University of Waterloo

Electronic Devices
ECE 331

Solar Cell Lab Study

Experiment #2

Authors:
William Ngana
20533462

Michael Hamel
20519421

Waterloo, ON

Date Performed: January 31, 2018
Date Submitted: February 9, 2018

1 Prelab

i) Defining the following:

The Fill Factor — The ratio of maximum obtainable power to the product of the open-circuit voltage and short-circuit current. (FF = $\frac{V_{max} \cdot I_{max}}{V_{oc} \cdot I_{sc}}$) This is geometrically defined by the largest rectangle which will fit inside of the illuminated I-V curve and is a measure of efficiency where the higher the fill factor, the better the solar cell.

V_{oc} and I_{sc} — V_{oc} is the open circuit voltage which is also known as the no load voltage (I = 0), this is an equilibrium point where the forward current compensates for the reverse photo-current. and I_{sc} is the short circuited (V = 0) current, where the current is solely due to the collection of the optically generated carriers.

Solar cell efficiency — The solar cell efficiency refers to the portion of energy in the form of sunlight that can be converted via photovoltaics into electricity.

ii) I-V characteristics curve of a typical solar cell:

The I-V curve of a typical solar cell with no illumination is described by that of the usual diode graph, therefore it is an exponential graph with Voltage as the x-axis. When the light is applied to the cell, the exponential shape of the graph does not change but a negative baseline current is generated. Hence the graph crosses the y-axis at I_{sc} due to the generated photoelectric current, and intersects the x-axis at V_{oc}.

2 In-Lab Data Collection

2.1 Characteristic as function of light intensity

Variac (Volts)	**Light Intensity(Amps)**
120	446
110	363
100	285
90	220
80	159
70	109
60	68
50	37
40	16
30	6.4
20	1.7
10	1.0

Table 1: Variac versus Light Intensity

Variac (Volts)	V_{oc}		I_{sc}	
	V_{oc} **(V)**	**Thermistor** **(**$K\Omega$**)**	I_{sc} **(A)**	**Thermistor** **(**$K\Omega$**)**
120	2.42	5.12	0.00594	5.11
110	2.38	5.13	0.00449	5.12
100	2.34	5.11	0.00335	5.11
90	2.30	5.10	0.00229	5.10
80	2.24	5.10	0.00154	5.09
70	2.18	5.09	0.00093	5.08
60	2.11	5.10	0.00056	5.09
50	2.04	5.10	0.00036	5.08
40	1.98	5.10	0.00026	5.087
30	1.95	5.108	0.00021	5.090
20	1.942	5.120	0.00021	5.094
10	1.946	5.126	0.00021	5.098

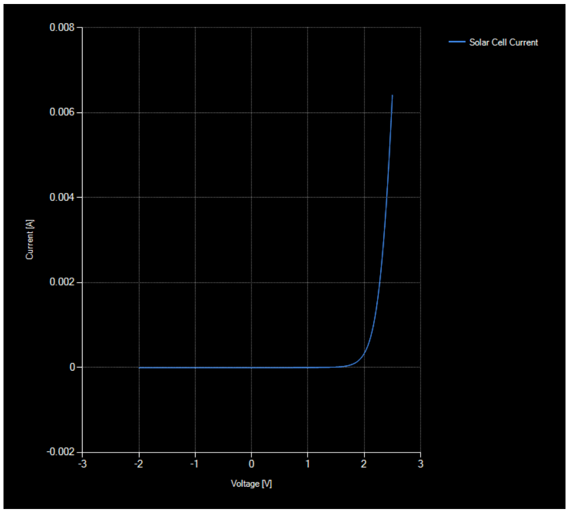
Table 2: Open Circuit Voltage and Short Circuit Current

