UNIT-III

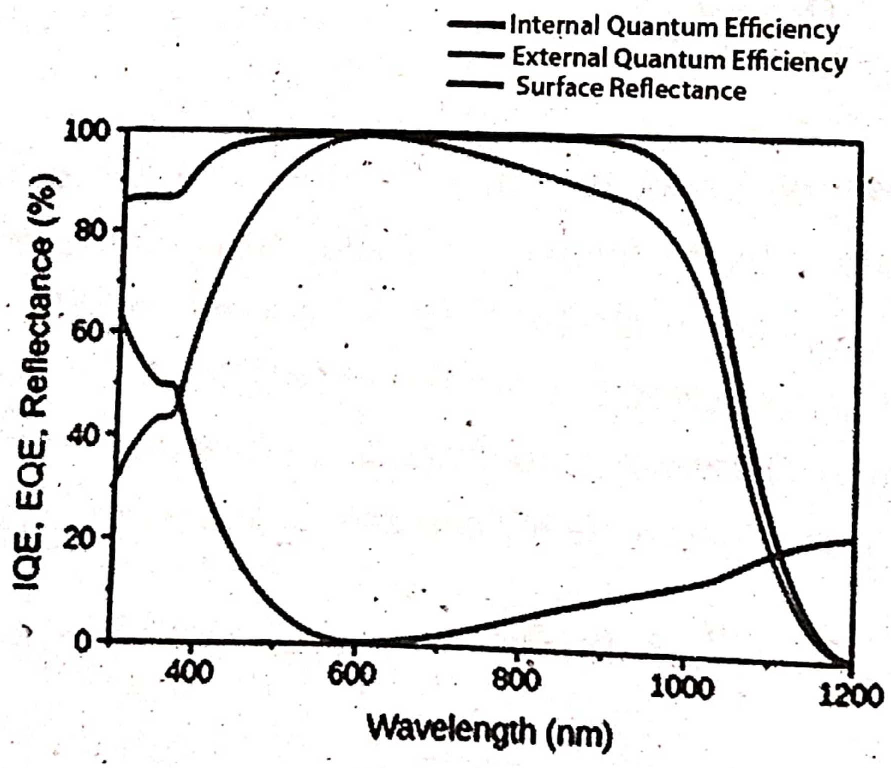
FUNDAMENTALS OF SOLAR CELLS

ESSAY QUESTIONS

Q. 4. *What is quantum efficiency of solar cell and explain different types of efficiencies?*

The term quantum efficiency (QE) may apply to incident photon to converted electron (IPCE) ratio of a photosensitive device, or it may refer to the TMR effect of a Magnetic Tunnel Junction. In a Charge-Coupled Device (CCD) or other photodetector, it is the ratio between the number of charge carriers collected at either terminal and the number of photons hitting the device's photoreactive surface. As a ratio, QE is dimensionless, but it is closely related to the responsivity, which is expressed in amps per watt. Since the energy of a photon is inversely proportional to its wavelength, QE is often measured over a range of different wavelengths to characterize a device's efficiency at each photon energy level. For typical semiconductor photodetectors, QE drops to zero for photons whose energy is below the band gap. A photographic film typically has a QE of much less than 10%, while CCDs can have a QE of well over 90% at some wavelengths.

Quantum efficiency of solar cell :



A graph showing variation of internai quantum efficiency, external quantum efficiency, and reflectance with wavelength of a crystalline silicon solar cell.

A solar cell's quantum efficiency value indicates the amount of current that the cell will produce when irradiated by photons of a particular wavelength. If the cell's quantum efficiency is integrated over the whole solar electromagnetic spectrum, one can evaluate the amount of current that the cell will produce when exposed to sunlight. The ratio between this energy-production value and the highest possible energy-production value for the cell (i.e., if the QE were 100% over the whole spectrum) gives the cell's overall energy conversion efficiency value. Note that in the event of multiple exciton generation (MEG), quantum efficiencies of greater than 100% may be achieved since the incident photons have more than twice the band gap energy and can create two or more electron-hole pairs per incident photon.

