Thermodynamics & Electronics

Unit: - 4

Semiconductor Device

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Semiconductor Device

Topics:

- Introduction
- Light-Emitting Diode (LEDs)
- Condition
- Multicolor LEDs
- Application of LEDs
- Photo Diode
- Varacter Diode
- Solar Cell (Photo voltaic Cell)
- Thermistor

Introduction:

The most common application of Diodes is rectification. The rectifier diodes are used in power supplies to convert A. C. voltage into D. C. voltage. But rectification is not all that a diode can do. A number of specific types of diodes are manufactured for specific applications in this fast developing world. Some of the more common special-purpose diode are Zener diode, light emitting diode, photo diode, varactor diode, solar cell etc.

Light-Emitting Diode (LEDs)

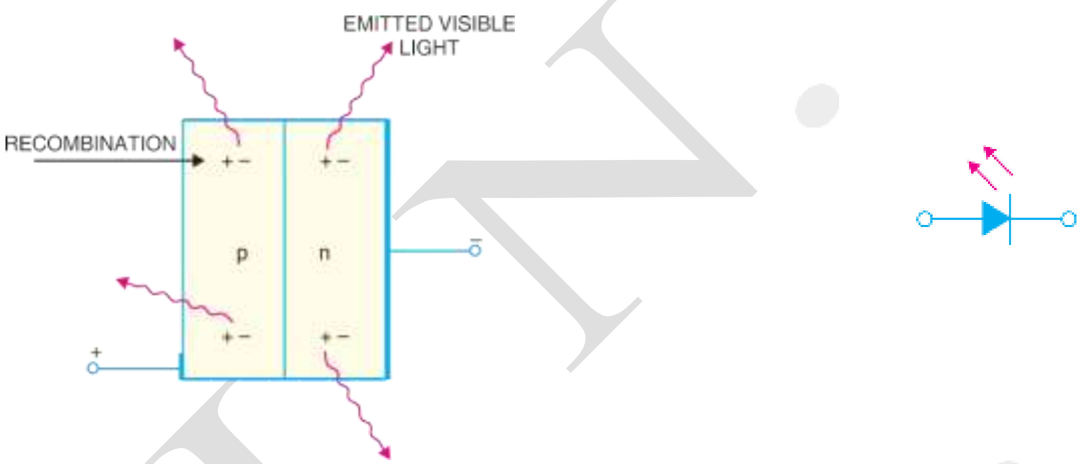
- ✰ A light-emitting diode (LED) is a diode that gives off visible light when forward biased.
- ✰ Light-emitting diodes are not made from silicon or germanium but are made by using elements like gallium, phosphorus and arsenic.
- ✰ By varying the quantities of these elements, it is possible to produce light of different wavelengths with colours that incluedred, green, yellow and blue.
- ✰ For example, when a LED is manufactured using gallium arsenide, it will produced red light. If the LED is made with gallium phosphide, it will produce a greenlight.

Fig 1

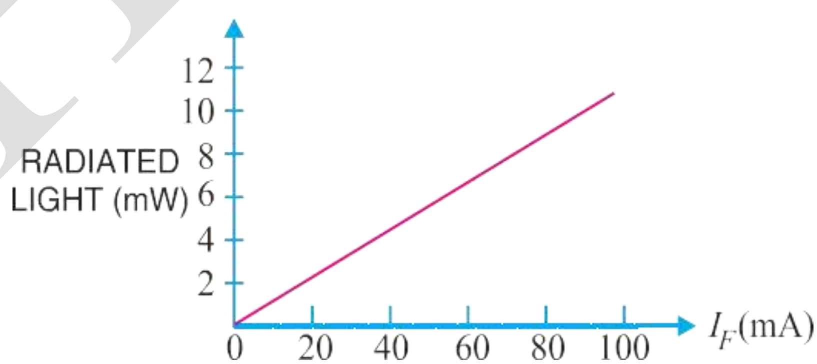
- ✰ When light-emitting diode (LED) is forward biased as shown in Fig. (a) the electrons from the *n*-type material cross the PN junction and recombine with holes in the *p*-type material. Recall that these free electrons are in the conduction bandand at a higher energy level than the holes in the valence band.

- ✰ When recombination takes place, the recombining electrons release energy in the form of heat and light. In germanium and silicon diodes ,almost the entire energy is given up in the form of heat and emitted light is insignificant.

- ✰ The graph between radiated light and the forward current of the LED. It is clear from thegraph that the intensity of radiated light is directly proportional to the forward current of LED.



