Temperature dependence of Solar Cell I-V Characteristics

Theory

In the previous experiment, we found that a solar cell (p-n junction) under illumination generates a current. You have also measured the current- voltage characteristics and found that it is in the fourth quadrant. This shows that the solar cell can be used as a power source, when the current is fed into a load.

In real applications, sunlight is used as the source of illumination and energy is harvested from the sun by the solar cell (and hence the name) to generate power. In the field, the temperature of the solar cell will increase above the ambient temperature. The rise in temperature depends on many factors. It obviously depends on the intensity of the light incident on the cell. It also depends on wind and many other factors. As a rule of thumb, the typical increase in temperature of the solar cell above the ambient temperature is about 20-25^{0}C. For instance in Mumbai, the operating temperature of the cell can be as high as 50^{0}C and in Rajasthan as high as 75^{0}C. We need to understand how the cell behaves at high temperature to design a power plant based on solar cells. This provides the motivation for this experiment.

The dark characteristics are also very important in the functioning of the solar cell. You will study how the temperature influences the dark characteristics, open circuit voltage, the short circuit current and the fill factor. This understanding is crucial to correctly design a solar cell system for power generation.

Dark characteristics

We have studied the basic operation and I/V characteristics of solar cell in the last experiment. The solar cell is essentially a "special "semiconductor diode with large area. The ideal semiconductor diode equation is given by

$$I = I_{01}(e^{\frac{qV_D}{kT}} - 1) \tag{1}$$

However, real materials have defects and they influence the diode current. The current voltage relationship of a real diode (solar cell in dark) is given by Eq. 2

$$I = I_{01}[e^{\frac{qV_D}{kT}} - 1] + I_{02}[e^{\frac{qV_D}{2kT}} - 1] + \frac{V - IR_s}{R_{Sh}} \tag{2}$$

Fig.1 shows a generalized equivalent circuit of the diode in the dark. It is important to remember that one has access only to terminals A and B. In the above expression V$_D$ is the voltage across the diode and V is the applied voltage across the diode. At large currents (large values of Rs) V can be different from V$_D$.The difference being the IR$_S$ drop across the series resistor. R$_S$ and R$_{Sh}$ arise due to technology used.

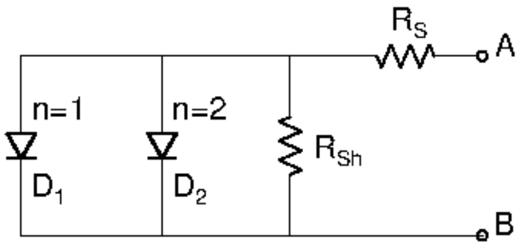

Figure 1: Equivalent circuit of solar cell under dark conditions

For a one sided junction,

$$I_{01} = q\left(\frac{D_p}{\tau_p}\right)^{\frac{1}{2}}\left(\frac{n_i^2}{N_A}\right) \tag{3}$$

and

$$I_{02} = \left(\frac{qW\sigma v_{th}N_T n_i}{2}\right) \tag{4}$$

where,

$$n_i^2 = N_C N_V e^{\frac{-E_g}{kT}} \tag{5}$$

D and τ are the diffusion constant and lifetime respectively, n_i the intrinsic carrier concentration, N_D the donor doping density, W the depletion width,N_C and N_V are the effective densities of states for conduction band and valence band respectively, σ as capture cross-section and v_{th} the thermal velocity.

The term involving I_{02} is caused by the presence of defects with energy near the midgap. This can be seen in Eq. 4 where I_{02} is proportional to the defect density N_T. Usually I_{02} is much larger than I_{01}. Hence, at low voltages, the term I_{02} in Eq. 2 dominates the I-V characteristic. The inverse of the slope of the curve of *ln* I v/s V_D is given by η kT/q. where η the ideality factor equal to 2. The magnitude of I_{02} and the range of voltage where η =2 is a measure of defect density in the material.

As the applied voltage V increases, the term I_{01} dominates the I-V characteristic as the I_{01} term increases more steeply with voltage (ideality factor η =1). The magnitudes of I_{01} and I_{02} is a measure of the "goodness" of the diode. The smaller the values, the better the technology and will make a better solar cell.

Lighted Characteristics

Under illumination there is a constant generation of free carriers that gives rise to a "reverse" current I_L. The solar cell acts as a current generator. This is shown in Figure 1b.

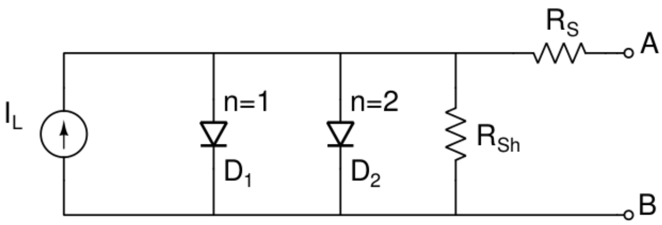

Figure 2: Equivalent circuit of a Solar Cell under illumination

Under illumination, the diode equation becomes

$$I = I_{01}[e^{\frac{qV_D}{kT}} - 1] + I_{02}[e^{\frac{qV_D}{2kT}} - 1] + \frac{V + IR_s}{R_{Sh}} - I_L \tag{6}$$

We see from Eq.6 that under illumination, the current is essentially the photo-generated current I_L bucked by the forward "dark current". The shape of the lighted I-V curve is essentially the same as the dark I-V displaced by I_L. The Fill Factor, which is the "squareness" of the lighted I-V characteristic depends on the shape of the dark I-V curve. The short circuit current is the current in the circuit by shorting leads A and B. The open circuit voltage is the voltage between A and B at zero current.

