Unit-V

SEMICONDUCTOR DEVICES

Formation of a PN Junction and working of a PN Junction, Energy band Diagram of a open circuited PN Diode, I-V Characteristics of PN Junction, Application - LED, Solar Cell and Photo diode.

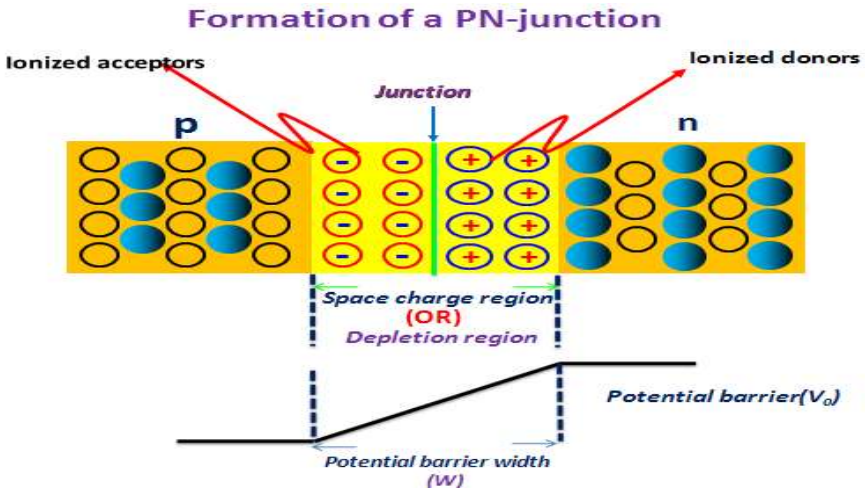
Introduction

In electronics a diode is a two- terminal electronic component with asymmetric conductance; it has low (ideally zero) resistance to current in one direction, and high (ideally infinite) resistance in the other.

Formation of pn – Junction

When a **p**-type Semiconductor is joined together with an **n**-type Semiconductor a **pn** junction is formed. And it is also known as a Semiconductor Diode.

Semiconductor diodes are widely used in Rectifiers which converts input AC signal into DC output signal.



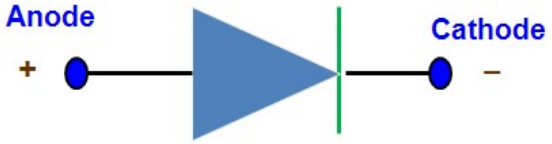
Depletion Region & Space Charge

The diffusing majority carriers from the two regions recombine near the junction and disappear.

The uncompensated Acceptor and Donor ions set up an Electric field which halts majority carrier Diffusion and causes minority carrier Drift.

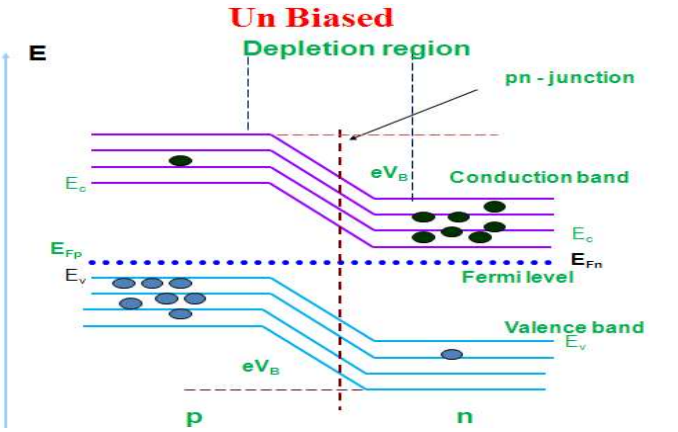
The two kinds of majority carriers diffusing across the junction meet each other near the junction and undergo recombination's, leaving negative ions on the **p**-side and positive ions on the **n**-side of the junction.

