Engineering Physics

(PHY1701)

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Module-7: Optoelectronic Devices & Applications of Optical fibers

Contents

- Introduction to Semiconductors
- Sources-LED & Laser Diode,
- Detectors, Photodetectors- PN & PIN (AG 209, 235, 238),
- Applications of fiber optics in communication, and
- Endoscopy*

*: Self Study

❖ Introduction to Fiber Optics, Ajoy Ghatak and K. Thyagarajan, Cambridge University Press, 2010 (AG)

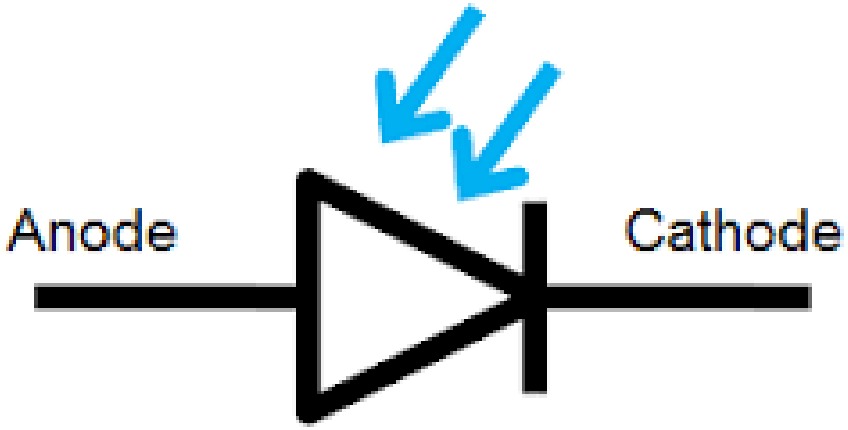
Photodiode (PN junction Photodiode)

- A photodiode is a PN-junction diode that consumes light energy to produce electric current. Sometimes it is also called as photo-detector, a light detector, and photo-sensor.
- These diodes are particularly designed to work in reverse bias condition, it means that the P-side of the photodiode is associated with the negative terminal of the battery and n-side is connected to the positive terminal of the battery.
- These diodes have a slow response time when the surface area of the photodiode increases. Photodiodes are alike to regular semiconductor diodes.
- *"A photodiode is a reverse-biased silicon or germanium pn junction in which reverse current increases when the junction is exposed to light"*.

Principle:

- A photodiode with its pn junction is exposed to light, the reverse current increases with the increase in light intensity and vive-versa.
- The reverse current is produced by thermally generated electron-hole pairs which are swept across the junction by the electric field by the reverse voltage.
- When light falls on the pn junction, the energy is imparted by the photons to the atoms in the junction. This will create more free electrons (and more holes). These additional free electrons will increase the reverse current.
- As the intensity of light incident on the pn junction increases, the reverse current also increases. In other words, as the incident light intensity increases, the resistance of the photo-diode decreases.

