Photovoltaic Effect

→ Sunlight can be converted to electricity due to the photovoltaic effect discovered by Edmund Becquerel, a French scientist in 1839.

→ Sunlight is composed of photons, or packets of energy. These photons contain various amount of energy corresponding to the different wavelengths of light.

→ When photons strike a solar cell, a semiconductor P-N junction device, they may be reflected or absorbed, or they may pass through the cell.

→ Absorption of a photon in a solar cell results in the generation of electron-hole pair (EHP)

→ This EHP, when separated from each other across the PN junction, results in the generation of a voltage across the junction.

→ This voltage can drive a current in an external circuit, which is called as photocurrent

→ The device is called as Photovoltaic cell or device.

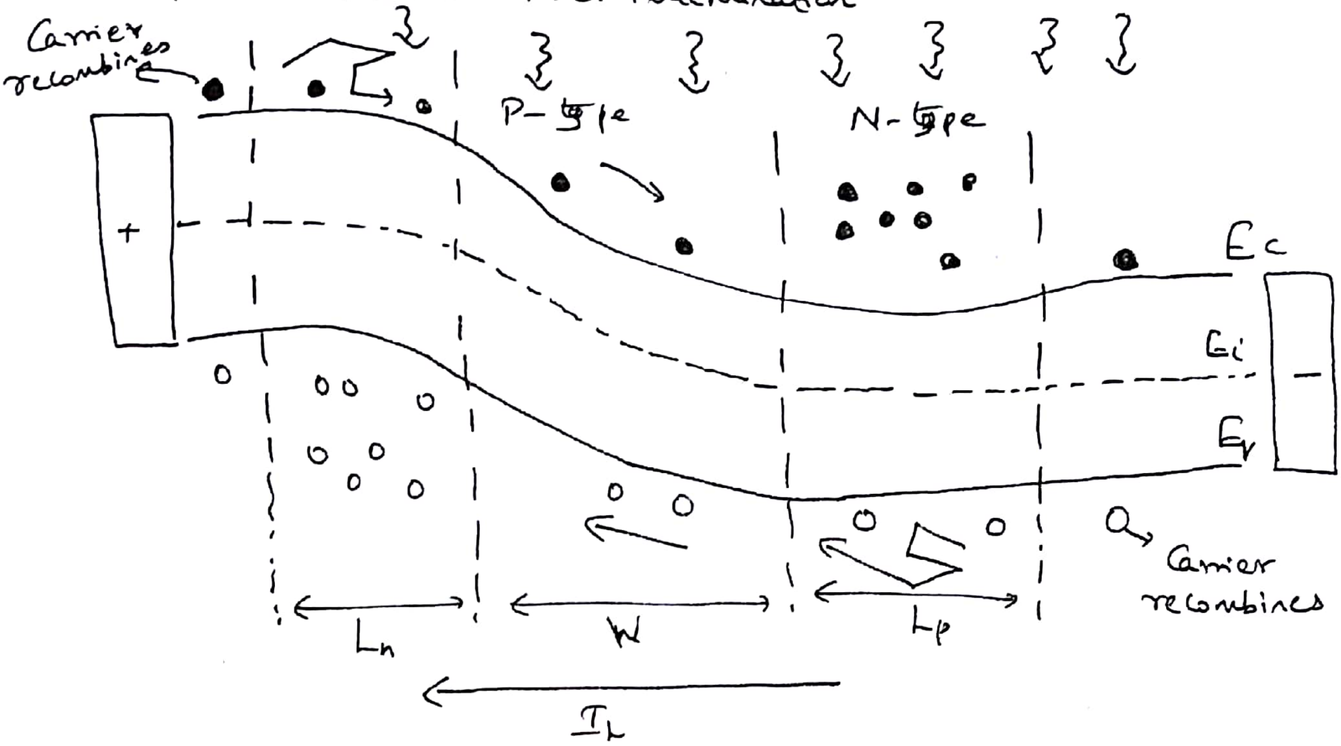
Photovoltaic Effect - p-n Junction under Illumination.

→ When there is no light falling on the diode (p-n junction) no electron-hole pair is generated for photocurrent.

→ But p-n junction is illuminated, it absorbs solar radiation and electron-hole pairs are generated.

→ It can be safely assumed that the generation rate of electron-hole pairs will be uniform in the p-n junction area, extended to the entire device area.

p-n Junction Under illumination



→ Under the uniform illumination Condition, generation of Carrier will occur in the Space-Charge region as well as quasi-neutral region.

→ The Carriers that are generated in the Space-Charge region will be immediately be swept away due to the electric field (electrons towards N-side and holes towards p-side).

→ Due to the electric field, chances of recombination of these electron pairs are quite less.

→ The electron-hole pairs which are generated in the quasi-neutral region will move around in a random manner.

→ In their random motion, Some of the generated minority Carriers will Come near to the Space-charge region edge, where they will experience a force due to electric field and will be pulled at the other side.

→ Only the minority Charge Carriers will cross the junction.