(a) (b)



(c) Radiated Light Vs forward current

Advantages of LED

- ☆ LEDs are of small size and light weight.
- ☆ They are available in a different colour.
- ☆ They have longer life as compared to the lamps.
- ☆ They are stable at high operating speed as they take less than 1μs to turn on or off.
- ☆ Easily interfaced with the other electronic circuits.

Disadvantages of LED

- ☆ Output power is affected by change in temperature.
- ☆ Over current can easily damage the LEDs
- ☆ Luminous efficient of LEDs is low.

Multicolor LED

- ☆ A LED that emits one colour when forward biased and another colour when reverse biased is called a multicolour LED.
- ☆ One commonly used schematic symbol for these LEDs is shown in Fig. a

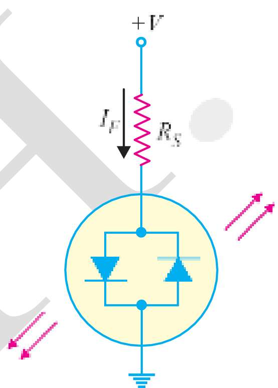


Fig. i

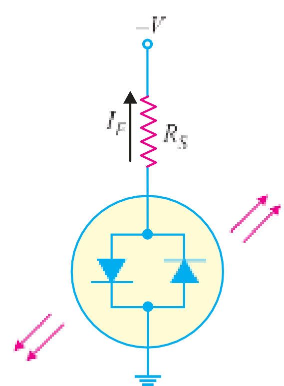


Fig. ii

☆ Multicolour LEDs actually contain two pn junctions that are connected in reverse-parallel i.e. they are in parallel with anode of one being connected to the cathode of the other.

☆ If positive potential is applied to the top terminal as shown in Fig. (i), the pn junction on the left will light. Note that the device current passes through the left pn junction. If the polarity of the voltage source is reversed as shown in Fig. (ii), the pn junction on the right will light.

☆ Multicolour LEDs are typically red when biased in one direction and green when biased in the other.

☆ If a multicolour LED is switched fast enough between two polarities, the LED will produce a third colour. A red/green LED will produce a yellow light when rapidly switched back and forth between biasing polarities.

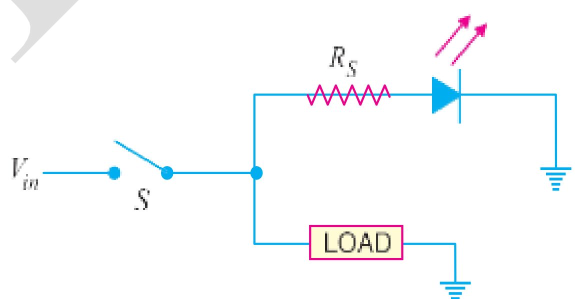
Application of LEDs

Probably the two most common applications for visible LEDs are:

1. As a power indicator
2. Seven-segment display.

As a power indicator:

☆ A LED can be used to indicate whether the power is on or not. Fig. shows the simple use of the LED as a power indicator.



☆ When the switch S is closed, power is applied to the load. At the same time current also flow through the LED which lights, indicating power is on. The resistor R_S in series with the LED ensures that current rating of the LED is not exceeded.

Seven-segment display

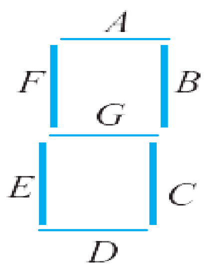


Fig. i

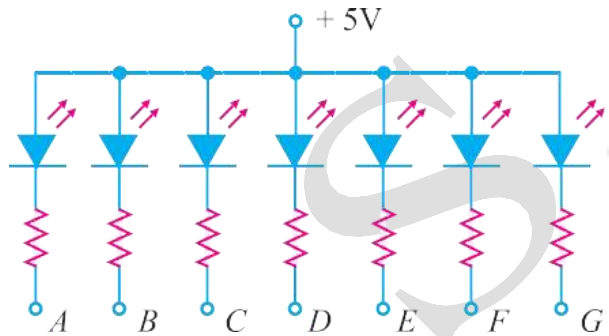


Fig. ii

✰ LEDs are often grouped to form seven-segment display. Fig. 7.9 (i) shows the front of a seven segment display. It contains seven LEDs (A, B, C, D, E, F and G) shaped in a figure of 8. Each LED is called a segment.

✰ If a particular LED is forward biased, that LED or segment will light and produces a bar of light. By forward biasing various combinations of seven LEDs, it is possible to display any number from 0 to 9.

✰ For example, if LEDs A, B, C, D and G are lit (by forward biasing them), the display will show the number 3. Similarly, if LEDs C, D, E, F, A and G are lit, the display will show the number 6. To get the number 0, all segments except G are lit.

