❖ **Solar cells:** A Solar cell is defined as the electrical device that converts light energy into electrical energy through the photovoltaic effect. A solar cell is an example of photovoltaic device whose electrical characteristics such as current, voltage and resistance vary when exposed to light. It is basically a P-N Junction diode although its construction is little bit different than the conventional P-N junction diode. A very thin layer and heavily doped of *N* type semiconductor is grown on a relatively thicker lightly doped P-type semiconductor as shown in figure 1. Then apply a few finer electrodes on the top of the *N* type semiconductor layer. The electrodes should not obstruct light to reach the thin N- type layer. Just below the N-type layer there is a PN junction

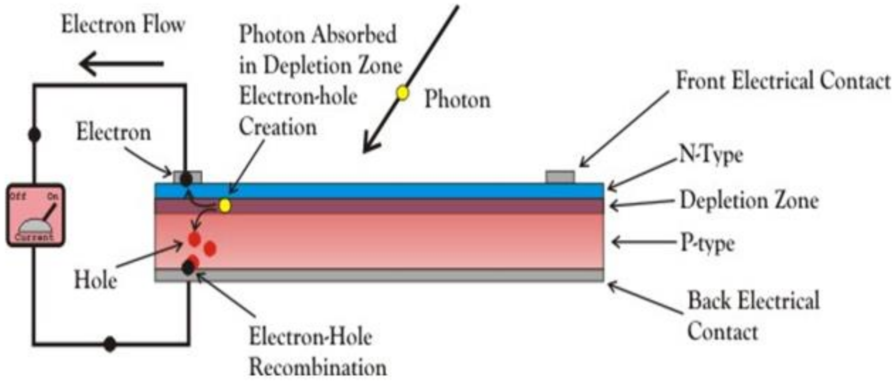

Fig. 1 Schematic of solar cell

Working Principle of Solar Cell: When light reaches the PN junction, the light photons can easily enter in the junction though very thin N type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs (EHP) as shown in Fig.1. The incident light breaks the thermal equilibrium condition of the junction. Due to the built-in potential and electric field in the depletion region electrons move to the n region and the holes to the p region. Once, the newly created free electrons and holes come to the n-type side and p- type side respectively cannot further cross the junction because of barrier potential of the junction. As the concentration of electrons becomes higher in one side, i.e. n-type side of the junction and concentration of holes becomes more in another side, i.e. the p-type side of the junction, the p-n junction will behave like a small battery cell. A voltage is set up which is known as photo voltage. If we connect a small load across the junction, there will be a tiny current flowing through it. The carriers are extracted by the metal electrodes on either side as shown in Fig. 1.

Characteristics of Solar Cell: The I-V characteristics of solar cell depend on the intensity of the incident radiation and also the operating point (external load) of the cell. If the external circuit is a short circuit (external load resistance is zero) then the only current is due to the generated EHPs by the incident light. This is called the photocurrent, denoted by I_{ph} and it can also be termed as short circuit current $I_{SC.}$ By definition of current which is opposite to the photo current and is related to the intensity of the incident radiation A_{OP} by

$$I_{SC} = -I_{ph} = -k\mathrm{A}_{op} \qquad \text{……………… (1)}$$

Where K is the constant depends on the particular device. Equivalent circuit for solar cell is shown in Figure 2

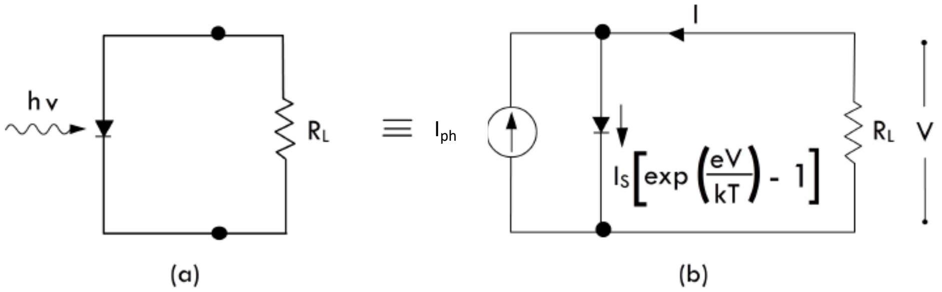

Fig.2: (a) A solar cell connected to an external load (b) Equivalent circuit, with a constant current source, a forward biased PN junction and the external load. The current from the forward biased PN junction opposes the constant current source.