→ Minority electrons from P-side will come to N-side (leaving behind their positively charged partner, hole)

→ Minority holes will come from N-side to P-side (leaving behind their negatively charged partner, an electron).

→ There is a net increase in the positive charges at P-side and a net increase in negative charge at N-side.

→ This build up of a positive and negative charge causes a potential difference to appear across the P-N junction due to light falling on it.

→ This generation of photovoltage is called Photovoltaic effect

→ The contribution to the photovoltage is coming only from the carriers that are generated within the width $(L_n + w + L_p)$

Light Generated Current

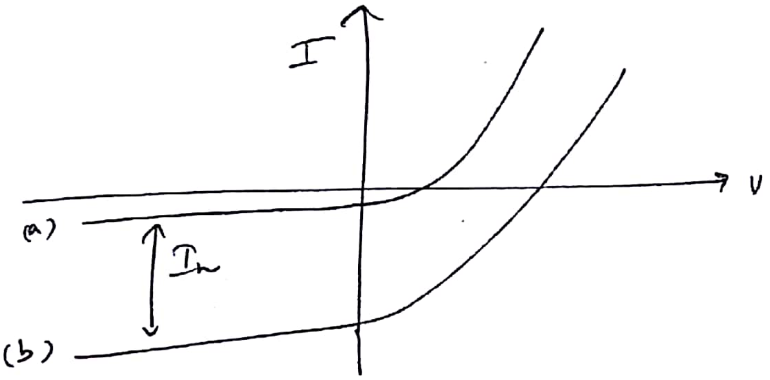
→ In a P-N junction diode, four current component are present in equilibrium condition: electron drift, electron diffusion hole current and hole diffusion.

→ In equilibrium condition, net current is zero which requires the drift and diffusion currents of carriers to be equal and opposite.

→ When pn-junction is illuminated, a net large drift current due to minority electrons and holes, which flows from N-side to p-side.

→ Since, this current flow is generated by light, it is known as light-generated current or photocurrent, I_L.

→ Hence, the power can be generated by the device.



(a) Dark I-V Curve.

(b) when light shines on a P-N Junction diode,
IV Curve of illuminated p-n Junction

→ The overall effect of light shining is to shift the I-V Curve of the diode downwards in the current-voltage axis.

Application of Photovoltaic Effect - Solar Cell.

→ When light shines on a Solar Cell, photovoltage is generated.

→ The generated voltage across the Solar cell Can drive the current in external Circuit and therefore Can deliver power.

→ In order to collect the energy of a photon in the form of of electrical energy, through Solar Cells, the following actions must take place:

(a) increase in the potential energy of Carriers (generation of electron-hole pair).

(b) Separation of Carriers.

→ I-V equation for the Solar Cell Can be derived in the Same manner as that for a P-N junction diode.

→ Here, the generation term G will not be zero, as it is taking place in the Space charge region and recombination is zero.

→ The Total Current through the junction is given by,

$$I_{total} = qA\left(\frac{D_n}{L_n} n_{p0} + \frac{D_p}{L_p} p_{n0}\right)\left(e^{qV/kT} - 1\right) - qAG\left(L_n + L_p + W\right)$$

$$I_{total} = I_0\left(e^{qV/kT} - 1\right) - I_L.$$

where $I_L = qAG(L_n + L_p + W)$ is the light generated Current.

→ This indicates that the Carriers generated within the volume of Cross-Sectional area A and length $(L_n + L_p + W)$ Contribute to I_L.

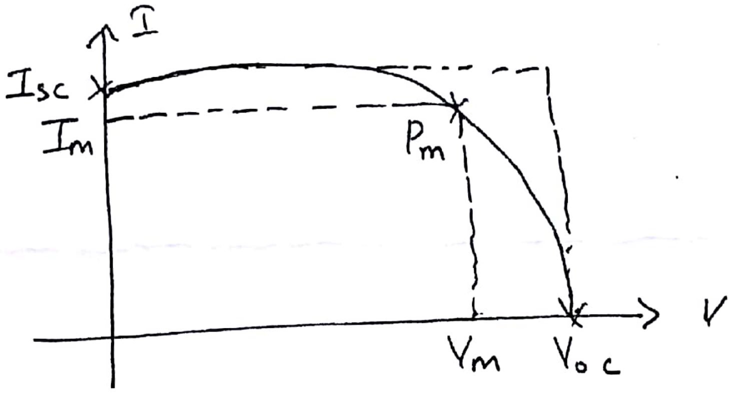
Determination of Efficiency of a Solar Cell.

→ Solar Cells are characterized and compared with each other with four parameters:

(1) Short Circuit Current, I_{sc}: (mA/cm^2)

→ This is the maximum current ~~that~~ flows in a Solar Cell when its terminals at p-side and N-side are shorted with each other, i.e, $V = 0$

→ $I_{sc} = -I_L$, where Shorcircuit current is nothing but the light-generated current.



Typical plot of a solar cell I-V curve and its parameters.