Symbol and Photodiode Package



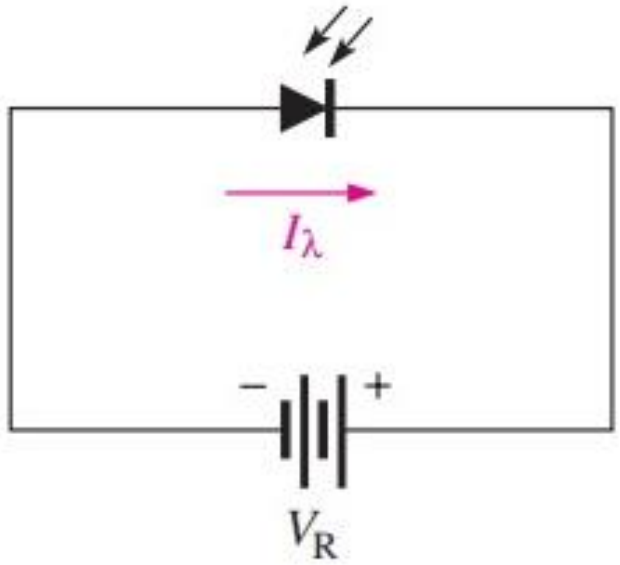
Photodiode symbol

Photodiode

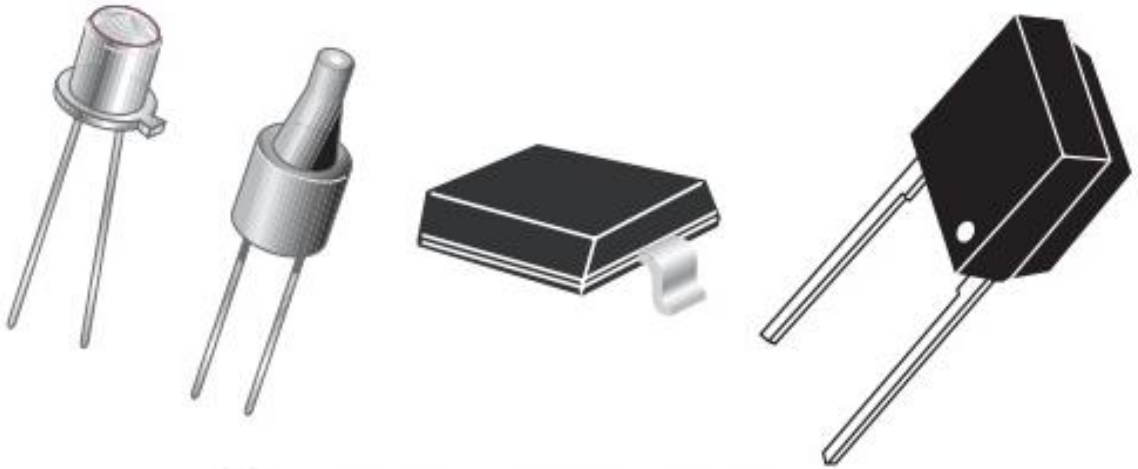
- It consists of a *pn* junction mounted on an insulated substrate and sealed inside a metal case. A glass window is mounted on top of the case to allow light to enter and strike the *pn* junction.
- The two leads extending from the case are labelled anode and cathode. The cathode is typically identified by a tab extending from the side of the case.

Types of Photodiodes

- The types of the photodiodes can be classified based on its construction and functions as follows.
  - PN Photodiode
  - Schottky Photo Diode
  - PIN Photodiode
  - Avalanche Photodiode



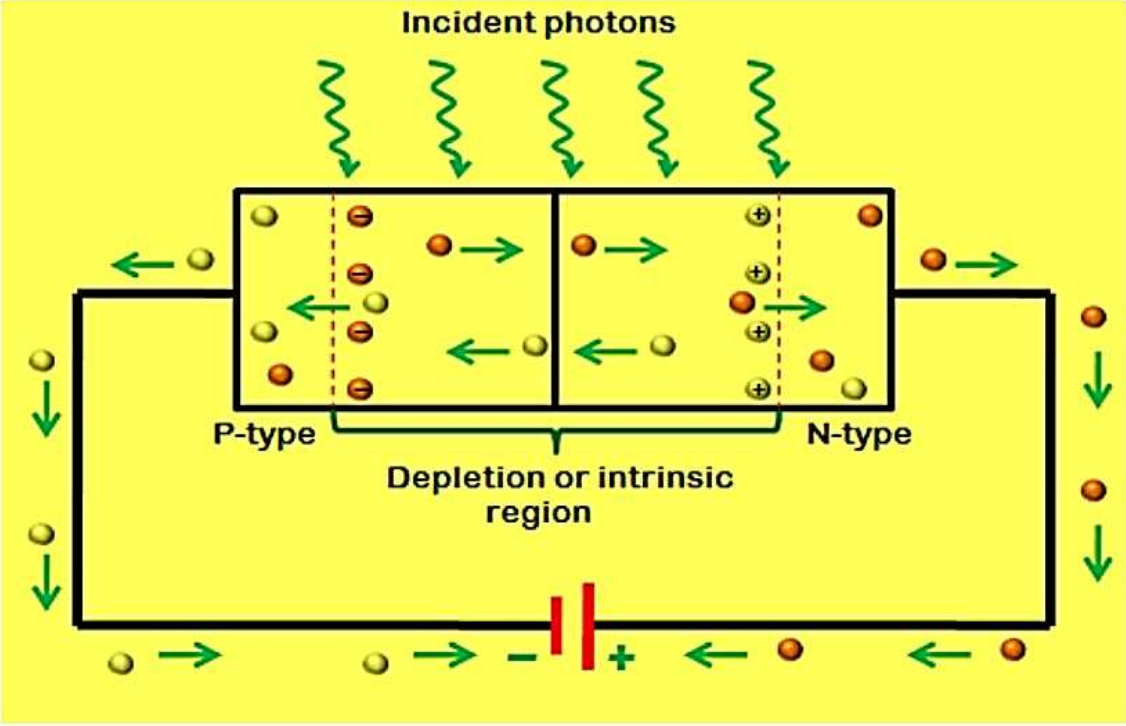
(a) Reverse-bias operation using standard symbol



(b) Typical Photodiodes

Working of Photodiode

- When a photon of ample energy strikes the diode. It makes a couple of an electron-hole. This mechanism is also called as the inner photoelectric effect.
- If the absorption arises in the depletion region junction. Then the carriers are removed from the junction by the inbuilt electric field of the depletion region.