Types of quantum efficiency :

Two types of quantum efficiency of a solar cell are often considered:

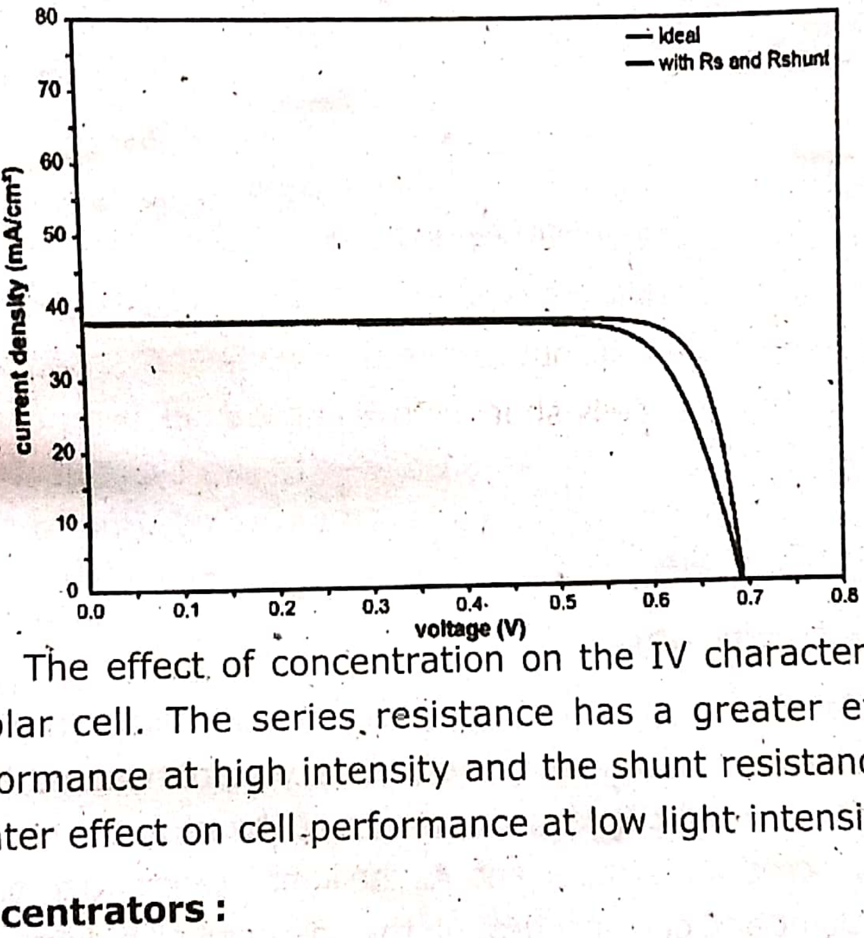
(i) **External Quantum Efficiency (EQE)** is the ratio of the number of charge carriers collected by the solar cell to the number of photons of a given energy *shining on the solar cell from outside* (incident photons).

(ii) **Internal Quantum Efficiency (IQE)** is the ratio of the number of charge carriers collected by the solar cell to the number of photons of a given energy that shine on the solar cell from outside *and* are absorbed by the cell.

The IQE is always larger than the EQE in the visible spectrum. A low IQE indicates that the active layer of the solar cell is unable to make good use of the photons, most likely due to poor carrier collection efficiency. To measure the IQE, one first measures the EQE of the solar device, then measures its transmission and reflection, and combines these data to infer the IQE. The external quantum efficiency therefore depends on both the absorption of light and the collection of charges. Once a photon has been absorbed and has generated an electron-hole pair, these charges must be separated and collected at the junction. A "good" material avoids charge recombination. Charge recombination causes a drop in the external quantum efficiency.

Q. 6. Explain the effect of light intensity on solar cell.

Changing the light intensity incident on a solar cell changes all solar cell parameters, including the short-circuit current, the open-circuit voltage, the FF, the efficiency and the impact of series and shunt resistances. The light intensity on a solar cell is called the number of suns, where sun corresponds to standard illumination at AM1.5, or 1 kW/m^2.



The effect of concentration on the IV characteristics of a solar cell. The series resistance has a greater effect on performance at high intensity and the shunt resistance has a greater effect on cell performance at low light intensity.