✰ Fig. (ii) shows the schematic diagram of seven-segment display. External Series resistors are included to limit currents to safe levels.

✰ Note that the anodes of all seven LEDs are connected to a common positive voltage source of +5 V. This arrangement is known as common-anode type.

Photo Diode

- ✰ A photo-diode is a reverse-biased silicon or germanium pn junction in which reverse current in- creases when the junction is exposed to light.
- ✰ The reverse current in a photo-diode is directly proportional to the intensity of light falling on its pn junction. This means that greater the intensity of light falling on the pn junction of photo-diode, the greater will be the reverse current.

Principle

- ✰ When a rectifier diode is reverse biased, it has a very small reverse leakage current. The same is true for a photo-diode. The reverse current is produced by thermally generated electron- hole pairs which are swept across the junction by the electric field created by the reverse voltage.

- ✰ A photo-diode differs from a rectifier diode in that when its pn junction is exposed to light, the reverse current increases with the increase in light intensity and vice-versa.

- ✰ When light (photons) 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 device (photo-diode) decreases.

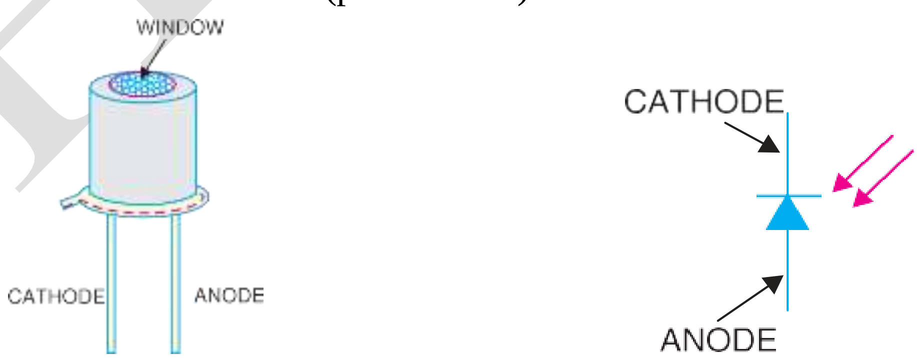
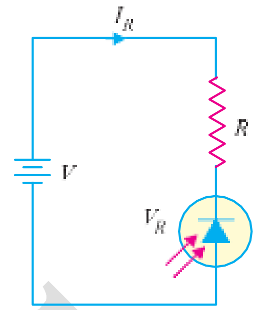


Fig. shows a typical photo-diode package and schematic symbol

Photo-diode Operation



☆ Fig. shows the basic photo-diode circuit. The circuit has reverse- biased photo-diode, resistor *R* and d.c. supply. The operation of the photo- diode is as under

☆ When no light is incident on the *pn* junction of photo-diode, the reverse current I_r is extremely small. This is called dark current. The resistance of photo-diode with no incident light is called dark resistance (R_R).

$$\text{Dark resistance of photo-diode } R_R = \frac{V_R}{dark\ resistance}$$

☆ When light is incident on the pn junction of the photo-diode, there is a transfer of energy from the incident light (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 increases, the reverse current I_R goes on increasing till it becomes maximum this is called saturation current.

Characteristics of Photo-diode

There are two important characteristics of photo- diode.

Reverse current-Illumination curve

Fig. i shows the graph between reverse current (I_R) and illumination (E) of a photo-diode. The reverse current is shown on the vertical axis and is measured in μA. The illumination is indicated on the horizontal axis and is measured in mW/cm^2. Note that graph is a straight line passing through the origin.

$$I_R = mE$$

Where m = slope of the straight line

The quantity *m* is called the *sensitivity* of the photo-diode.

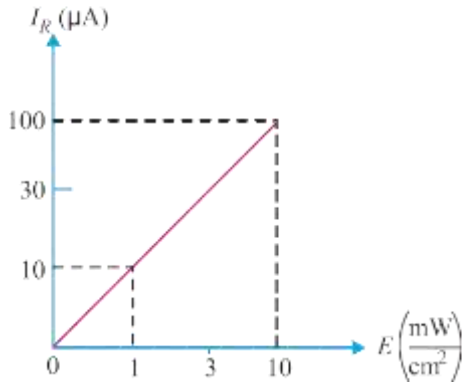


Fig i

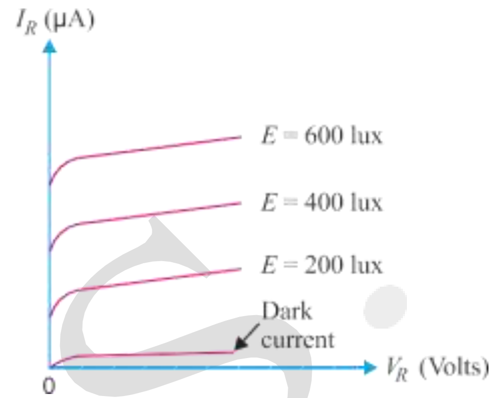


Fig ii

<u>Reverse voltage-Reverse current curve</u>

Fig. ii shows the graph between reverse cur- rent (I_R) and reverse voltage (V_R) for various illumination levels. It is clear that for a given reverse-biased voltage V_R, the reverse current I_R increases as the illumination (E) on the pn junction of photo-diode is increased.

