Module:7 *Photodetector*

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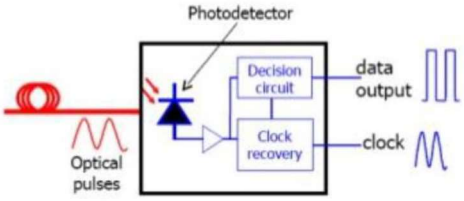
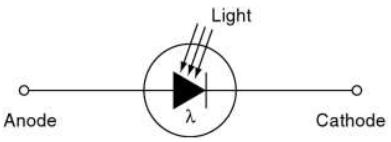
Photodetector

A photodetector is a p-n junction device which absorb light and convert optical energy into electrical energy



Symbol of photodiode



Photodiodes

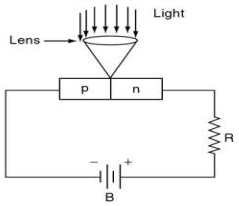
Photodetector

A photo diode is a reverse biased semiconductor p-n diode whose reverse current increases with the increase in intensity of light incident at the junction.

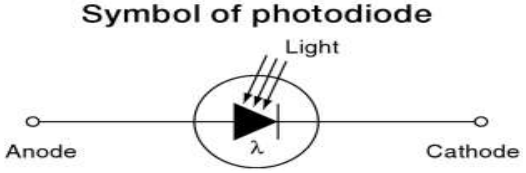
When light is incident on the p-n junction of a photo diode, the atoms at the junction absorb the energy of photons and create more free electrons and holes.

These additional carriers increase the reverse current. As the intensity of incident light on the junction increase the reverse current also increases. The lens is used to concentrate the light to the junction region.

The basic biasing arrangement and construction of a photodiode



Symbol of photodiode

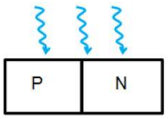


Types of Photodiode

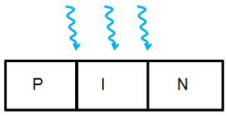
Photo detectors are made up of semiconductor materials, absorb incident photons and produce electrons/holes

Photo detector (diode) works on the reverse bias condition

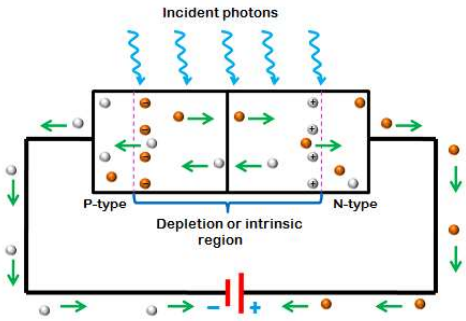
PN Photodiode (p-type and n-type)



PIN photodiode (p-type, intrinsic, n-type)



Working PN photo diode



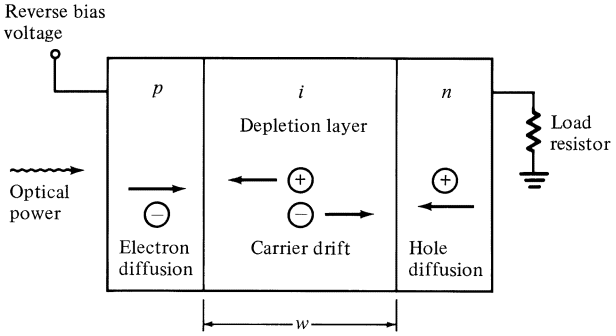
Width of the depletion region increases upon reverse bias of the p-n junction diode leading to higher quantum efficiency

The strong depletion region electric field and the external electric field increase the drift velocity of the free electrons

Because of this high drift velocity, the minority carriers generated in the depletion region will cross the p-n junction and constitute a current flow in the circuit

Working PIN photo diode

In PIN photodiode, an addition layer called intrinsic semiconductor is placed between the p-type and n-type semiconductor to increase width of depletion region and thereby **the minority carrier current.**



When light energy is applied to the PIN diode, most part of the energy is observed by the intrinsic or depletion region. As a result, a large number of electron-hole pairs are generated.

Photons entering these layer produces charge carriers, this action results in high quantum efficiency of this device.

