The Islamia University of Bahawalpur

Department Of Physics

Physics lab (Phy-01604/Phy-21205)

Solar Cell

Objective:

The purpose of this experiment is to gain familiarity with solar cells and their operation. This experiment will measure the following solar cell characteristics: short circuit current, open circuit voltage, and the dark and light I-V characteristics.

Introduction:

In the Semiconductor optics experiment, two different types of photo detectors will be introduced: the photoconductor and the photodiode. The photodiode has a current voltage characteristic as shown in Figure 1a.

The photodiode is usually operated in reverse bias mode, so that the carriers generated within the depletion region are quickly swept toward the terminals. This is one reason why the response speed of a photodiode is fast. A photodiode is operated in the third quadrant of the I-V curve in Figure 1. A p-n junction can also be operated in the fourth quadrant.

If the p-n junction is operated in the fourth quadrant, the product of a negative current and a positive voltage will yield a negative power. Physically, this corresponds to a source of power. Consequently, a p-n junction operated in the fourth quadrant can be used as a source of power; this is the principle behind the solar cell.

Theory:

Recall that the current and voltage through a p-n junction diode can be written

$$I = I_{sat}\left(e^{qV/nkT} - 1\right) \qquad (1)$$

Where I_{sat} the reverse saturation is current and n is an ideality factor that is introduced to modify the theoretical expression for use with "real" diodes.

Under the presence of an optical stimulus, photons are absorbed to create electron hole pairs. Pairs that are generated within a diffusion length of the depletion region will be swept by the built in potential across the depletion region. Consequently, when being excited by light, a current is produced due to the optical generation of carriers. Including this generation current in equation (1):

$$I = I_{sat}\left(e^{qV/nkT} - 1\right) - I_{gen} \qquad (2)$$

Figure 1b demonstrates how optical excitation effects the I-V characteristic of the solar cell. Note that a large generation rate corresponds to a larger generation current, corresponding to a larger downward shift in the I-V.

Figure 2 show an equivalent circuit that may be used to model the behavior of a solar cell. Notice that the current generated by the photons is represented by an independent source. The two resistors shown in Figure 2 model two of the losses in a solar cell. R_S is a series loss due primarily to the ohmic loss in the surface of the solar cell. The shunt resistance R_{Sh}, is used to model leakage current. A shunt resistance of a few hundred ohms does not reduce the output power of the solar cell appreciably. In reality, R_{Sh} is much larger than a few hundred ohms and can in most cases be neglected. The series resistance, however, can drastically reduce output power. For example, a series resistance of only 5 Ω can reduce output power by 30%.

Figure 2: Equivalent circuit of a "real" solar cell showing both a shunt and series resistive loss. In reality, the shunt resistance can be neglected, but the series resistance cannot.

Two quantities of interest for a solar cell are the following: short circuit current (I_{SC}) and open circuit voltage (V_{OC}). Expression for both I_{SC} and V_{OC} can be found from equation (2). The short circuit current is found by setting V = 0 in equation (2). This results in the following expression for I_{SC}.

$$I_{SC} = - I\ (V = 0) \qquad (3a)$$

$$I_{SC} = I_{gen} \qquad (3b)$$

The minus sign in equation (3a) results from the fact that the current I_{SC} is by definition the magnitude of the current at V=0. To find the open circuit voltage, let I=0 in equation (2) and solve for V:

$$V_{OC} = \frac{nkt}{q}\ln\left(\frac{I_{gen}}{I_{sat}} + 1\right) \qquad (4)$$

Again, by using the fact that $I_{SC} = I_{gen}$ equation (4) can be further simplified:

$$V_{OC} = \frac{nkt}{q}\ln\left(\frac{I_{gen}}{I_{sat}}\right) \quad \text{for } I_{SC} > I_{Sat} \qquad (5)$$

Note: In all of the preceding equations, we have neglected the effects of R_{sh} R_S. That is, we have let R_{sh} =   and R_s = 0.

Another characteristics property of solar cells of interest is the fill factor, FF, which is defined as:

$$FF = \frac{P_{max}}{I_{sc}\ V_{oc}} = \frac{I_{\max pwr}\ V_{\max pwr}}{I_{sc}\ V_{oc}} = \frac{I_m\ V_m}{I_{sc}\ V_{oc}} \qquad (6$$

Procedure:

Caution:

1. The lamp you will use is only rated to 0.95A. Allowing current to exceed 0.95A through the lamp will destroy the filament.
2. Before starting the experiment, make sure that the lamp and the plastic case are not in contact. The heat produced by the lamp can reach levels that will melt the plastic case.