Varactor Diode

- ☆ A junction diode which acts as a variable capacitor under changing reverse bias is known as a varactor diode.
- ☆ When a pn junction is formed, depletion layer is created in the junction area. Since there are no charge carriers within the depletion zone, the zone acts as an insulator.
- ☆ The p-type material with holes (considered positive) as majority carriers and n-type material with electrons (-ve charge) as majority carriers act as charged plates. Thus the diode may be considered as a capacitor with n-region and p-region forming oppositely charged plates and with depletion zone between them acting as a dielectric.
- ☆ This is illustrated in Fig. (i). A varactor diode is specially constructed to have high capacitance under reverse bias. Fig. (ii) Shows the symbol of varactor diode.

☆ The values of capacitance of varactor diodes are in the pico farad (10^{-12} F) range

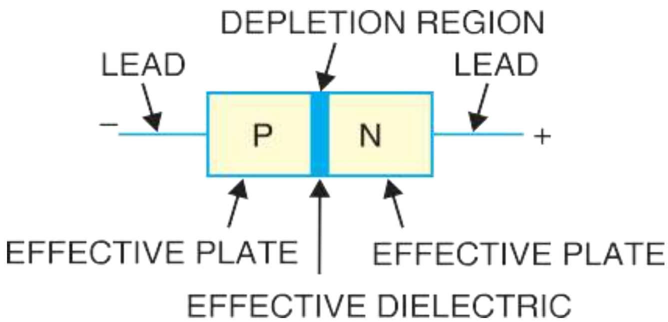
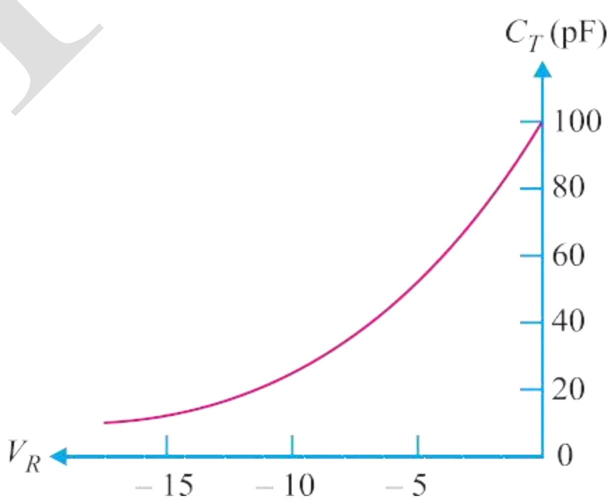


Fig 1

☆ For normal operation, a varactor diode is always *reverse biased. The capacitance of varactor diode is found as

$$C_T = \varepsilon \frac{A}{W_d}$$

Where C_T= Total capacitance of the junction
ε= Permittivity of the semiconductor material
A= Cross-sectional area of the junction
W_d= Width of the depletion layer



- ✰ When reverse voltage across a varactor diode is increased, the width W_d of the depletion layer increases. Therefore, the total junction capacitance C_T of the junction decreases. On the other hand, if the reverse voltage across the diode is lowered, the width W_d of the depletion layer decreases. Consequently, the total junction capacitance C_T increases.

Solar Cell (Photovoltaic Cell)

Principle

Solar cell is semiconductor junction device used for converting radiaton energy in to electrical energy.

Construction

- ✰ Selenium and silicon are the most widely used materials for solar cells, though gallium arsenide, indium arsenide and cadmium sulphide are also used.

