

Getting a Charge out of PV

Do solar cells obey Ohm's law? In this lab, you will explore the relationship among current, voltage, power, and light intensity for silicon photovoltaic cells. There are specific features that are characteristic to all solar cells. These are the open-circuit voltage (V_{oc}), voltage at maximum power (V_p), short-circuit current (I_{sc}), current at maximum power (I_p) and fill factor (ff).

The *open circuit voltage*, V_{oc} , is a measure of the distance between the valence band and conduction band in the cell. This is defined by the type of material used and any dopants present in the material (e.g. p-doped silicon). The *short circuit current*, I_{sc} , is the current the solar cell generates when there is no resistive load (maximum current flow). Although the values obtained from measuring the V_{oc} and I_{sc} are at their respective maximum at these operating points, the power obtained from the solar cell is zero ($P = V \times I$)

Voltage at maximum power and *current at maximum power* are defined by the product of $V \times I$ as a load is applied to the cell. The point at which power is maximized defined V_p and I_p .

The two combinations of V and I yield two rectangles with areas $V_{oc}I_{sc}$ and V_pI_p . The fill factor is defined as the ratio of the areas of the two rectangles (Fig. 1).

$$ff = \frac{V_p I_p}{V_{oc} I_{sc}} = \frac{P_{meas}}{V_{oc} I_{sc}}$$

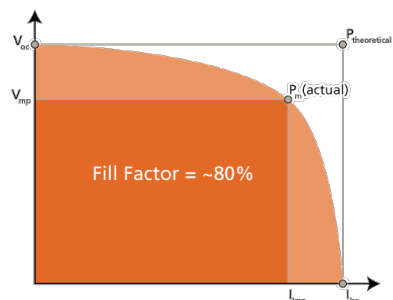


Figure 1. Diagram illustrating how fill-factor is calculated.

The fill-factor (figure 1) is always less than one due to internal resistance within the cell as well as external shunt resistance in the circuit. A higher quality solar cell will have a fill-factor close to unity, 1. The most important factor to consider on any solar cell is the overall cell efficiency. This is defined as a measure of the output power divided by the input power.

$$\text{efficiency, } \eta = \frac{\text{maximum power}}{\text{incident light power}}$$

You will study the photocurrent generated a light source, including the short circuit current, the open circuit voltage of the cell, and the effect of a load resistance on the cell.

Materials

- Silicon PV cell
- Vernier LabQuest with Voltage and Current probes
- Resistance box
- Light source (halogen light, sunlight, etc.)
- Assorted alligator clips

Getting Started

You will need to setup the Vernier LabQuest for current and voltage probe measurements. Data acquisition should be done under “Events by Entry”. Setup an experiment where current is plotted against voltage (I is y and V is x) on one graph.

Solar Cell I-V curve

- Begin by assembling your simple circuit with the Vernier current probe in-line with the solar cell similar to figure 2. Connect the voltage probes to themselves to force 0V. No resistance box is required.
- Place your cell in front of the light source and begin data acquisition. If the value is negative, simply switch the leads. Keep this current value and record it as I_{sc} .
- Connect the voltage probe to the two solar cell leads and short the current probe so it reads zero (opposite of Figure 2). If the voltage value is negative, simply switch the leads. Record this value as V_{oc} . After this point, DO NOT MOVE YOUR CELL.
- Rewire the circuit as shown below in figure 3, with the resistance box in line with the solar cell and current probe. Connect the voltage probes across the resistance box.
- Set the resistance to minimum (10Ω) and begin collecting data. Keep a data point for the 10Ω resistance, naming it “10” then switch to the next resistance and keep that data point (naming it 22). Continue increasing the resistance until the Voltage and Current no longer change (probably $400\text{-}500\Omega$).
- End data collection

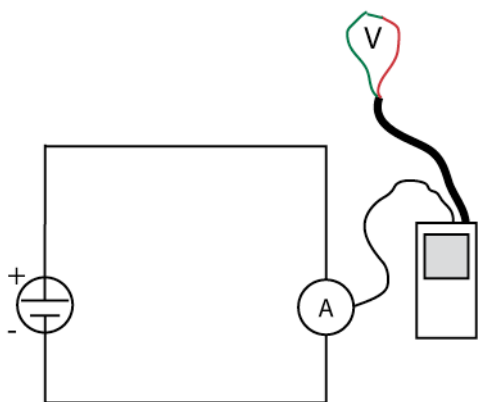


Figure 2. Connecting the Vernier to collect current data for I_{sc} measurement.