Concentrators :

A concentrator is a solar cell designed to operate under illumination greater than sun. The incident sunlight is focused or guided by optical elements such that a high intensity light beam shines on a small solar cell. Concentrators have several potential advantages, including a higher efficiency potential than a one-sun solar cell and the possibility of lower cost. The short-circuit current from a solar cell depends linearly on light intensity, such that a device operating under 10 suns would have 10 times the short-circuit current as the same device under one sun operation. However, this effect does not provide an efficiency increase, since the incident power also increases linearly with concentration. Instead, the efficiency benefits arise from the logarithmic dependence of the open-circuit voltage on short circuit. Therefore, under concentration, V_{oc} increases logarithmically with light intensity, as shown in the equation below;

$$V'_{OC} = \frac{nkT}{q} \ln\left(\frac{XI_{SC}}{I_0}\right) = \frac{nkT}{q}\left[\ln\left(\frac{I_{SC}}{I_0}\right) + \ln X\right] = V_{OC} + \frac{nkT}{q} \ln X$$

where X is the concentration of sunlight.

The efficiency benefits of concentration may be reduced by increased losses in series resistance as the short-circuit current increases and also by the increased temperature operation of the solar cell. As losses due to short-circuit current depend on the square of the current, power loss due to series resistance increases as the square of the concentration.

Low Light Intensity :

Solar cells experience daily variations in light intensity, with the incident power from the sun varying between 0 and 1 kW/m^2. At low light levels, the effect of the shunt resistance becomes increasingly important. As the light intensity decreases, the bias point and current through the solar cell also decreases, and the equivalent resistance of the solar cell may begin to approach the shunt resistance. When these two resistances are similar, the fraction of the total current flowing through the shunt resistance increases, thereby increasing the fractional power loss due to shunt resistance. Consequently, under cloudy conditions, a solar cell with a high shunt resistance retains a greater fraction of its original efficiency than a solar cell with a low shunt resistance.

Q. 8. Explain Effect of Temperature on efficiency of a solar cell.

Like all other semiconductor devices, solar cells are sensitive to temperature. Increases in temperature reduce the bandgap of a semiconductor, thereby affecting most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. Lower energy is therefore needed to break the bond. In the bond model of a semiconductor bandgap, a reduction in the bond energy also reduces the bandgap. Therefore, increasing the temperature reduces the bandgap.

In a solar cell, the parameter most affected by an increase in temperature is the open-circuit voltage. The impact of increasing temperature is shown in the figure below.

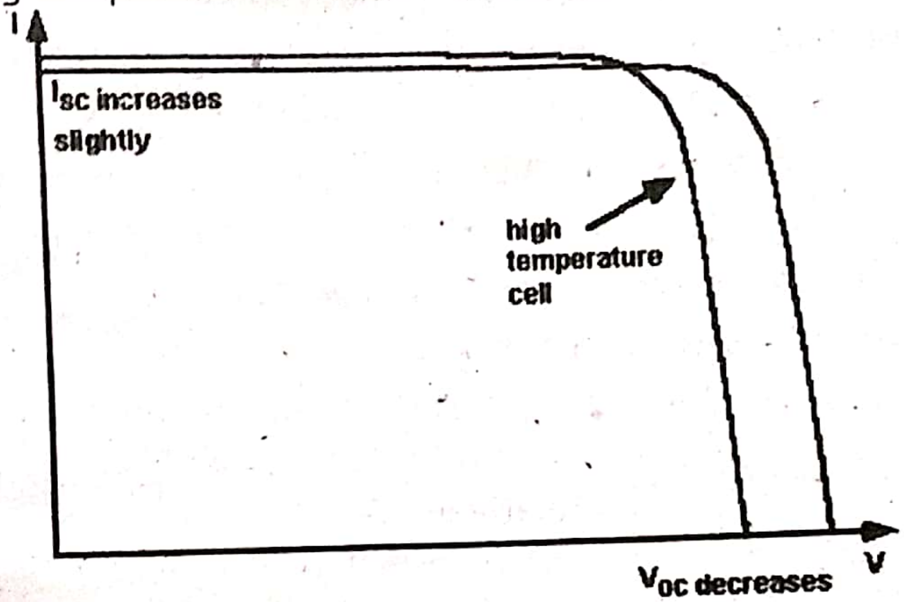


Fig : The effect of temperature on the IV characteristics of a solar cell.

The open-circuit voltage decreases with temperature because of the temperature dependence of I_0. The equation for I_0 from one side of a *p-n* junction is given by

$$I_0 = qA\frac{Dn_i^2}{LN_D}$$

where:

q is the electronic charge given in the constants page

A is the area;

D is the diffusivity of the minority carrier given for silicon as a function of doping in the Silicon Material Parameters.