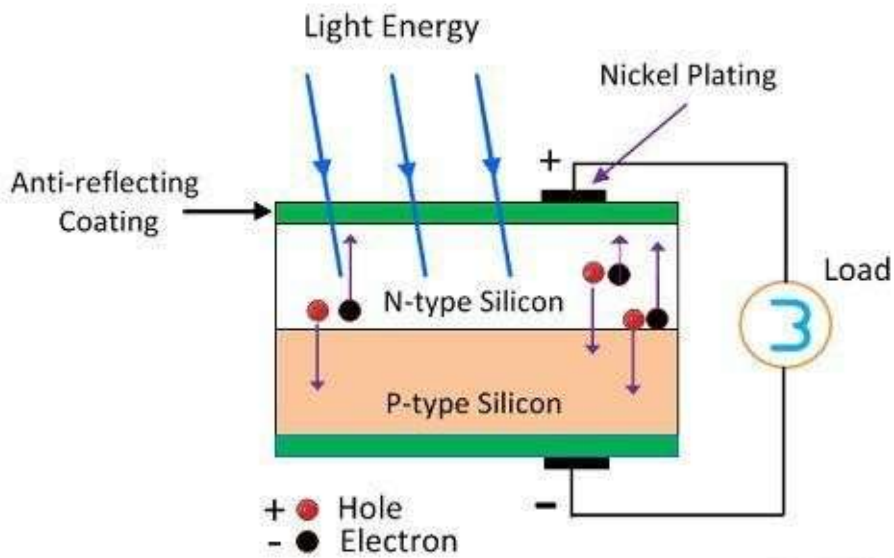
- ✰ A solar cell is basically a pn jumction with both the p and n regions thin and highly doped. At the bottom of n region a metal sheet is placed to work as a negative terminal and grid structure also allows the light to fall on the device. At top a glass window is provided which allow the light and protect the device physically.

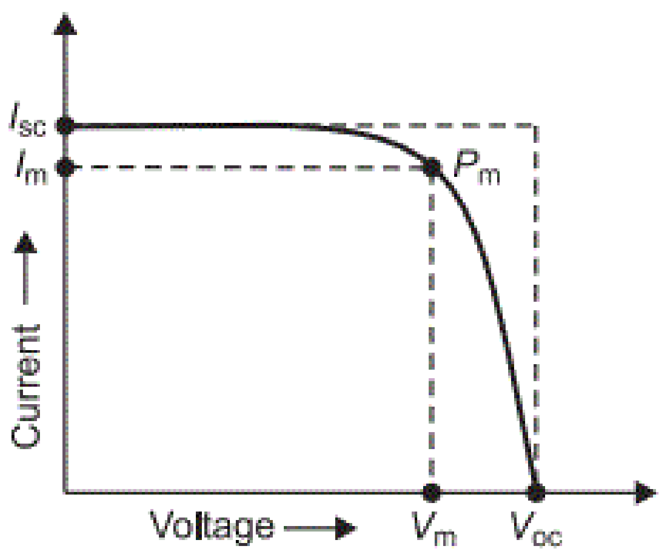
- ✰ Solar cells are characterized by their I-V characteristics at different illumination levels. The maximum output power is obtained at knee point accordingly a maximum power locus is shown by a dotted line.

Working

- ✰ To understand the working of solar cell, consider fig. when light falls on the pn junction diode, the energy of photon will be absorbed by the valence electrons. If this energy is sufficient to break the covalent bond, the electrons will leave their parent atoms leaving behind the holes.

☆ This electron-hole pairs are generated in p and n regions. These carriers will be separated the holes from the n region will constitutes a minority current which is directly proportional to the illumination and the areas of exposure.





I-V characteristic curve of solar cell

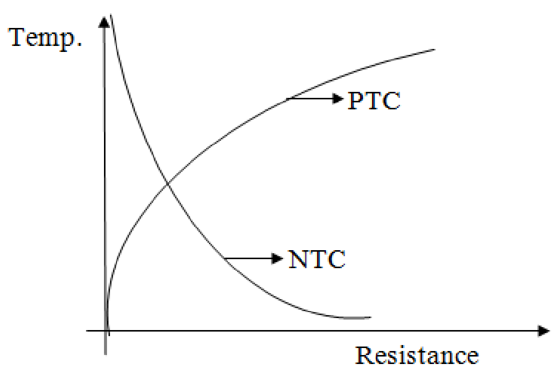
Thermistor

- ✰ The word thermistor is a combination of thermal + resistor = Thermistor. A Thermistor is a resistor with definite thermal characteristics. most thermistors have a negative temperature coefficient (NTC), but there are two type of Thermistor NTC and PTC.

- ✰ Modern Thermistor are manufactured from the oxides of metals like manganese, nickel, cobalt, copper, iron, zinc, aluminium, titanium, magnesium and uranium.

- ✰ Thermistor has a very nonlinear resistance temperature relation, as obvious from the characteristics curve of NTC and PTC Thermistor as show in fig.

- ✰ Thermistors are essentially semiconductor devices that behave as resistor with high negative temperature coefficient.



Temp. vs Resistance

Symbol of thermistor