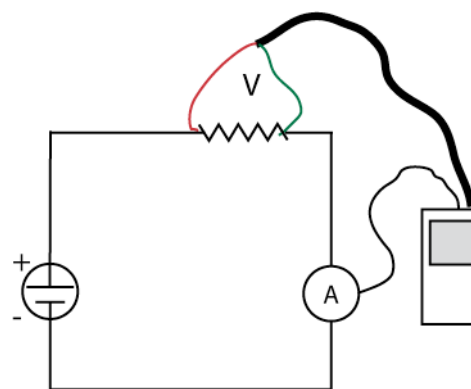
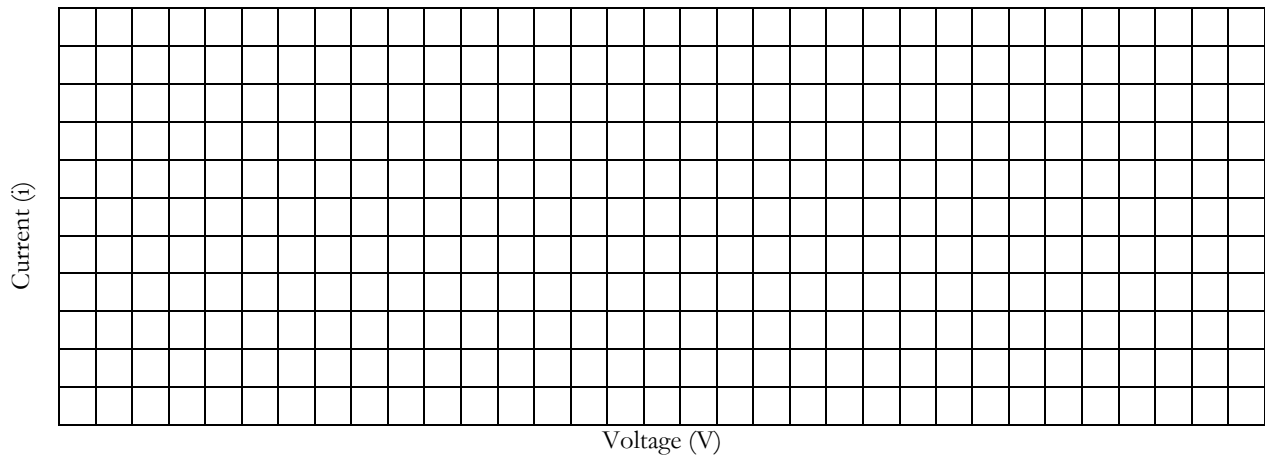


Figure 3. Connecting Vernier system to collect current and voltage with a resistance load.

Data Analysis

- Construct an I - V curve by hand and label the V_{oc} and I_{sc} , and maximum power rectangle.
- Using your acquired data, calculate the maximum power of your solar cell (*use calculated column*).
- Insert a column that calculates resistance of the cell, assuming the circuit obeys Ohm's law.
 - Compare the marked resistance on the resistance box with the calculated resistance
 - Does the circuit obey Ohm's law? If there is error in the resistance calculation, is it consistently high or low? Why might this be?

- Construct a power vs. resistance curve. *Recall that $P=VI$ and $V=IR$.*
 - What is the maximum power with a theoretical fill factor of 100%?
 - What is the actual maximum power point of the cell?
 - What is the fill-factor of the solar cell?



The Effect of Heat on Cell Performance

As we have discussed, the open-circuit voltage, V_{oc} , is related to the bandgap and is defined by the difference between the valence band and the conduction band in typical semiconductors. Upon heating, the relative distance between these two bands can shift in response to the average energy level of the ground state electrons. You will now examine the effect of heating on open-circuit voltage in a silicon solar cell.

Procedure

Rewire the circuit so you are measuring the open-circuit voltage, V_{oc} , of the cell only. No current probe or resistance is required. Setup the LabQuest to record Voltage vs. time, taking measurements at a rate of 10 samples per second for 3 minutes. Setup your silicon cell so it is stable and a fixed distance from a light source. Shutter the cell from the light (or keep the light off). Start collecting data and remove the shutter (or turn on the light) for the allotted time. What do you observe?

- Why are heat sinks added to the back of solar cells? This is known as passive cooling.
- Watt for watt, why might a silicon solar cell be more efficient in the cooler Northeast?

Efficiency analysis

- Using the ruler in your drawer, measure the approximate area of your solar cell.
- The typical power from the sun that strikes the Earth is 100 mW/cm^2 . Given this value and the area of your solar cell, calculate the maximum *incident* power on the solar cell.
- Previous measurements have recorded the maximum output power of your PV cell under solar conditions as 7.25 watts. What is the efficiency of your cell?

FYI

Like the motor/turbine experiment, solar cells can work forward and backward. Photovoltaic cells contain *p-n* junctions, the same that are found in all modern electronics. The solar cell absorbs photons and generates a current in the *forward* direction. If instead we take a *p-n* junction and connect it to a battery that drives current in the opposite direction, we will drive electrons and *holes* together, causing them to recombine and create photons with an energy equal to the *band gap*. This process creates the device known as a light emitting diode.