2.2 Temperature Dependence of no-load voltage

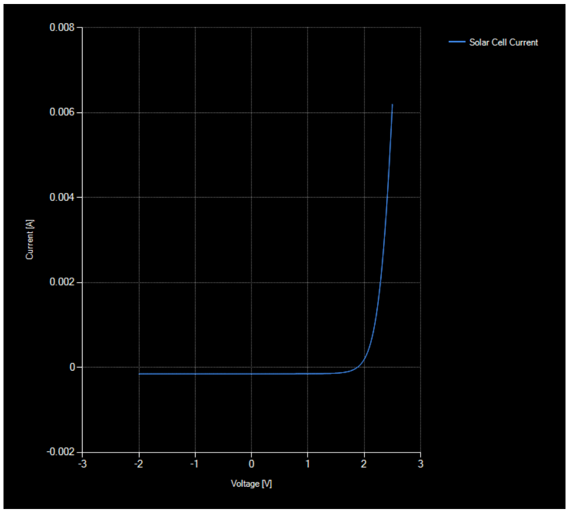
Thermistor around 5k ∼23°C (Room Temp)	**Fluke IR (°C)**	**V_{oc} at 60V Vairac**
5.149	room temp(24.0)	1.9206
4.28	30.0	1.886
4.99	35.0	1.918
3.51	40.0	1.872
3.13	45.0	1.839
2.45	50.0	1.841
1.81	55.0	1.780
1.76	61.2	1.752
1.72	65.0	1.710
1.38	69.6	1.688
1.18	75.1	1.631
0.96	80 °C (max)	1.571

Table 3: Temperature Effect on V_{oc}

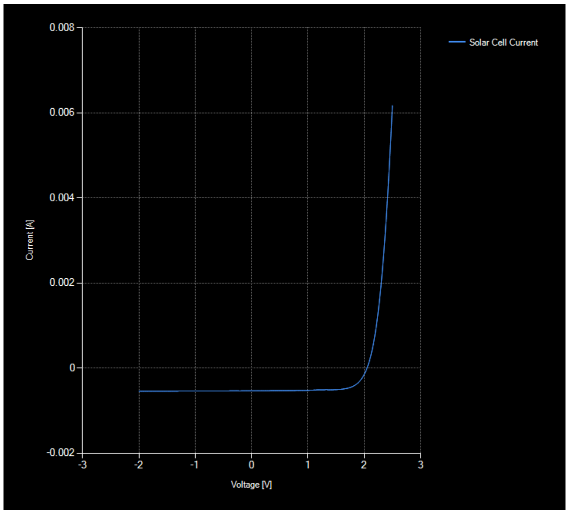
2.3 I-V characteristics of the solar cell



