Organic Solar Cell Characterization

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Abstract

This summer I developed a solar cell characterization station to source voltage and measure current on organic solar cells (OSC) that were fabricated in the laboratory. The OSCs that were fabricated in the laboratory were made from P3HT (poly(3-hexylthiophene-2,5-diyl) and C_{60} in a bulk heterojunction solution dissolved in a dichlorobenzene (DCB). The P3HT:C_{60} solution was spin coated on to indium tin oxide (ITO) coated quartz and plastic substrates. To control the voltage source meter and the lamp modifications, corrections, and updates were made to an in house LabView program for data collection as well as interfacing with the statistical software OriginPro. Before the fabrication process could begin, the design of the testing station needed completion as well as a run of efficiency tests on a commercial solar cells to calibrate the whole characterization apparatus. After the OSC's were spin coated, optical images were taken as well as atomic force microscopy (AFM) on the samples to characterize the topology of the thin films.

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This summer at Appalachian State University I undertook the project of developing an organic solar cell (OSC) recipe as well as a standard operating procedure for fabrication. To test the solar efficiencies the OSC's, a solar characterization station was designed and manufactured. An extensive literature review of the current state of OSC, and the process of fabricating them, was done to get up to speed on the topic. A P3HT (poly(3-hexylthiophene-2,5-diyl) and C_{60} bulk heterojunction mixture was a favored recipe because of the relatively low cost of manufacturing. With some chemical tuning, P3HT:C_{60} solar cells have reached efficiencies of 2.56% as of 2011 [1]. In any solar cell there are two types of material needed to generate electricity from incoming light, the p-type and the n-type. The p-type material is one that has holes in it's electron configuration and are looking to accept other electrons to fill this void, known as the acceptor material. The n-type material is one with an excess of electrons and is looking to get rid of these unwanted electrons, known as the donor material. Utilizing a combination of these materials allows us to separate any excitons (an electron/hole pair) generated by incoming light. With the OSC's fabricated in the laboratory our p-type, acceptor material, is C_{60} and our n-type, donor material, is P3HT. The current state of OSCs involves studying derivatives of these base compounds, often P3HT:PCBM, in an attempt to gain a higher efficiency reaching up to 6.1% [2].

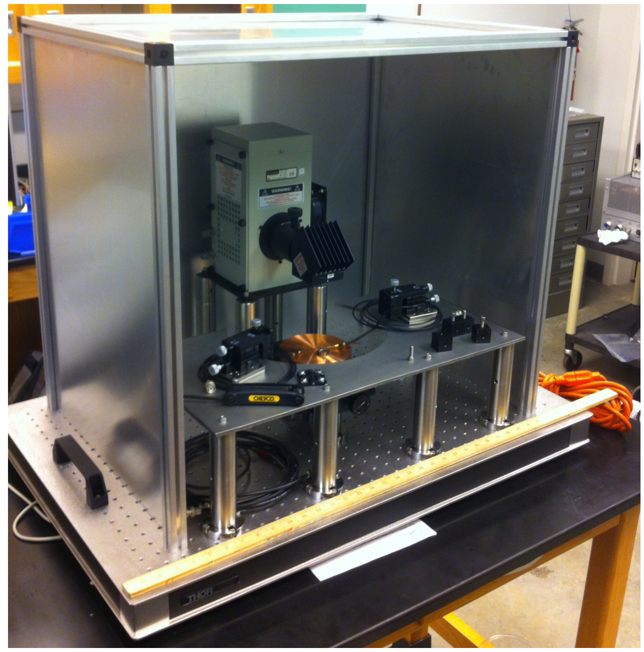

Figure 1: *The solar cell characterization station with it's aluminum covering. To simulate solar conditions a Newport 150 W Low Cost Solar Simulator was installed [3]. Tungsten probes were used to apply voltages and measure current to characterize various solar cells.*

Starting the summer by enhancing the exterior design of the solar cell characterization station, aluminum sheets were added covering the outside of the station to block any harmful ultraviolet emissions from the lamp as well as keep external light from throwing off the characterization results (see Figure 1). A door was also added making it easy to access the samples in between runs. Tungsten probes were used for fine placement of the voltage source during the characterization process.The probes used were connected to a Bayonet Neill-Concelman (BNC) cable, so a box was made to convert the BNC cables to a wire that could be connected to the Keithley source meter used to source and measure voltage, and current respectively. Adaptations were made to the in house LabView program to control the lamp power supply via serial communication and a Xenon 150W lamp was installed in the Newport 150 W Low Cost Solar Simulator lamp housing [3]. There was no mirror in the setup so a mirror was adapted from an overhead projector to fit into a beam turning assembly. There was also a filter holder apparatus installed for future tests to emulate the effect of the sunlights path threw the atmosphere at different times of the day. (see Figure 2)