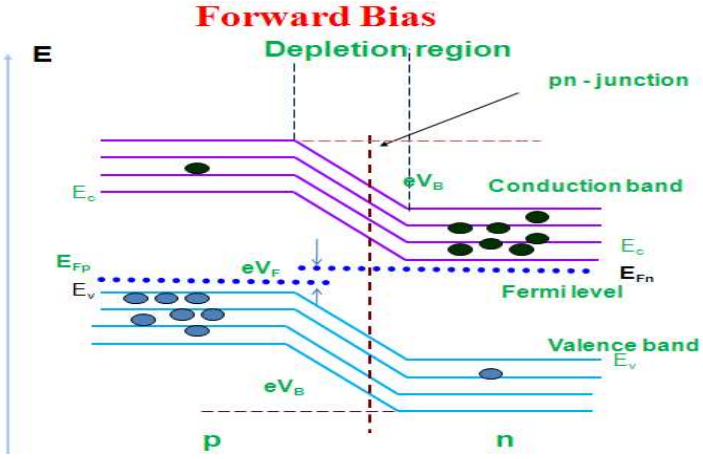
This distribution of Positive and Negative Charges is called Space charge.

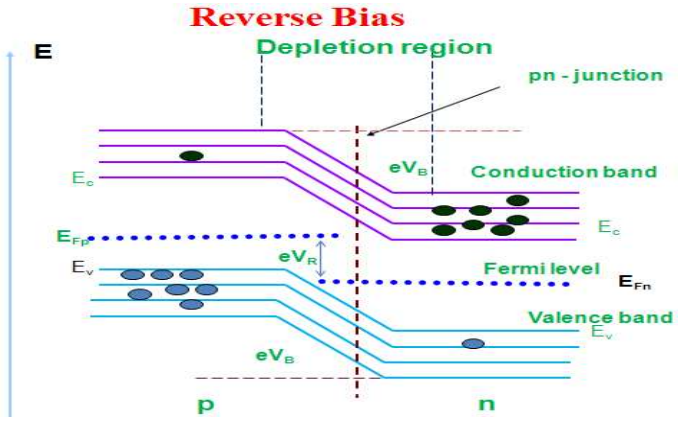


Diode Symbol

Energy Diagram of pn Diode:





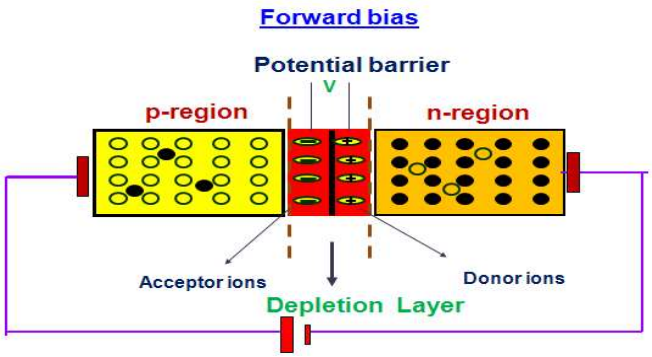


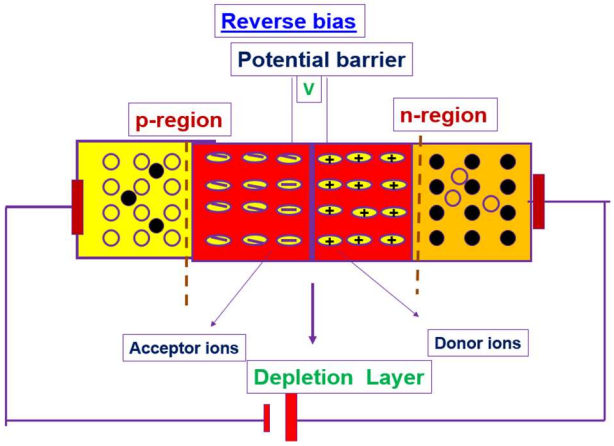
V - I Characteristics of pn Junction:

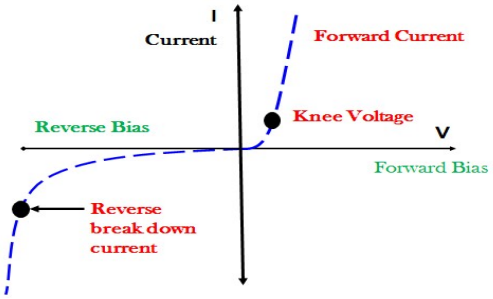
The diode can be operated in two different ways, as Forward and Reverse bias.