Dark Current

when no light is applied to the reverse bias photodiode, it carries a small reverse current due to external voltage. This small electric current under the absence of light is called dark current. It is denoted by I λ.

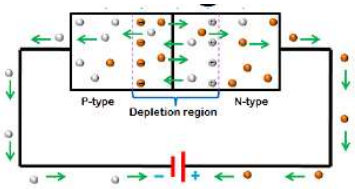
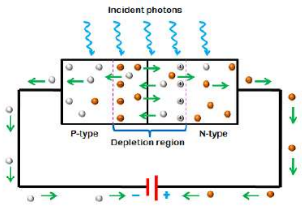


Photo Current

The electric current generated in the photodiode due to the application of light is called photocurrent.



In a photodiode, reverse current is independent of bias voltage and it is mostly depends on the light power

What are the properties of Photodiode?

- ❑ The noise produced by the photodiode is very less.
- ❑ The life span of the photodiode is very long.
- ❑ It is one of the light weighted and compact diodes.
- ❑ With respect to incident light, the linearity of the diode is good.
- ❑ Wide spectral response is expected from the photodiode.
- ❑ It can be mechanically rugged

Responsivity (R) and Quantum efficiency (η)

Responsivity is a measure of the conversion efficiency of a photo detector.

The photocurrent produced is proportional to the power of incident beam

$$I_p \alpha P \text{ (input power)}$$
$$I_p = RP$$

R is a constant called responsivity, measured in Amp/Watt

$$R = \frac{I_{photo}}{P} \quad \text{----------} \quad [1]$$

❑ **Responsivity**

$$R = \frac{Photocurrent\ (A)}{Incident\ Optical\ Power\ (W)} = \frac{I_{ph}}{P_0}$$

$$I_{photo} = \frac{N_e.e}{t}$$

$$P = \frac{N_p.E_p}{t}$$

Substitute these equation in equation 1

$$R = \frac{N_e.e}{N_p.E_p}$$ ---------- [2]

Substitute as $E_p = \frac{hc}{\lambda}$ **in equation 2**

$$R = \frac{N_e.e\lambda}{N_p.hc}$$

Quantum Efficiency of PIN photodiode

- The electrical current produced by e^- and h^+ generated by incident photons are called as photocurrent (I_p). I_p is proportional to light power (P) (of suitable $h\nu$).
- -¿ $I_p \propto P$; $I_p = RP$. $\Longrightarrow$ $R = \frac{I_p}{P}$, here R-responsivity of photodiode.
- $I_p = \frac{Q}{t} = \frac{N_e e}{t}$; here $\frac{N_t}{t}$-no. of e^- generated per unit time.
- Light power $P = \frac{E}{t} = \frac{N_p E_p}{t}$; here $\frac{N_p}{t}$- no. of photons incident on depletion region per unit time. E_p- average energy of incident photon.
-

$$R = \frac{I_p}{P} = \frac{\frac{N_e e}{t}}{\frac{N_p E_p}{t}} = \frac{N_e}{N_p}\frac{e}{E_p} = \frac{N_e}{N_p}\left(\frac{e\lambda_p}{hc}\right)$$

$$R = \left(\frac{N_e}{N_p}\right)\left(\frac{e\lambda}{hc}\right)$$

$$R = \eta\frac{e\lambda}{hc}$$

Responsivity R is a measure of the conversion efficiency of a photo detector.

Where $\eta = \frac{N_e}{N_p}$ **is called quantum efficiency of a photodiode**

The ratio of number of electrons produced (N_e) to the number of photons falling (N_p) shows the efficiency of the semiconductor material to convert light into current.

This ratio is called as quantum efficiency η of a photo diode

A p-n photodiode has a quantum efficiency of 50% at a wavelength of 0.9 μm. Calculate (i) the responsivity at 0.9 μm (ii) the received optical power if the mean photocurrent is 10^{-6} A and (iii) the corresponding number of received photons per second at this wavelength.

A Si pin photodiode has an active light receiving area of diameter 0.4 mm. When radiation of wavelength 700 nm (red light) and intensity 0.1 mW cm^{-2} is incident it generates a photocurrent of 56.6 nA. What is the responsivity and QE of the photodiode at 700 nm?