(2) Open Circuit Voltage V_{oc}: (mV or V)

→ It is the maximum voltage generated across the terminals of a Solar Cell when they are kept open, i.e, $I = 0$.

$$V_{oc} = \frac{kT}{q} \ln\left(\frac{I_L}{I_o} + 1\right)$$

(3) Fill factor FF: (%)

→ It is the ratio of the maximum power $P_m = V_m \times I_m$ that can be extracted from a Solar Cell to the ideal power $P_o = V_{oc} \times I_{sc}$.

$$FF = \frac{P_m}{P_o} = \frac{V_m I_m}{V_{oc} I_{sc}}$$

→ ff represents the Squareness of the Solar I-V Curve.

4. Efficiency η : (mW/cm^2 or W/m^2)

→ The ratio of the power output to power input.

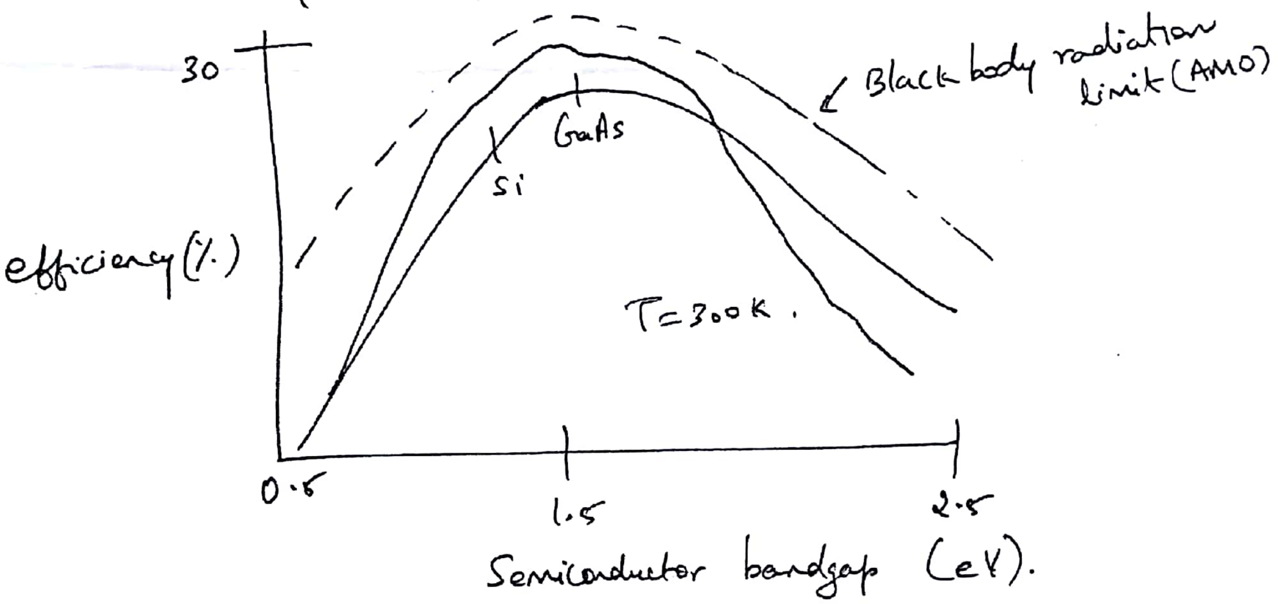
→ The power output is the maximum power point P_m of a solar cell.

→ Input power is the power of Solar radiation P_{rad}.

$$\eta = \frac{P_m}{P_{rad}}$$

$$\eta = \frac{V_m I_m}{P_{rad}} = \frac{I_{oc} I_{sc} \, ff}{P_{rad}}$$

Efficiency in terms of Bandgap.



Maximum Possible Solar Cell efficiencies as a function of energy band gap of semiconductor materials.

→ There is an optimum band gap for which efficiency of a solar cell would be maximum.

→ The open circuit voltage of a solar cell increases with increase in bandgap.

Losses in Solar Cells determining efficiency.

(1) Loss of low energy photons:

→ Photons of energy value less than that of the bandgap values donot get absorbed in the material.

(2) Loss due to excess energy of photons:

→ when the photon energy E is higher than the bandgap energy E_g, the excess energy $= E - E_g$ is given off as a heat to the material.

(3) Voltage loss:

→ The voltage corresponding to the bandgap of a material is obtained by dividing the bandgap by charge, E_g/q. This is referred to as bandgap voltage.

(4) Fill factor loss:

→ The ff factor is around 0.89.

→ This type of loss arises due to the parasitic resistance (series and shunt resistance) of the cell.

(5) Loss by reflection.

→ A part of incident photons is reflected from the cell surface

(6) Loss due to incomplete absorption.

→ The loss of photons which have enough energy to get absorbed in the solar cell, but do not get absorbed in the cell due to limited solar cell thickness.

(7) Loss due to metal coverage:

→ Shadows due to metal contacts, reduce illumination area.

(8) Recombination Losses:

→ Not all the generated electron-hole pairs contribute to the solar cell current and voltage due to recombination losses.