Working of Photodiode

- The holes in the region move towards the anode, and electrons move toward the cathode, and a photocurrent will be generated.
- The entire current through the diode is the sum of the absence of light and the photocurrent.
- So the absent current must be reduced to maximize the sensitivity of the device.
- As the intensity of light increases, the reverse current I_R goes on increasing till it becomes maximum. This is called saturation current.
- When no light is incident on the *pn* junction of photodiode, the reverse current I_r is extremely small. This is called dark current.

PIN Diode (Photo detector)

- A PIN Photodiode is device that consumes light energy to generate electric current. It is also sometimes referred as photo-detector, photo-sensor, or light detector.
- PIN Photodiodes are specially designed to operate in reverse bias condition.
- PIN Photodiode is very sensitive to light so when light or photons falls on the photodiode it easily converts light into electric current.
- Solar cell is also known as large area photodiode because it converts solar energy or light energy into electric energy. However, solar cell works only at bright light.

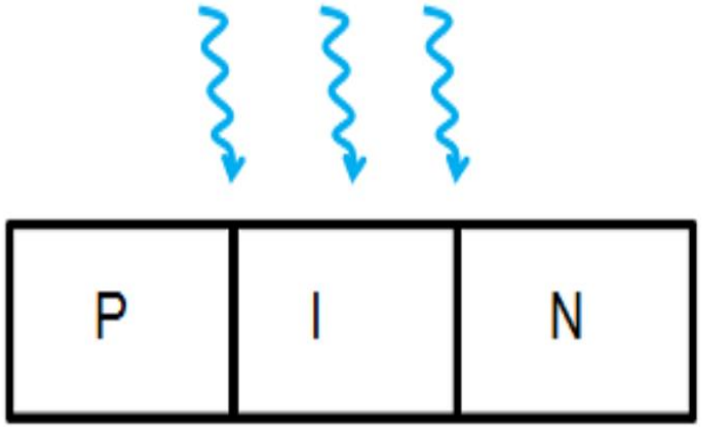
Symbol and construction

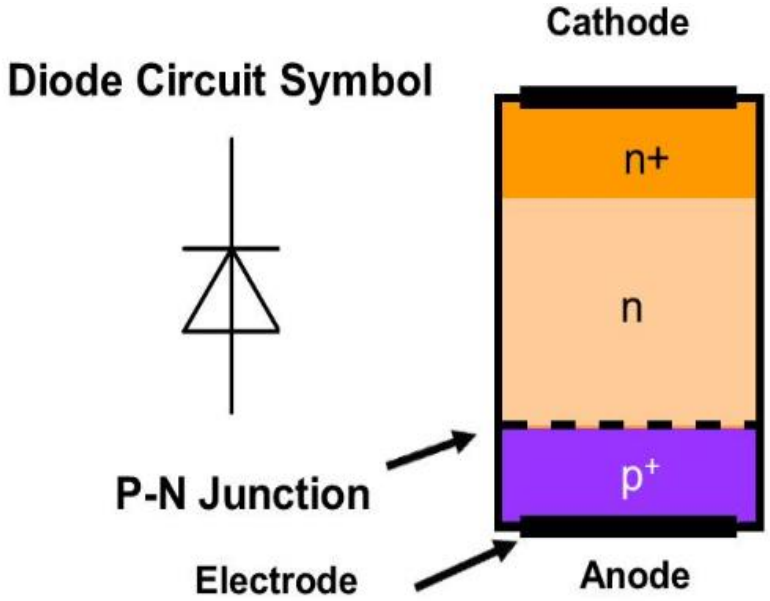
- The construction and working of PIN photodiode is almost similar to the normal p-n junction diode. PIN (p-type, intrinsic and n-type) structure is mostly used for constructing the photodiode instead of p-n (p-type and n-type) junction structure because PIN structure provide fast response time. PIN photodiodes are mostly used in high-speed applications.
- In a normal p-n junction diode, voltage is used as the energy source to generate electric current whereas in photodiodes, both voltage and light are used as energy source to generate electric current.