Temperature Dependence

It turns out that both I_{01} and I_{02} are temperature dependent and their temperature dependence comes through n_i, which varies exponentially with temperature. This causes both, dark and lighted characteristics to depend on temperature.

In this experiment, we will measure dark and lighted characteristics and investigate how the parameters I_{SC}, V_{OC}, fill factor, cut-in voltage vary with temperature. Fig.3 shows I/V characteristics of solar cell at different temperatures under dark conditions. It is very clear from the characteristics that the cut-in voltage decreases as temperature increases.

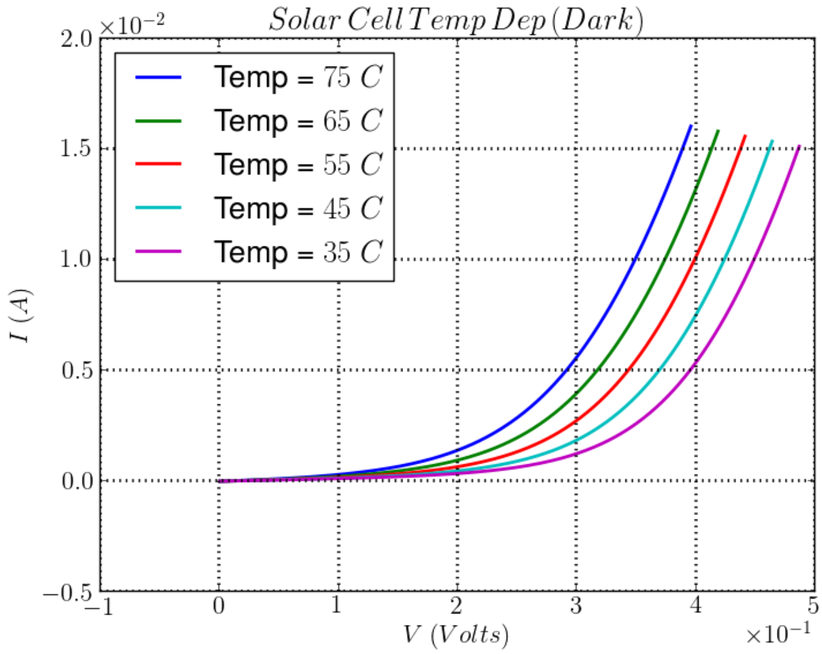

Figure 3: Temperature dependent I-V characteristics under dark conditions

Fig.4 shows I/V characteristics of solar cell at different temperatures under illumination of constant intensity.

It is found that ideally I_{SC} increases marginally with increase of temperature(may not be obvious from these characteristics. The expected fractional increase in I_{SC} with temperature is given as [1]

$$\left[\frac{1}{I_{SC}}\right]\left[\frac{\Delta I_{SC}}{\Delta T}\right] \sim 0.0003/K \tag{7}$$

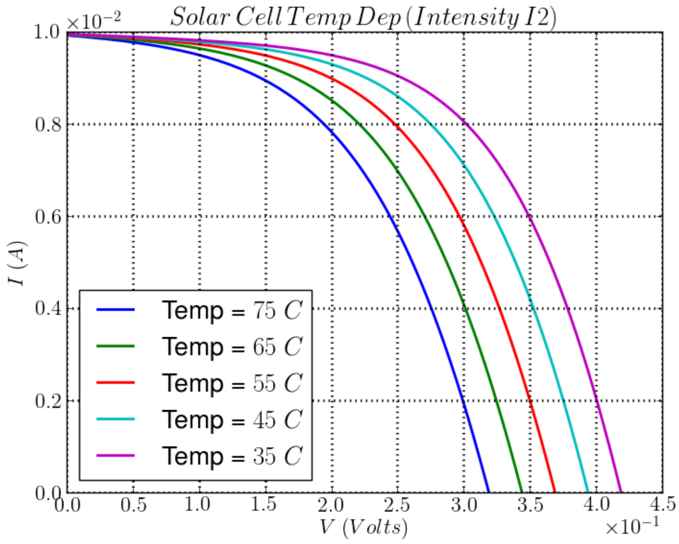

Figure 4: Temperature dependent I-V characteristics under illumination

The increase is related to small reduction in the semiconductor band gap with increase of temperature such that the semiconductor absorbs more photons from the incident sun light.

In contrast with I_{SC}, the V_{OC} shows a very substantial decrease with increase in temperature. The expected fractional decrease of V_{OC}[1]

$$\left[\frac{1}{V_{OC}}\right]\left[\frac{\Delta V_{OC}}{\Delta T}\right] \sim -0.003/K \tag{8}$$

which works out to be decrease of roughly 2 mV per degree.

The cut-in voltage is defined as the voltage across the diode at a fixed forward current and it decreases as T increases. The open circuit voltage V_{oc} will also decrease. If you plot the cut-in voltage as a function of T and the V_{oc} also as a function of T on the same graph, you should expect to see a similar dependence of both quantities. The lighted I-V characteristics are intimately connected with the dark I-V characteristics.

References

1. J C C Fan, "Theoretical Temp Dependence of Solar Cells", Solar Cells 17, 309(1986).