To test the station, a piece of indium tin oxide (ITO) that was deposited on a plastic sheet was cut and the resistance was attempted to be measured. One of the benifits of OSC's is that they can be deposited on flexible surfaces which allows for roll to roll production, reducing manufacturing costs [4]. The process of taking measurements of a thin film was harder than expected because the placement of the probes was very important. If the probes were to puncture the ITO film then the apparatus would be measuring the resistance of the plastic and not solely the ITO. Multiple measurements of the current were made as the probes sourced a range of voltages, between 0V and 60V. Using Ohm's Law

$$V = IR$$

where V is the voltage between the probes, I is the current running through the material, and R is the resistance of the material, the ITO was characterized by resistance as a function of separation distance between the probes. As the separation distance increased there was also an increase in the resistance as expected because there was more material for the charge to travel through. The ITO that was tested was rated to have a sheet resistance of $100\frac{\Omega}{\square}$, and this was confirmed though the test of the characterization station. Both the $100\frac{\Omega}{\square}$ plastic ITO sheet and a $60\frac{\Omega}{\square}$ plastic ITO sheet were used for the OSC's as well as a 30-$60\frac{\Omega}{\square}$ sample of ITO deposited on glass.

With the mirror set up, the lamp installed, the probes tested, and the LabView program updated characterization could now begin on some commercially available ploysilicon solar cells. These solar cells had aluminum gates on the front and back, so for characterization, one probe was placed on an front aluminum contact and the other probe was placed on the copper chuck of the testing station. The initial surface area of the solar cell was large enough that the I-V curves of our scans were being cut off by the current limit of the machine. By reducing the surface area of the solar cell a more detailed characterization could be done. The initial solar cell was cut into three smaller cells of varying size.The

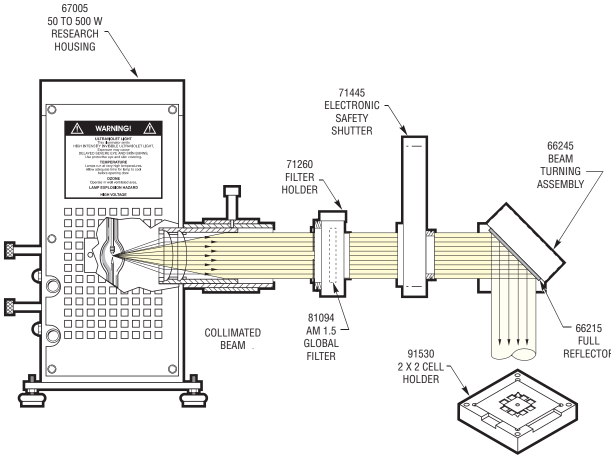

Figure 2: *This is a schematic of the Newport 150 W Low Cost Solar Simulator with the beam turning assembly as well as the filter holder. Each item is displayed with the corresponding Newport serial number. [3]*

smaller of the three cells had a higher efficiency than the larger ones which matched the theory used to compute the solar efficiencies.

$$\eta = \frac{P_m}{E \times A_c}$$

where η is the solar efficiency of the cell, P_m is the maximum power that the solar cell produces, E is the intensity of the incoming light, and A_c is the surface area of the solar cell. As the surface area of the solar cell is increased, there was a drop in efficiency do to the fact that the maximum power of the cell stays the same because it is a property of the photoactive material and not of the dimensions of the device. Once all of the data was collected the statistical programming language R [5]and statistical software OriginPro were used to calculate other material properties of the solar cell such as open circuit voltage (V_{oc}) and short circuit current (I_{sc}) (see Figure 4).

