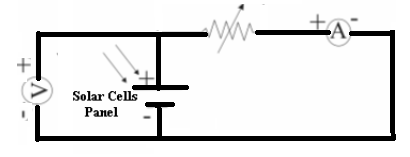
**2. Solar Cell**

**Objective: -** To draw the characteristics of solar cell and to estimate Fill Factor (FF) of solar cell.

**Apparatus Required**: - Solar cell, rheostat, ammeter, voltmeter, illumination source, Bulb and connecting wires.

**Circuit diagram: -**



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**Figure 1 Setup for determining characteristics of a solar cell**

**Theory and Formula Used:** Solar cell is basically a two terminal p-n junction device designed to absorb photon absorption through the electrical signal or power in the external circuits. Therefore it is necessary to discuss the physics of semiconductor p-n junction diode, which converts the optical energy into electrical signals.

Photovoltaic systems convert sunlight directly into electrical energy. The backbone of this technology is semi-conducting materials such as silicon. A typical solar cell consists of two differently doped semiconductors. Doping is the controlled introduction of impurities into the host material. Starting out with a pure semiconductor crystal (say, silicon) this is achieved by substituting some of the atoms in the crystal lattice with elements that have one more or less valence electron than the host material (valence electrons are the electrons that determine the chemical behavior of a material, they are located in the outermost orbital shell of the atom). Semiconducting elements have four valence electrons all of which are used for bonding in the crystal lattice. If the doping material has five valence electrons there will be one additional, loosely bound electron per dopant atom. These 'free' atoms can move about easily in the lattice and are responsible for an increase in conductivity. Since they have a negative charge the material doped in this way is called as n-type semiconductor. If, on the other hand, the doping material has only three valence electrons the lattice structure will be deficient of electrons and there will be one hole, or positive charge, per dopant atom. Similar to the free electrons above, the holes can easily move about in the lattice, again causing an increase in conductivity. Since in this case the free charge carriers are positive this kind of semiconductor is said to be of p-type. When a p-type semiconductor is joined to an n-type semiconductor, a p-n junction is created. While each side by itself is electrically neutral (there are as many electrons as there are protons) this is not the case for certain areas of the combined configuration. The concentration differences of holes and free electrons between n- and p- regions produce diffusion current: electrons flow from the n-side and fill holes on the p-side. This creates a region that is almost devoid of free charge carriers (i.e. free electrons or holes) and is therefore called the depletion zone. In the depletion zone there is a net positive charge on the n-side and a net negative charge on the p-side resulting in an

electric field that opposes a further flow of electrons. The more electrons move from the n- to the p-side the stronger the opposing field will be and eventually an equilibrium will be reached in which no further electrons are able to move against the electric field. The potential difference of the equilibrium electric field is called diffusion voltage. It cannot be used externally. However, when light hits the solar cell the equilibrium conditions are disturbed and the so-called inner photo effect creates additional charge carriers that are free to move in the electric field of the depletion zone. Holes move towards the p-region and electrons towards the n-region, thus creating an external voltage (no-load voltage) at the cell. The no-load voltage of a solar cell is material dependent and does not depend on the cell's surface area. A silicon solar cell has a no-load voltage of about 0.5 V. Higher voltages can be obtained by connecting individual cells in series. The current delivered by a solar cell is proportional to the intensity of the incoming light. Higher currents can be achieved by connecting cells in parallel. The power of a solar cell depends not only on the cell itself but also on the connected

electrical load. The maximum power point (MPP) can easily be determined from the power-voltage characteristic of the cell. The efficiency of a solar cell is temperature dependent. It will decrease with

increasing temperature.

**Characteristics of a Solar Cell :**

The usable voltage from solar cells depends on the semiconductor material. In silicon it amounts to approximately 0.5 V. Terminal voltage is only weakly dependent on light radiation, while the current intensity increases with higher luminosity. A 100 cm² silicon cell, for example, reaches a maximum current intensity of approximately 2 A when radiated by 1000 W/m².

The output (product of electricity and voltage) of a solar cell is temperature dependent. Higher cell temperatures lead to lower output, and hence to lower efficiency. The level of efficiency indicates how much of the radiated quantity of light is converted into useable electrical energy.

**Fill Factor (FF):**

The fill factor (**FF**) percentage measures the "squareness" of the I-V curve. It states the degree to which the voltage at the maximum power point (Vmp ) matches the open-circuit voltage (Voc ) and that the current at the maximum power point (Imp) matches the short-circuit current (Isc). Therefore, a more “squared” I-V curve will have a higher fill factor.

This relation is given by.



**Efficiency of solar cell:**

The efficiency of the solar cell is the ratio of produced electrical power (Pout) and the incident radiant power (Pin). Efficiency of solar cell, 

Where Pout is the electrical power (maximum power point) Pin is calculated by multiplying approximated irradiance (“irradiance” means radiant power of the light incident per unit area) by the effective area of the solar cell on the panel.

This method used the fact that the practical value of the current (maximum photoelectric current measured) is proportional to the photons (radiation) striking the solar cell. This current is therefore proportional to the incident radiant power of the light.

The open circuit voltage depends on the semiconductor material of which solar cell is made. It is not proportional to the incident radiant power and therefore cannot be used for this measurement.