When positive terminal of the battery is connected to the **p**-type & negative terminal is to the **n**-type of the **pn**-junction diode, known the diode is kept in forward bias.

When negative terminal of the battery is connected to the **p**-type & positive terminal is to the **n**-type of the **pn**-junction diode, known the diode is kept in reverse bias.







From the graph the following points are noted.

- The region between knee voltage & breakdown voltage is known as non - ohmic region.
- Above the knee & breakdown voltage the current increases.
- Breakdown voltage is due to thermally broken covalent bonds.
- Diode is conducting in forward bias & non-conducting in reverse bias.

Light emitting diode (LED)

LED is a semiconductor **pn**-junction diode which converts electrical energy to light under forward biasing. It emits light in both visible & IR region.

NOTE:

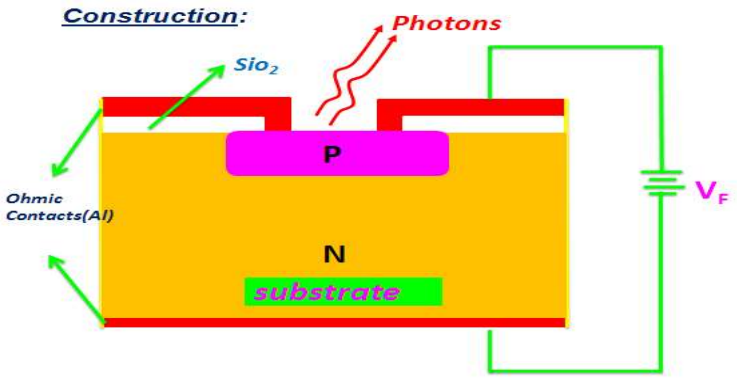
LEDs are typically made of compound semiconductors (OR) direct band gap semiconductors like gallium arsenide.

Principle:

Injection Luminescence

When LED is forward biased, the majority charge carrier moves from 'p' to 'n' & similarly from 'n' to 'p' region and becomes excess minority charge carriers. Then these excess minority charge carriers diffuse through the junction and recombines with the majority charge carriers in 'n' & 'p' region respectively to produce light.

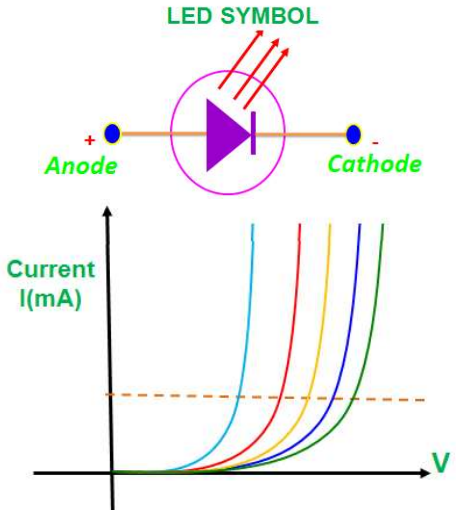
LED is a highly doped diode



- The **pn**-junction is made by doping silicon by GaAs crystal. Here silicon can act both as donor & acceptor.
- Therefore, a shallow **pn**-junction is formed on GaAs substrate such that **p**-layer is formed by diffusion on **n**-layer as shown in figure.
- In order to increase the probability of radiative recombination's, the thickness of the **n**-layer is taken higher than that of the thickness of the **p**-layer.
- The top layer of the **p** material is left uncovered for the emission of light.

Working:

- If the diode is properly biased the charge carriers move across the junction. If the biasing voltage is further increased, these excess minority carriers diffuse away from the junction and directly recombine with the majority carriers.
- Therefore, electron-hole recombination occurs more & more and thereby light is emitted through the top layer of the **p**-material which is left uncovered as shown in figure.