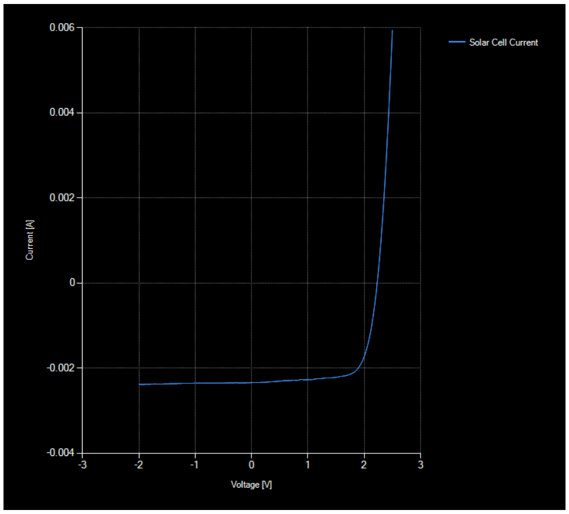
(a) Dark enclosure



(b) Light at variac = 30V



(c) Light at variac = 60V



(d) Light at variac = 90V

Figure 1: Solar cell I-V characteristics captured in various lighting conditions

2.4 Carrier life time, response time

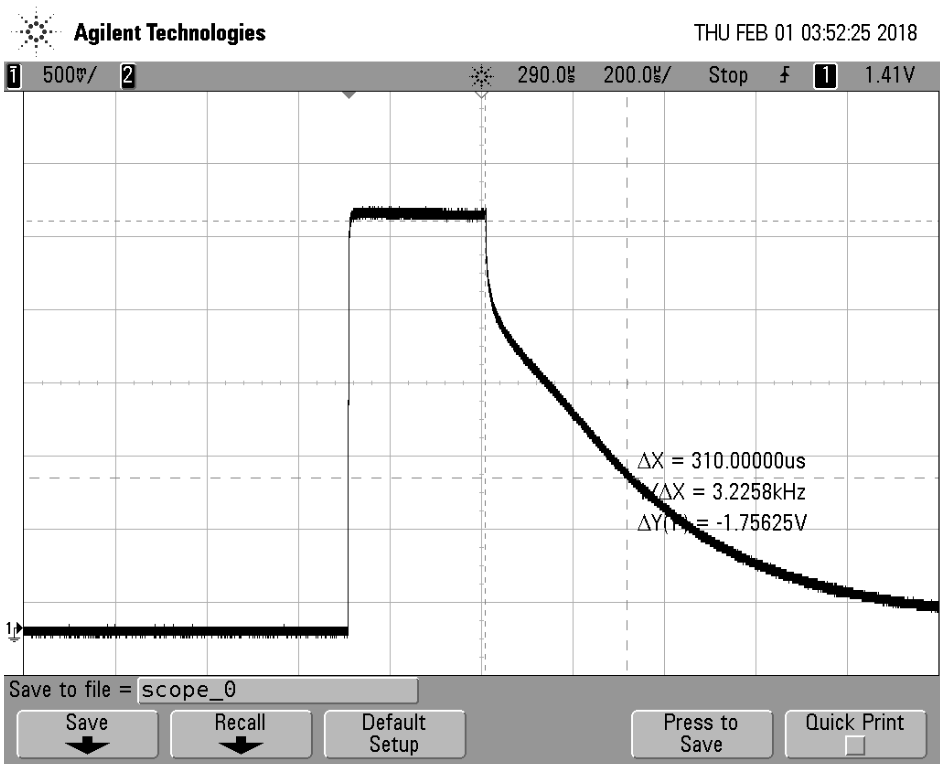


Figure 2: Carrier decay time, decay time indicators measured from 100% to 37%

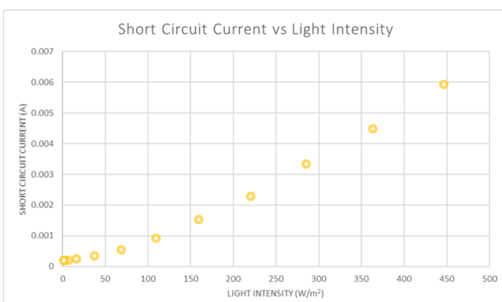
3 Post Lab Data Analysis

3.1 Characteristic as function of light intensity

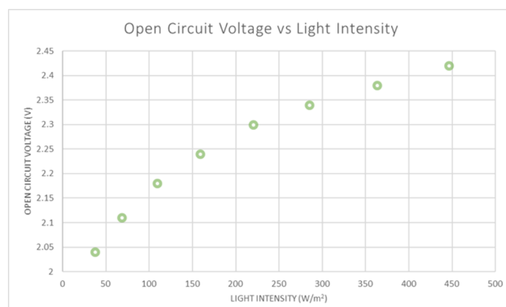
Based off of Table 1 we are able to convert the values of our inputted lamp voltage and change it into intensity. We use these intensity values in relation with the current and voltage in Figure 3.

In the voltage ramp seen in Figure 3b we are able to see that the voltage increases with more light, but the rate of voltage change is decreasing. This is due to a process known as thermalization, since some photons have more energy than the bandgap and this excess energy is put into the lattice rather than used for liberating atoms in the bandgap.

For the short circuited current, the intensity of the light is theorized to generate a linearly increasing amount of current as well. However a deviation from this idealization is seen in Figure 3a. The major issue that we will attribute this to is that the temperature of the panel increases as we go lower in intensity (due to previous runs) and this will decrease efficiency of the cell, leading to lower currents than are expected in our data. Generally we note that this non-ideal solar panel has a electron loss which does not scale with intensity, instead dominating at low intensities.



(a) Short circuited current



(b) No Load Voltage

Figure 3: Solar cell current and voltage characteristics as a function of intensity ramps

3.2 Temperature Dependence of no-load voltage

In Figure 4 and Table 3 we see the data for the temperature relation of open circuit voltage. we first note that our data for low temperatures is noisy. This is likely due to inequal heating of the cell or due to the IR laser of the heat gun causing some generation of electrons which is inequal between different trials.