L is the minority carrier diffusion length;

N_D is the doping; and

n_i is the intrinsic carrier concentration given for silicon in the Silicon Material Parameters.

In the above equation, many of the parameters have some temperature dependence, but the most significant effect is due to the intrinsic carrier concentration, n_i. The intrinsic carrier concentration depends on the bandgap energy (with lower bandgaps giving a higher intrinsic carrier concentration), and on the energy which the carriers have (with higher temperatures giving higher intrinsic carrier concentrations). The equation for the intrinsic carrier concentration is;

The short-circuit current, I_{sc}, increases slightly with temperature since the bandgap energy, E_G, decreases and more photons have enough energy to create e-h pairs. However, this is a small effect, and the temperature dependence of the short-circuit current from a silicon solar cell is typically;

$$\frac{1}{P_M}\frac{dP_M}{dT} \approx -(0.004\ to\ 0.005) per\ {}^{\circ}C\ for\ Si$$

or 0.06% per °C for silicon.

The change of I_{SC} with temperature is more dependent upon the design of the cell than the semiconductor material properties. A lower performance cell with little light trapping and a poor performance in long wavelengths near the band edge will have very little change in I_{SC} with temperature. Conversely, a cell with a high response near the band edge will see a much larger change in ISC with temperature. In either case, the change of I_{SC} with temperature is smaller than the change of V_{OC}.

The temperature dependency FF for silicon is approximated by the following equation;

$$\frac{1}{FF}\frac{dFF}{dT} \approx \left(\frac{1}{V_{OC}}\frac{dV_{OC}}{dT} - \frac{1}{T}\right) \approx -0.0015\ per\ {}^{o}C\ for\ Si$$

The effect of temperature on the maximum power output, P_m, is;

$$P_{Mvar} = \frac{1}{P_M}\frac{dP_M}{dT} = \frac{1}{V_{OC}}\frac{dV_{OC}}{dT} + \frac{1}{FF}\frac{dFF}{dT} + \frac{1}{I_{SC}}\frac{dI_{SC}}{dT}$$

$$\frac{1}{P_M}\frac{dP_M}{dT} \approx -(0.004\ to\ 0.005) per\ {}^{o}C\ for\ Si.$$

or 0.4% to 0.5% per °C for silicon.

SHORT ANSWER QUESTIONS

Q. 5. What is shunt resistance?

Significant power losses caused by the presence of a shunt resistance, R_{SH}, are typically due to manufacturing defects, rather than poor solar cell design. Low shunt resistance causes power losses in solar cells by providing an alternate current path for the light-generated current. Such a diversion reduces the amount of current flowing through the solar cell junction and reduces the voltage from the solar cell. The effect of a shunt resistance is particularly severe at low light levels, since there will be less light-generated current. The loss of this current to the shunt therefore has a larger impact. In addition, at lower voltages where the effective resistance of the solar cell is high, the impact of a resistance in parallel is large.

