistance R increases.

As a result, the voltage drop across R increases keeping the voltage across the zener diode constant because the diode operates in the reverse breakdown.