However we can see that as the temperature increases, the amount of voltage which is generated decreases. This is because voltage is the potential difference between the electrons at rest and those in an excited state. At colder temperatures that difference is lager then hotter temperatures. This is because when you are heating up the electron you are giving them energy so the hotter it gets the less the difference between the rest and excited states becomes.

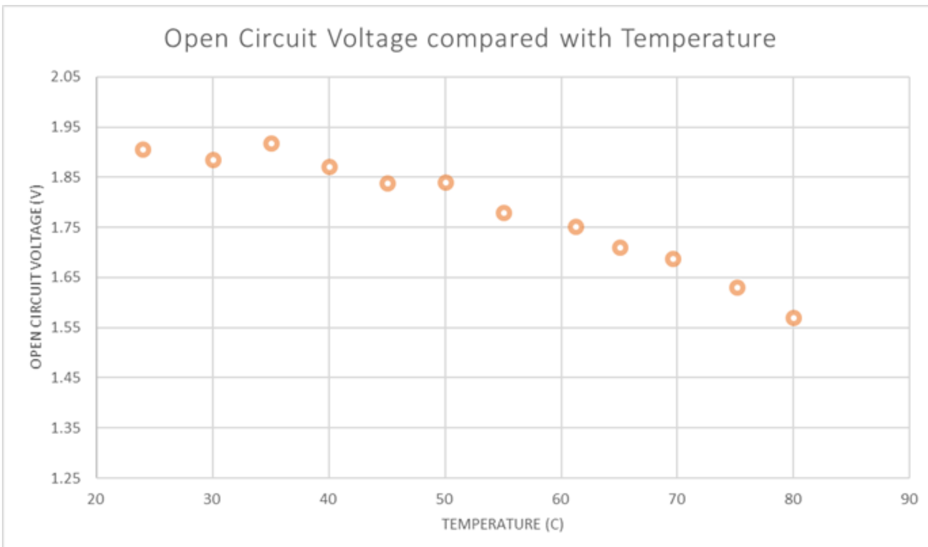


Figure 4: Voltage of the solar cell with an increasing temperature.

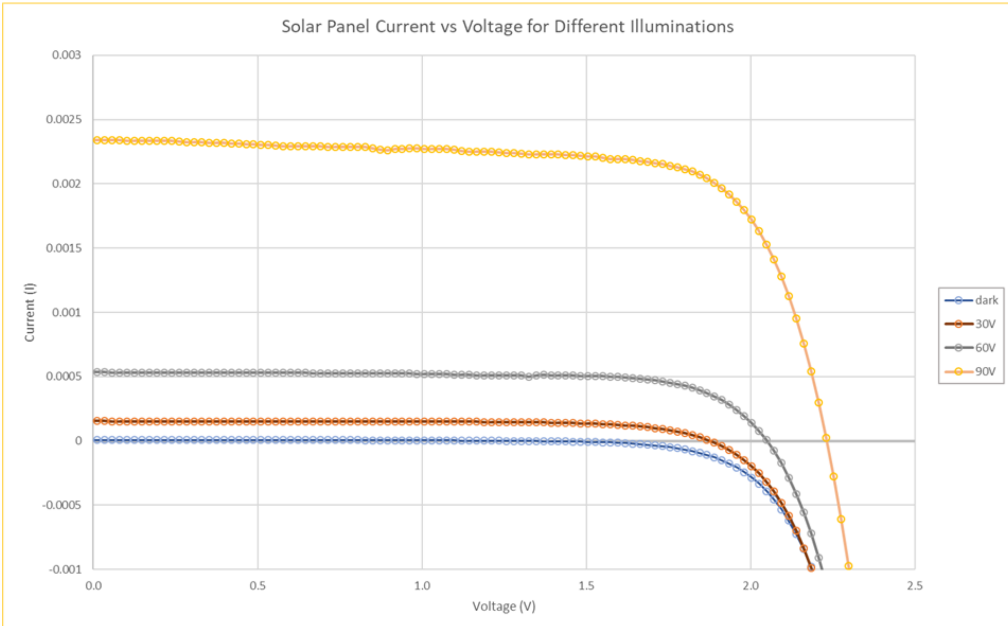
3.3 I-V characteristics of the solar cell

We see in Figure 5a that as more intense light is being inputted into the solar panel, the current dramatically increases. We see this in the dramatic changes between the dark to 30V and then successively for each of the increased intensities after that. The shape of the graph are as predicted from theory, however when compared to the ideally power generating solar cell we see that it is not very rectangular, indicating that the fill factor is not high. This is shown in our calculations shown in Table 5a.