The net current through the diode can be expressed as

$$I = I_S[\exp\left(\frac{eV}{k_BT}\right) - 1] - I_{ph} \qquad \text{…………………………… (2)}$$

Open circuit voltage, $V_{oc} = V\,\big|_{I=0}$

From Equation (2)

$$0 = I_{SO}[\exp\left(\frac{eV}{k_BT}\right) - 1] - I_{ph}$$

$$\frac{I_{ph}}{I_{so}} + 1 = \exp(\frac{eV_{oc}}{k_BT})$$

$$V_{oc} = \frac{k_BT}{e}\ln(\frac{I_{ph}}{I_{so}}) \qquad \text{………………….. (3)}$$

And short circuit current, $I_{sc} = I\,\big|_{V=0}$

From equation (2)

$I_{SC} = (1-1) - I_{ph}$

$$I_{sc} = -I_{ph} \qquad \text{……………………(4)}$$

Therefore the *I-V* characteristic of solar cell is shown in the figure 3

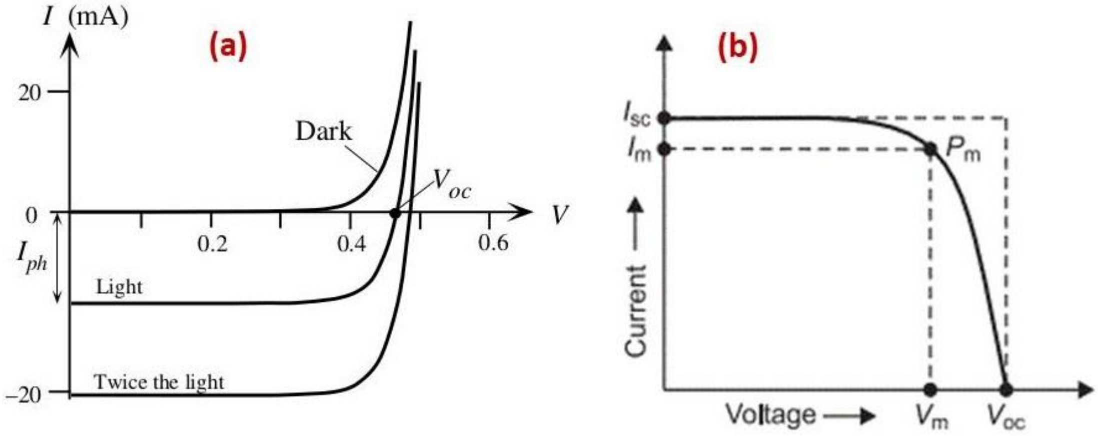

Fig.3: (a) I-V characteristics of pn junction solar cell under dark conditions and under illumination with light of increasing intensity. (b) Conventional plot of the fourth quadrant of I-V characteristics.

The power of the solar cell is the area under the I-V characteristics under illumination of light.

The maximum obtainable power $P_m = V_m I_m$

The ratio between maximum obtainable power to the product of short circuit current and open circuit voltage provides the fill factor (FF). It is a measure of the performance of solar cell. A solar cell with a higher voltage has larger possible FF. The FF can be expressed as

$$FF = \frac{I_m V_m}{I_{SC} V_{OC}} = \frac{P_m}{I_{SC} V_{OC}} \quad \text{.........................} \quad (5)$$

The efficiency of the solar cell can be expressed as

$$\eta = \frac{p_m}{P_i} = \frac{FF\, I_{SC} V_{OC}}{P_i} \quad \text{.........................} \quad (6)$$

Where, P_i is the power of incident light.