Advantages:

- They are smaller in size.
- Its cost is very low.
- It has long life time.
- They are available in different Colours at low cost.
- They can operate with low voltage, faster response $\approx 10^{-9}$ seconds.
- Its intensity controlled easily & operates wide range temperature.

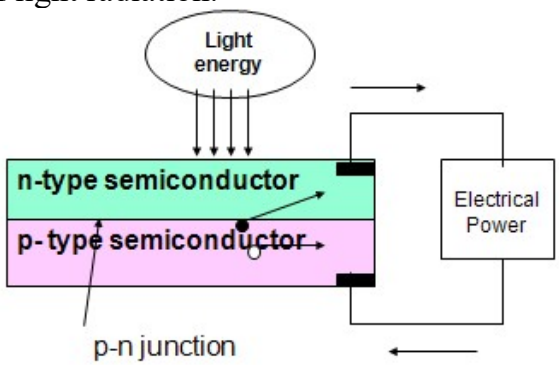
Disadvantages:

- Its output power is low.
- Its intensity is less than laser.
- Its light cannot travel through longer distance.
- Its light will not have directionality, incoherent & not in phase.

SOLAR CELL:

Solar cell is a photovoltaic device that converts the light energy into electrical energy based on the principles of photovoltaic effect.

Principle: The solar cells are based on the principles of photovoltaic effect. The photovoltaic effect is the photo generation of charge carriers in light absorbing materials as a result of absorption of light radiation.



Construction and working of Solar cell:

Construction:

- Solar cell (crystalline Silicon) consists of a *n-type semiconductor (emitter)* layer and *p-type semiconductor layer (base).* The two layers are sandwiched and hence there is formation of p-n *junction.*
- The surface is coated with *anti-refection coating* to avoid the loss of incident light energy due to reflection.
- Proper metal contacts are made on the n-type and p-type side of the semiconductor for electrical connection.

Working:

- When a solar *panel exposed to sunlight*, the light energies are absorbed by a semi conduction materials.
- Due to this absorbed energy, the electrons are liberated and produce the external DC current.
- The DC current is converted into 240-volt AC current using an inverter for different applications.

Advantage:

1. It is clean and non-polluting
2. Solar cells do not produce noise and they are totally silent.
3. They require very little maintenance
4. They are long lasting sources of energy which can be used almost anywhere
5. They have long life time
6. There are no fuel costs or fuel supply problems

Disadvantage:

1. Solar power cannot be obtained in night time
2. Solar cells (or) solar panels are very expensive
3. Energy has not be stored in batteries
4. They need large area of land to produce more efficient power supply

Applications:

- **Solar pumps** are used for water supply.
- **Domestic power supply** for appliances includes refrigeration, washing machine, television and lighting.
- **Ocean navigation aids:** Number of lighthouses and most buoys are powered by solar cells.
- **Telecommunication systems:** radio transceivers on mountain tops, or telephone boxes in the country can often be solar powered.
- **Electric power generation in space**: To providing electrical power to satellites in an orbit around the Earth.

- **Photo diode:**

A PN-junction diode which converts the photonic energy into its equivalent Electrical energy under in reversed bias is called photo diode.

Its operation is quite reverse from LED & used in optical communication.

Symbol:

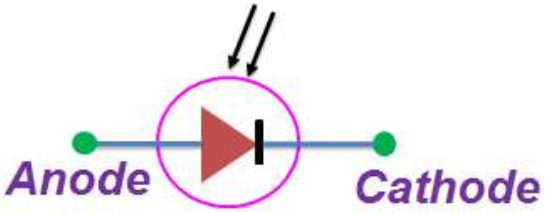


Photo diode is two types

- **p-i-n** photo diode (**pin** Diode)
- Avalanche photo diode (APD)