**Procedure :**

**1.** Take the Solar Energy Trainer along with Solar Panel.

**2.** Place the solar panel in the stand and adjust the panel at an angle of about 45º with the ground. Direct the sunlight straight at the solar panel (angle of 90º).

**Note :** If sunlight is not properly available then any source of light like lamp can be used.

**3.** With the DB15-connector connect the Solar Energy Trainer with Solar Panel. Then wait for 1 minute to avoid errors due to temperature fluctuations.

**4.** Set the potentiometer to maximum resistance i.e. at fully clockwise position and measure and record its resistance into the Observation Table.

**5.** Connect the solar cell as shown in the following circuit diagram (Fig. 1).

**a.** Connect positive terminal of solar cell to P1 terminal of the potentiometer.

**b.** Connect other end of potentiometer i.e. P2 to positive terminal of ammeter.

**c.** Connect negative terminal of ammeter to negative terminal of solar cell.

**d.** Now connect the positive terminal of voltmeter to P1 and negative terminal of voltmeter to P2.

**6.** Record the values of corresponding voltage and current into the Observation Table.

**7.** Now gradually move the potentiometer in anti- clockwise direction so that the resistance of the potentiometer decreases. Now measure the resistances at successively smaller values and record the corresponding values of voltages and current into the Observation Table below.

**Note:** To measure the resistance of potentiometer at any position, first remove the patch cords from P1 and P2 and measure resistance by multimeter. Reconnect these connections again for further measurements.

**Observation Table :**

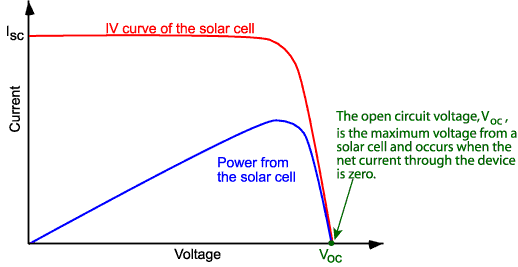
|  |  |  |  |
| --- | --- | --- | --- |
| **S. No**. | **Voltage, V**  **(Volts)** | **Current, I**  **(mA)** | **Power calculated**  **P = V. I (Watts)** |
| **1.** |  |  |  |
| **2.** |  |  |  |
| **3.** |  |  |  |
| **4.** |  |  |  |
| **5.** |  |  |  |
| **6.** |  |  |  |
| **7.** |  |  |  |
| **8.** |  |  |  |
| **9.** |  |  |  |
| **10.** |  |  |  |

**8.** Plot the I-V characteristics from the measurements recorded in the table, to show how the photoelectric current depends on the photoelectric voltage and to find maximum power point.

9. Plot the power (VI) as a function of voltage to determine maximum power.

10. The fill factor (FF) is defined by the ratio





**Fig 2. Current-voltage characteristic of the solar cell**

**Calculations:**

1. Plot the IV characteristic of the solar cell.

2. Plot the power (= VI) vs V and determine the maximum power.

3. Determine the fill factor(FF).



**Results:**

1. The I-V characteristic was drawn for given solar cell
2. Fill factor (FF) =...............................

**Precautions:**

1. Make sure that all the connections are tight.

2. Wait for few minutes to avoid errors due to temperature fluctuations.

3. To measure the resistance of potentiometer at any position, first remove the patch cords from P1 and P2 and then measure the resistance by a multimeter.

**Observation Table :**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S. No**. | **Voltage, V**  **(Volts)** | **Current, I**  **(mA)** | **Power calculated**  **P = V. I (Watts)** | **P = V. I (Watts)**  P=VI/100 |
| **1.** | 0 | Isc= 104 | 0 | 0 |
| **2.** | 0.5 | 103.8 | 0.0519 | 5.19 |
| **3.** | 1 | 102.5 | 0.1025 | 10.25 |
| **4.** | 1.5 | 101.5 | 0.15225 | 15.225 |
| **5.** | 2 | 101.2 | 0.2024 | 20.24 |
| **6.** | 2.5 | 100.3 | 0.25075 | 25.075 |
| **7.** | 3 | 99.6 | 0.2988 | 29.88 |
| **8.** | 3.5 | 98.7 | 0.34545 | 34.545 |
| **9.** | 4 | 98.4 | 0.3936 | 39.36 |
| **10.** | 4.5 | 98 | 0.441 | 44.1 |
| **11** | 5 | 97.1 | 0.4855 | 48.55 |
| **12** | 5.5 | 94.5 | 0.51975 | 51.975 |
| **13** | 6 | 91.3 | 0.5478 | 54.78 |
| **14** | Vm = 6.5 | Im = 85.4 | 0.5551 | 55.51 |
| **15** | 7 | 79.1 | 0.5537 | 55.37 |
| **16** | 7.5 | 72.9 | 0.54675 | 54.675 |
| **17** | 8 | 64.2 | 0.5136 | 51.36 |
| **18** | 8.5 | 56 | 0.476 | 47.6 |
| **19** | 9 | 45.8 | 0.4122 | 41.22 |
| **20** | 9.5 | 28 | 0.266 | 26.6 |
| **21** | 9.7 | 18.6 | 0.18042 | 18.042 |
| **22** | Voc = 10.2 | 0 | 0 | 0 |