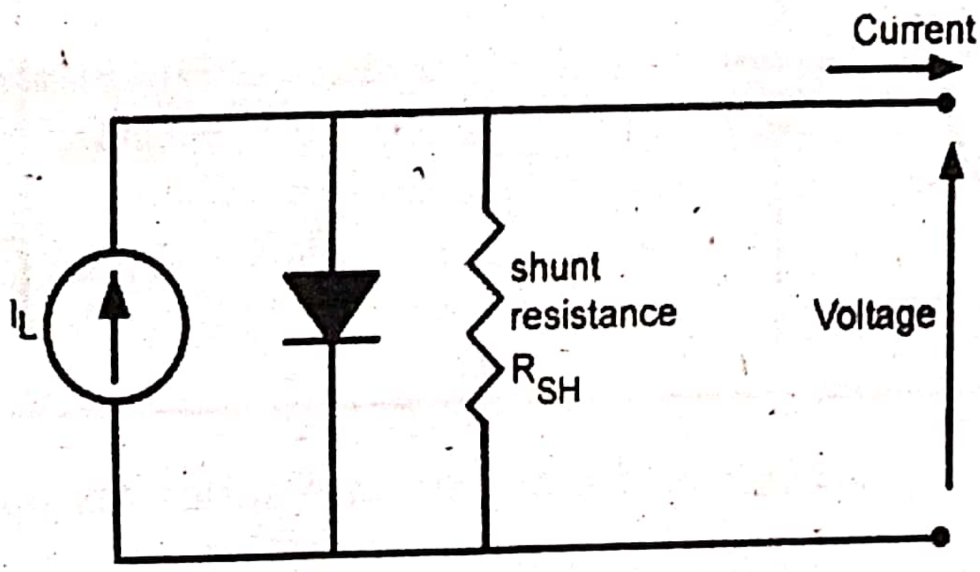


Fig : Circuit diagram of a solar cell including the shunt resistance.

The equation for a solar cell in presence of a shunt resistance is:

$$I = I_L - I_0 \exp[qV/nkT] - V/R_{SH}$$

where: I is the cell output current, I_L is the light generated current, V is the voltage across the cell terminals, T is the temperature, q and k are constants, n is the ideality factor, and R_{SH} is the cell shunt resistance.

Q. 6. *What is series resistance?*

Series resistance in a solar cell has three causes: firstly, the movement of current through the emitter and base of the solar cell; secondly, the contact resistance between the metal contact and the silicon; and finally, the resistance of the top and rear metal contacts. The main impact of series resistance is to reduce the fill factor, although excessively high values may also reduce the short-circuit current.

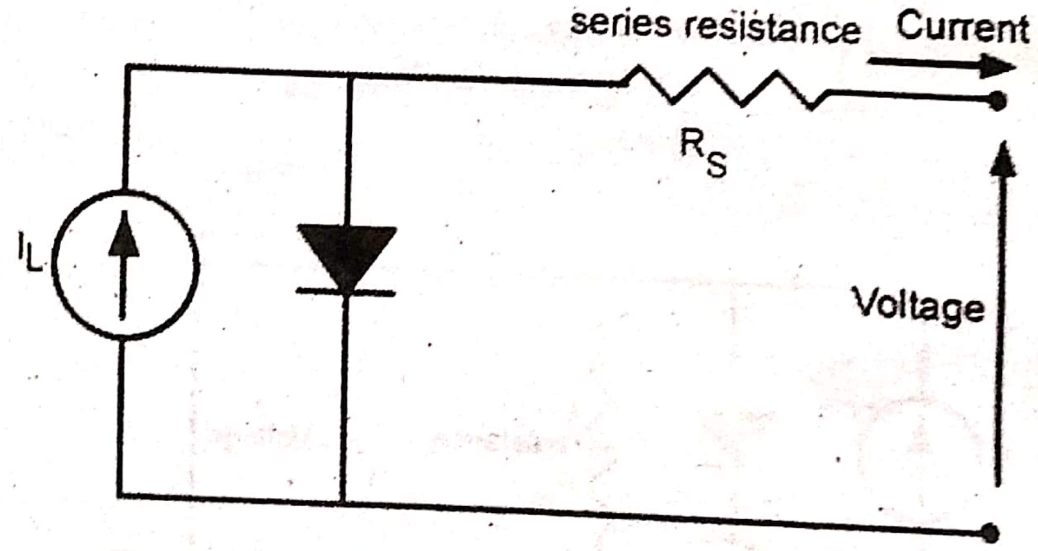


Fig : Schematic of a solar cell with series resistance.

$$I = I_L - I_0 \exp\left[\frac{q(V+IR_S)}{nkT}\right]$$

where : I is the cell output current,

I_L is the light generated current,

V is the voltage across the cell terminals,

T is the temperature,

q and k are constants,

n is the ideality factor, and

R_S is the cell series resistance.

The formula is an example of an implicit function due to the appearance of the current,

I, on both sides of the equation and requires numerical methods to solve.

VERY SHORT ANSWER QUESTIONS

Q. 1. What is homojunction and heterojunction?

In a simplest definition, a homojunction is a junction between the same materials with the same crystalline structure. A heterojunction is a junction between different materials or between the same materials, but with different crystal structure.

Q. 2. What do you mean by Schottky barrier?

The Schottky barrier is the energy difference between the valence (or conduction) band edge of the semiconductor and the Fermi energy of the metal, while the band offset is the energy difference of valence (or conduction) bands of two materials that construct theinterface.