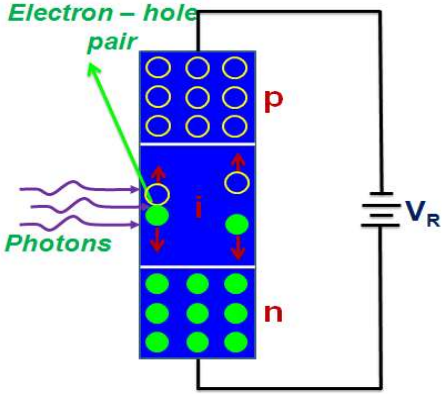
p-i-n photo diode (pin Diode):

Under reverse bias when light is made to fall on the neutral (or) intrinsic region 'i' electron hole pairs are generated. These electrons and holes are accelerated by the external electric field, which results in photo-current.

Thus light is converted into electrical signal.

Construction:

- It consists of three regions called positive (p), intrinsic(i) & negative(n). Hence it is called **pin**-diode.
- The **p**,**n** regions are made up of silicon, germanium & their alloys, also heavily doped.
- The **p**,**n** region is separated by an intrinsic region & made as large as possible in order to have more absorption of the incident photons.



Working:

- The **pin** diode is activated in high reverse bias. Since, the intrinsic region has very less mobile charges hence, the width of the depletion region gets increased.
- When a photon of energy greater than the band gap energy of the photo diode incidents on the depletion region, the electron-hole pair is created due to the absorption of photon.
- The mobile charges are accelerated by the applied voltage, which gives rise to photo current in the external current.
- In **pin**-diode the photo current is directly proportional to the optical power incident on it. Hence, it is called as a linear device.

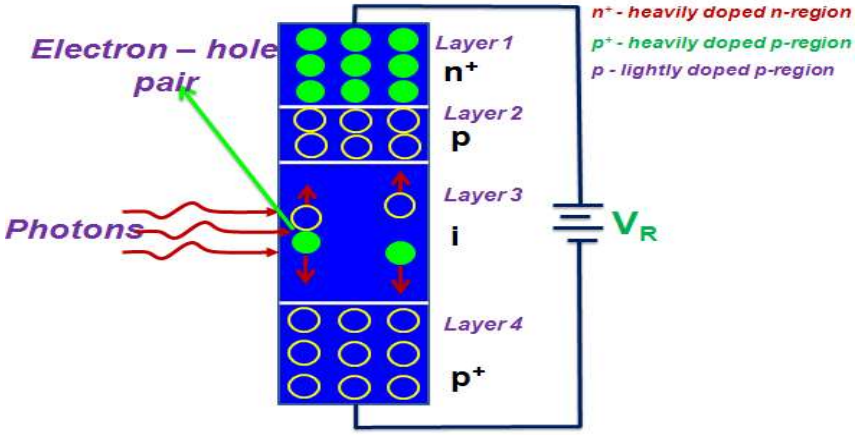
Avalanche photo diode (APD):

Under reverse bias when light is made to fall on the neutral (or) intrinsic region 'i' electron hole pairs are generated. By avalanche effect more number of electron-hole pairs are Created, which results in large photo current than of the **pin** diode.

Thus light is converted into electrical signal.

Construction:

- It consists of four layers called $\mathbf{p^+}$, **i, p** & $\mathbf{n^+}$. Layer 1 & 4 are heavily doped, layer 2 & 3 are lightly doped.
- Totally we can imagine the diode as **pn**-junction diode which the P-region is composed of three layer as **p, i,** $\mathbf{p^+}$.



Working:

- Due to reverse bias the depletion region gets widen. Here both i & P are lightly doped.
- When the light is fall on the intrinsic region, the incident light creates an electron-hole pairs in the intrinsic region.
- When the biasing voltage is increased the photo electrons are drift through the intrinsic region to **p** (layer-2) & **n** (layer-1) junction.
- Here, they collide with free electrons in the valence band & releases more number of free (OR) conduction electrons. Thus avalanche effect is produced.
- Therefore, a single photon generated 1000's of electrons by avalanche effect hence, increases the output current enormously.
- These diodes are termed as highly sensitive detectors.

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