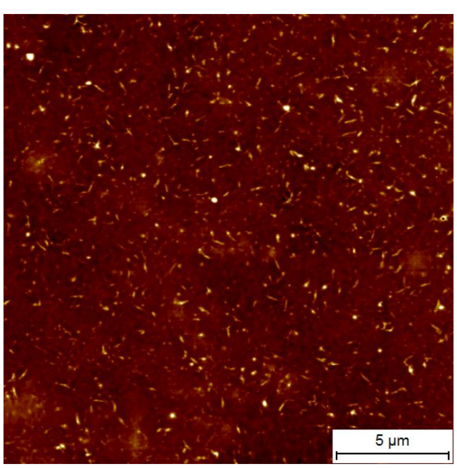

Figure 3: *AFM image of the P3HT:C_{60} solar cell. Small white features are C_{60} crystals. Longer wavelength features are natural variations in the film thickness*

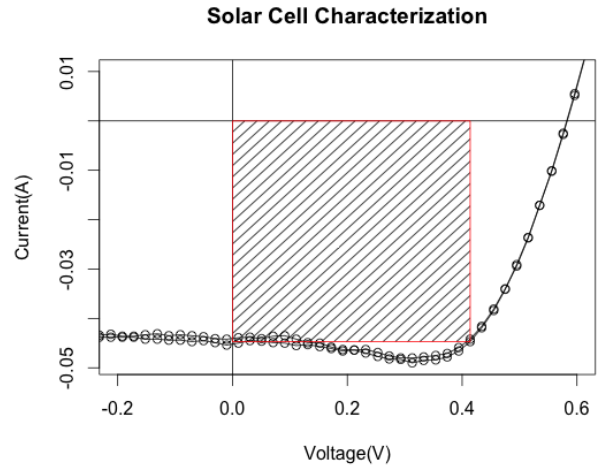

Figure 4: *I-V curve for a commercial solar cell. The shaded box represents the maximum power. The surface area of the cell was* $1.12\times10^-4m^2$ *and the intensity of the incoming light was* $1000\frac{W}{m^2}$. *I used the statistical programming language R to calculate the other material properties.* $\eta = 15.3\%$, $V_{oc} = 0.58V$, $I_{sc} = -0.044A$, $P_m = -0.018W$

A Laurell spin coater was installed and programmed with several spin routines. The spin coater holds a sample in place using a vacuum and spins it at a certain revolutions per minute (RMP) for a predefined amount of time. While the sample is spinning the solar active material is applied to the sample and because it is spinning a thin layer is formed. A 13.3 mg P3HT and 6.6mg C_{60} solution was made in 1ml of 1,2- dichlorobenzene [1]. This solution was used to spin coat multiple samples of various number of drops and spin routines to develop a method to get a uniform thin film. Using different spin routines allows for control of the thickness of the photoactive layer giving the OSC a darker shade (see Figure 5). A hot plate was also calibrated to more carefully analyze the annealing process which aids in the formation of crystals leading to higher efficiency [6]. The samples were then imaged using an atomic force microscope and on the nano scale the crystal structure could be studied. The thickness of our film was ∼40nm(see Figure 3).

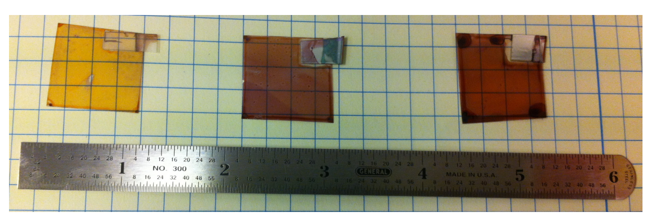

Figure 5: *Optical images of three flexible spun cast films on ITO/Plastic. From right to left there is an increase in the RPM's used to spin the samples*

Participating in research over the summer has been a very enlightening and educational experience. The skills I have learned about the scientific process as well as the dedication it takes to do research well have been a very important lesson. Developing a standard operating procedure that is reliable and reproducible is a very valuable skills in any laboratory. The programming skills required to adapt and modify LabView, and the statistical programing done with R will for sure be helpful for future lab instrumentation and automation projects. I know that the lessons I have learned this summer will carry on with me through the rest of my scientific career.

I plan to present my research at the Appalachian State University Annual Physics Research Day held in the Physics and Astronomy department. Faculty members as well as students who are interested in what opportunities there are in the Appalachian State Universities Physics and Astronomy department attend these talks. Students also get a chance to talk one on one with the undergraduate research students and this type of outreach helps to bring in new faces to the physics department. I have compiled my research efforts into a poster which I plan to present at the State of North Carolina Research and Creative Symposium (SNCRS), hoping to share my efforts with a wider audience as well as find out more about what projects other universities have undergraduate students working on.

References

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