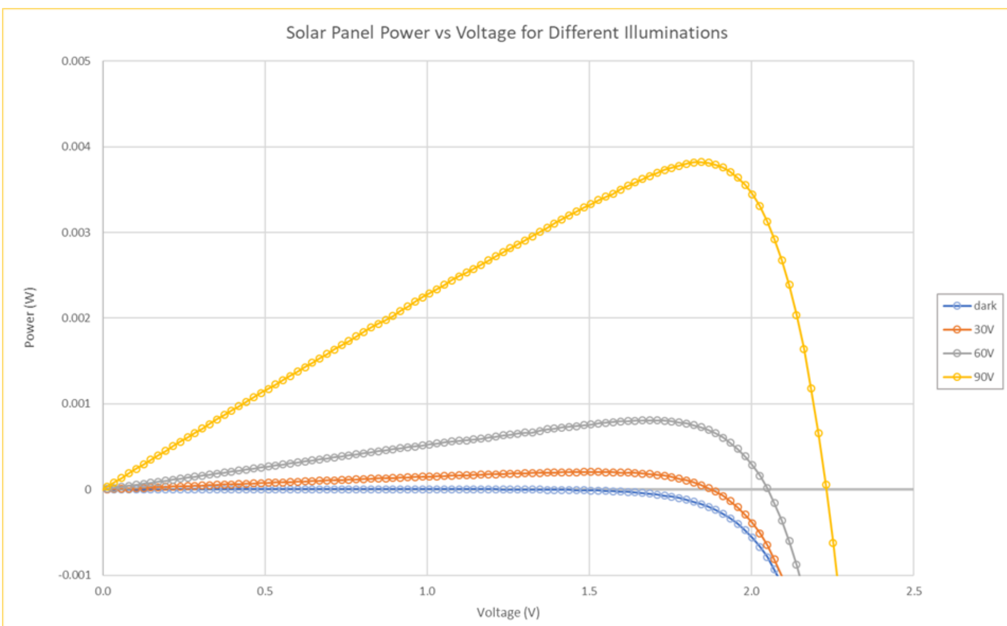
From Figure 5b we are able to see the power output of the cell as compared with the voltage. From this we are able to see that the maximal point is a sharp peak, meaning that if the cell is to be run optimally it will have to be run at a specific voltage. We also see the same relationship as seen in the Current vs Voltage graphs where the higher intensities scale with the higher currents/power.

	Dark	**30 V**	**60 V**	**90V**
V_{oc} **V**	1.256	1.867	2.048	2.229
I_{sc} **mA**	0.0062	0.154	0.534	2.34
R_{sh} **kΩ**	30.62	0.452	0.136	0.048
R_s **kΩ**	3853	288.5	57.8	24.48
Maximum Power (mW)	0.0047	0.204	0.806	3.82
Current at Max Power (mW)	0.0054	0.204	0.478	2.07
Voltage at Max Power	0.872	1.505	1.686	1.844
Fill Factor	0.60	0.71	0.74	0.73
Maximum Efficiency	N/A	1.69%	0.630%	0.923%

Table 4: Quantities which are calculated based off of the data shown in Figure 5.



(a) Current Voltage Curves



(b) Power Voltage Curves

Figure 5: Voltage relationships for each of the four light intensities. These are varied and the values shown in Table 4 show the calculation of several quantities based off of these graphs

3.4 Carrier life time, response time

As mentioned in the lab manual the minority carrier life time for both the N silicon wafer sample and the P silicon wafer sample was measured to be between 10 mircoseconds and 20 mircro seconds. The reason that the carrier lifetime for the solar cell could be that a solar cell is made up of both n-type and p-type semiconductors.It is the flow of electrons through these two semiconductors that creates electricity. That means that both semiconductors have different recombination. Since the carrier lifetime is defined as the average time it takes for a minority carrier to recombine having two semiconductors with different minority carries with different recombination rates and the fact that the electrons are flowing would all lead to the longer minority carrier lifetime in a solar cell