Project 2B – Building a Solar Cell (2): Solar Cell Performance

Objective:

In this project we are going to experimentally measure the I-V characteristics, energy conversion efficiency under simulated solar illumination, responsivity and external quantum efficiency (EQE) spectrum of silicon solar cells. We will also correlate the responsivity spectrum and the solar spectrum to the short circuit current (I_{sc}).

Samples:

We will measure two samples in this experiment. The first sample is a p-type silicon chip with heavy n-type doping on the surface. The cross-section of the devices is shown in Fig. 1a. This is the simplest version of a p-n junction. There is no antireflection coating on the surface and no metal wire contacts to minimize the resistance, so the performance is certainly not optimized. Despite its simplicity, it does show rectifying I-V characteristics and photoresponse under room light illumination. The second one is a piece of fully processed silicon solar cell from Evergreen Solar, Inc. that you are going to visit in the field trip in May. This one has antireflection coating and fully implemented metal contacts to minimize the resistance of the device. A schematic cross-section is shown in Fig. 1b. This design also involve heavily doped n and p type regions to enhance the electric field in the device and increase carrier collection efficiency. We will measure its energy conversion efficiency with the solar simulator light source, and EQE spectrum with a monochromator.
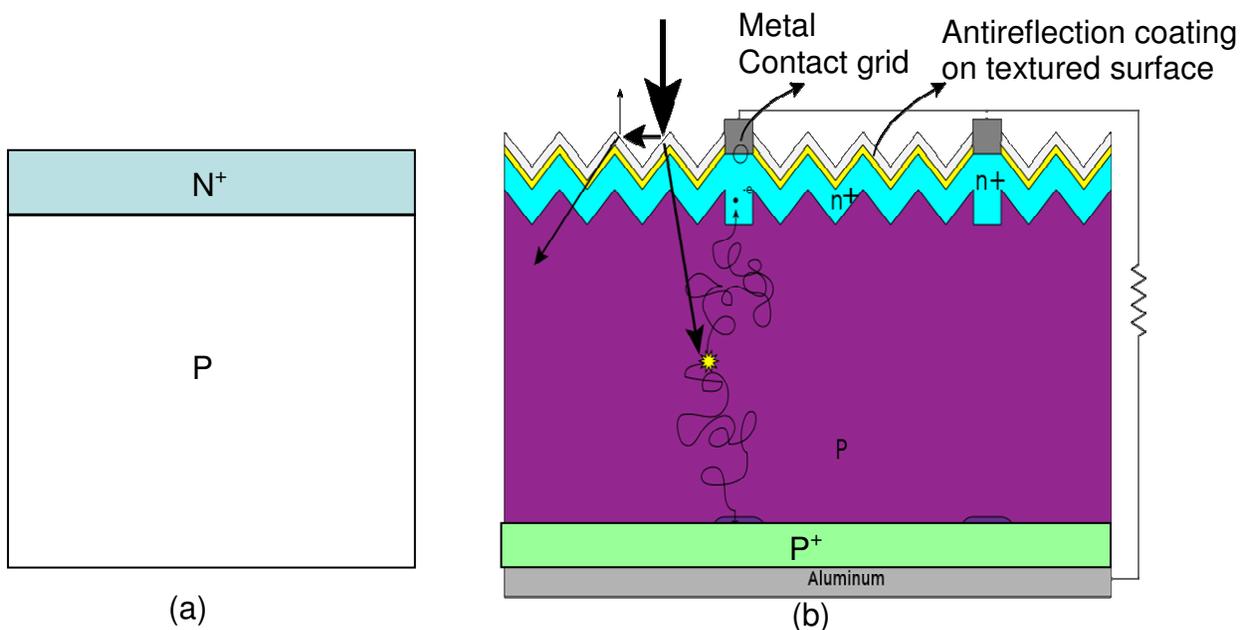
Image by Cyferz at Wikipedia.

Fig. 1 Schematic cross-section of (a) sample 1: a simple silicon p-n junction device, and (2) a fully processed silicon solar cell produced by Evergreen Solar.

1. Measure I-V characteristics with and without illumination

We will measure the I-V characteristics with an HP 4145A Semiconductor Parameter Analyzer.