Part 1: Measuring the dark I-V characteristic

1. Connect the circuit as shown in Figure3. Make sure that the solar cell is covered to keep out the ambient light in the laboratory.
2. With the variable DC power supply V_s , vary the current I_D should be varied from 1 mA to 50 mA in approximately 5 mA steps.
3. Record I_D and the voltage across the solar cell V_D.

Part 2: Measuring Open Circuit Voltage, V_{OC} and short circuit current, I_{SC}.

1. Connect the circuit as shown in Figure 4. Make sure that solar cell is covered.
2. Set the DC power supply (as a constant current source) to I_L = 0.5 A. This will supply power to the light source (the lamp) that will be used in this experiment. I_L can be read out directly from the display of the power supply.
3. At this value of I_L , measure and record V_{OC} and I_{SC}.
4. Repeat steps 2 and 3, Increasing I_L in 0.05 A increments to 0.95 A.

   Do not exceed 0.95 A or the lamp will burn out.

Part 3: Finding the Fill Factor of the Solar Cell

1. Connect the circuit as shown in Figure 5. The variable is a decade resistor box.
2. Set the power supply to I_L = 0.75 A.
3. Vary the resistance of the decade boxes in 10 steps from 0 Ω to 200 Ω.
4. Record R and V_r.

Report

1. Plot the dark I-V characteristic of the solar cell that you measured part 1.
2. Plot the ln (I_{SC}) vs. V_{OC} from part 2. From this plot, you should be able to obtain n (identify factor) and I_{SAT}.
3. Now, the dark I-V characteristic can be plotted again using equation (1) and the values of n and I_{SAT} you get above. Plot the dark I-V and compare it with the curve you obtained from Part 1.
4. From the data from part 3, calculate the current in the circuit $I_r = V_r/R$ for each resistance value R. plot I_r as a function of V_r. from this graph find I_{SC}, Compare these two values with the results you got in Part 2 (I_{SC} and V_{OC} @ I_L = 0.75 A).

5. Using the data collected in Part 3, plot power $P = V_r^2 / R$ as a function of V_r. Determine the voltage V_{max} at which the power P reaches maximum point. Find the current at the maximum power point $I_{max} = V_{max} / R$. using I_{max} and V_{max} calculate I_{max} / I_{SC} , V_{max} / V_{OC} and the fill factor $FF = I_{max} . V_{max} / (I_{SC} . V_{OC})$.

Questions:

1. Do your two dark I-V plots look exactly the same? Why or why not? (give other reasons besides human error)
2. The efficiency η of a solar cell is defined as the ratio of the maximum power generated to the input power: $\eta = P_{max} / P_{in}$. Find η in terms of FF, I_{SC} and V_{OC} and P_{in}.
3. How does the efficiency depend on the incident power, i.e. is it constant, increase with incident power, fall, or reach a maximum or minimum? Give calculations or reasoning.
4. In report. 4 above, you plotted I_r as a function of V_r. Does this graph appear anywhere in the graph of Figure 1 (b)? If so, where and why?

(1)

d(cm)	I_g (mA) (generated current in presence of source)
10	---
20	--- (I_{g1})
.	--- (I_{g2})
.	.--- (I_{g3})
.	.
.	.
.	.
.	.
100	-------

$I_{d(last)} > I_{g1} > I_{g2} > I_{g3}$

----

(2)

V(volts)	I_d (mA)
0.1	---
0.2	---
0.3	---
0.4	---
.	.
.	.
.	.
.	.
.	.
4.0	---

(3)

V(volts)	I_{net} ($I_d - I_{g1}$)	$I_{net\ 3}$ ($I_d - I_{g2}$)	$I_{net\ 3}$ ($I_d - I_{g3}$)
0.1			
0.2			
0.3			
0.4			
.			
.			
.			
.			
.			
4.0			

(4)

$$FF_1 = \frac{I_{max}\ V_{max}}{I_{sc}\ V_{oc}}$$

FF_2 & FF_3

$$F.F = \frac{FF1 + FF2 + FF3}{3}$$

$$F.F < 0.4$$