PIN photodiode

Construction

- A PN junction photodiode is made of two layers namely p-type and n-type semiconductor whereas PIN photodiode is made of three layers namely p-type, n-type and intrinsic semiconductor.
- In PIN photodiode, an additional layer called intrinsic semiconductor is placed between the p-type and n-type semiconductor to increase the minority carrier current.





WORKING

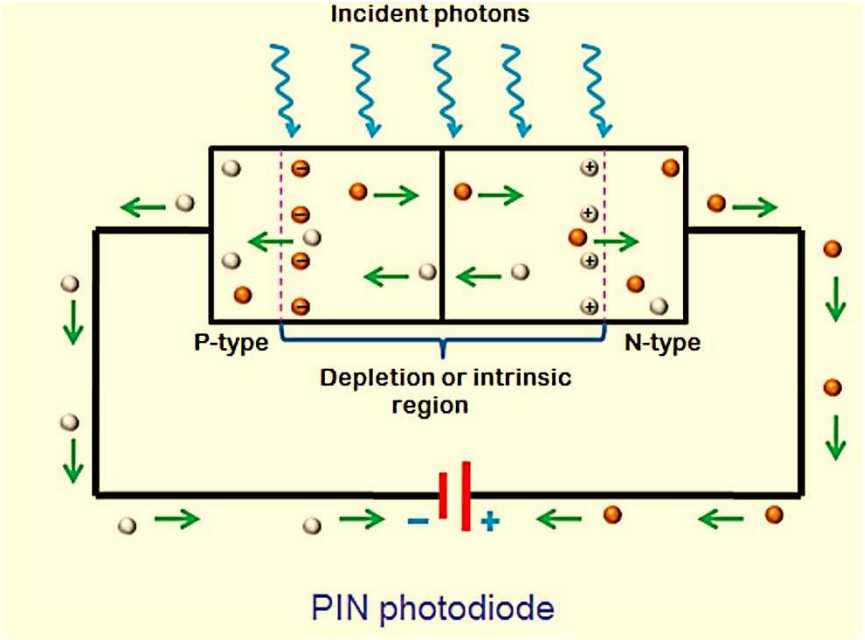
- A PIN photodiode is made of p region and n region separated by a highly resistive intrinsic layer. The intrinsic layer is placed between the p region and n region to increase the width of depletion region.
- The p-type and n-type semiconductors are heavily doped. Therefore, the p region and n region of the PIN photodiode has large number of charge carriers to carry electric current.
- However, these charge carriers will not carry electric current under reverse bias condition.
- On the other hand, intrinsic semiconductor is an un-doped semiconductor material. Therefore, the intrinsic region does not have charge carriers to conduct electric current.

WORKING

- Under reverse bias condition, the majority charge carriers in n region and p region moves away from the junction. As a result, the width of depletion region becomes very wide. Therefore, majority carriers will not carry electric current under reverse bias condition.
- When light or photon energy is applied to the PIN diode, most part of the energy is observed by the intrinsic or depletion region because of the wide depletion width. As a result, a large number of electron-hole pairs are generated.
- Free electrons generated in the intrinsic region move towards n-side whereas holes generated in the intrinsic region move towards p-side. The free electrons and holes moved from one region to another region carry electric current.

WORKING

- When free electrons and holes reach n region and p region, they are attracted to towards the positive and negative terminals of the battery.
- The population of minority carriers in PIN photodiode is very large compared to the PN junction photodiode.
- Therefore, PIN photodiode carry large minority carrier current than PN junction photodiode.
- When forward bias voltage is applied to the PIN photodiode, it behaves like a resistor.



WORKING

- We know that capacitance is directly proportional to the size of electrodes and inversely proportional to the distance between electrodes. In PIN photodiode, the p region and n region acts as electrodes and intrinsic region acts as dielectric.
- The separation distance between p region and n region in PIN photodiode is very large because of the wide depletion width. Therefore, PIN photodiode has low capacitance compared to the PN junction photodiode.
- In PIN photodiode, most of the electric current is carried by the charge carriers generated in the depletion region. The charge carriers generated in p region or n region carry only a small electric current.
- Therefore, increasing the width of depletion region increases the minority carrier electric current.

ADVANTAGES

- Wide bandwidth
- High response speed
- Generate low noise
- High sensitivity to light
- Low sensitivity to temperature
- Low cost
- Small size
- Long lifetime

DISADVANTAGES

- Photodiode should be always operated in reverse bias condition.
- Applied reverse bias voltage should be low.
- Light sensitive device
- Should not exceed the working temperature limit specified by the manufactures.