1. Put sample 1 (simple silicon p-n junction) on the metal stage. Move probe #1 on top of it and press it hard on the surface of the sample.
2. Connect two cables of HP 4145A to probe #1 and the metal stage, respectively.
3. Put the lid on the chamber and use aluminum foil to cover the hole on the side. This step is to minimize the light illumination on the sample so that we can measure the I-V characteristics without illumination.
4. Turn on HP 4145A. Open "4145A-diode" program on the computer and set the scan range from -1 to 1 V with a step of 20 mV. Start the scan. After the scan, rename the file "IV" on the desk top.
5. Now take off the lid and let room light illuminate on the sample surface. Measure I-V characteristics again. Do you see some changes? Is there any optical power converted to electrical power? Remember to rename the file after the scan is finished.
6. Measure the active area of sample 2 and record it. You can exclude the wide solder strip from the active device area.
7. Repeat the steps 1-5 for sample 2. Do you see a better diode behavior?
8. Put on your sunglasses. Move the solar simulator right on top of the sample. Turn on the fan for the Xeon light bulb, and then plug in and turn on the solar simulator. Gradually increase the current to 31 A.
9. Measure the I-V curve for sample 2 under solar simulator illumination. Can you estimate its energy conversion efficiency considering that the incident optical power is about 100 mW/cm^2?

2: Measure the responsivity and external quantum efficiency spectrum of the Evergreen solar cell

Now let's check out the responsivity and EQE spectra of sample 2. You have simulated the EQE spectra in Lab 4, and now we are going to measure it experimentally

1. Turn on the light source (a halogen lamp) by gradually increasing its current until it reaches the set limit. Turn on the monochromator and set the displayed wavelength on the controller to 2 times the reading on the dial of the monochromator. Remove any filter in the optical path length of the monochromator.
2. Input wavelength 470 nm, 532 nm and 625 nm, respectively and observe the color of the output light.
3. Put the optical box on top of the probe stage so that the light spot is incident on the solar cell.
4. Open the program "I-wavelength". Set the voltage to 0 since we want to measure photocurrent vs. wavelength at short circuit condition. Set the wavelength range from 400 to 690 nm and perform the scan. Remember to rename the file "I-wavelength" on the desktop to save this data.
5. Now input the wavelength 1000 nm and check out if you see any visible light coming out of the monochromator. The wavelength of 1000 nm is in the near infrared regime and

human eyes cannot see it. The bluish-green light you see is the second order diffraction of at 500 nm, since when the optical path difference is 1x1000 nm for the first order diffraction at 1000 nm, it also matches the diffraction condition at 500 nm (2x500 nm, second order). It is a common issue when using monochromator. To filter out this blue-green light, we will put on a red filter into the optical path for the scan between 700 and 1000 nm. Of course, it will also filter out the 3rd and 4th order diffraction at even shorter wavelengths.

6. Now scan the wavelength range of 700-1000 nm with the red filter on and save the data.
7. Turn off the light and do a background scan to find the zero line.
8. Now you have the photocurrent spectrum of the solar cell. Using the file "mono.xls" you will be able to derive the responsivity spectrum and the EQE spectrum (see the Question session below)

Questions:
1. Plot the I-V curves of both samples without illumination on the same figure. Which one seems to show a better rectifying behavior? Do you see any linear part at the forward bias region of sample 1? What is the possible reason, and how would you improve it?
2. Plot the I-V curves of both samples under room light illumination on the same figure. Do you see an increase in photocurrent with reverse bias for sample 1? How about sample 2? Can you think about the reason? Hint: (electric field inside the active photon absorption region increases with reverse bias, and carrier drift under an electric field is faster than diffusion…)
3. Plot the I-V curve of sample 2 under solar simulator illumination. Find out the maximum power output and calculate the power conversion efficiency. Record the voltage V_m, current I_m and corresponding load R_m at the maximum power output. Find the fill factor (FF) of the solar cell using the following formula:

$$FF = I_m V_m / (I_{sc} V_{oc}),$$

Where I_{sc} and V_{oc} are short circuit current and open circuit voltage, respectively.

4. Use the measured photocurrent spectrum and the given optical input spectrum of the monochromator in "mono.xls" to derive and plot the responsivity spectrum. Responsivity at a wavelength λ is defined as

$$Responsivity(\lambda) = \frac{photocurrent(\lambda)}{Input\ optical\ power(\lambda)},$$

so the unit is (A/W). Also derive and plot the EQE spectrum spectrum:

$$EQE(\lambda) = \frac{Number\ of\ carrier\ pairs\ generated(\lambda)}{Number\ of\ incident\ photos((\lambda)} \times 100\%$$

5. Examine the EQE spectrum. What is the reason for the sharp roll-off at ~1050 nm (hint: think about the band gap of Si)? How about the roll off at ~400 nm? (hint: the absorption

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coefficient of Si is $\alpha\sim30000/cm$, and most of the light is absorbed within a distance of $1/\alpha$ beneath the surface…if it is too shallow, then surface defects will play a significant role…Also check if the reflectance at 400 nm increases significantly from your simulation results in Lab. 4…)

6. Using the responsivity spectrum and AM1.5 solar spectrum in am1.5_solar.xls to derive the short circuit current Isc (hint: calculate the photocurrent at each wavelength and integrate it over the whole spectrum). Is the result consistent with the I_{sc} you directly measured? What could be the reasons for the small difference?

3.003 Principles of Engineering Practice
Spring 2010