ND Nano Undergraduate Research Fellowship (NURF)

2013 Project Summary

1) Student name: David O’Shaughnessy
2) Faculty mentor name: Jeffrey Christians, Prof. Prashant Kamat
3) Project title: Quantum Dot Solar Cells

4) Briefly describe any new skills you acquired during your summer research:
Over the past 10 weeks I have acquired a number of new skills from technical research related skills to interpersonal skills such as presentation experience. The biggest skill that I have acquired during my summer research is a basic understanding of the fundamental photochemistry and electrochemistry behind a solar cell. As an energy engineer I required more experience and knowledge of the chemistry aspects of solar cells but became familiar with the various processes and techniques over time. I also learned a number of new skills in the physical fabrication and testing of the solar cells such as:

- Spin coating
- Doctor blade method
- Spray pyrolysis
- Synthesis of methyl ammonium iodide using a rotary evaporator and vacuum filtration
- Testing of solar cell efficiency using simulated solar irradiation from a xenon lamp with Air Mass 1.5G filter and potentiostat
- Observed techniques such as SEM, TEM, deposition of Copper Iodide using syringe pump and metal evaporation of gold

5) Please briefly share a practical application/end use of your research:
Solar cells can be used to satisfy the world’s rising energy needs. Global energy demand (∼ 14 TW in 2008) is expected to double by 2050 and triple by 2100. To prevent anthropogenic climate interference, renewable and carbon neutral energy must become increasingly important in fulfilling this growing energy demand. It is clear from figure 1 that incident solar energy has a significantly greater potential than all the other renewable energies combined.

<table>
<thead>
<tr>
<th>Source</th>
<th>Power (TW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroelectric</td>
<td>0.5 TW</td>
</tr>
<tr>
<td>Tides and Oceans</td>
<td>2 TW</td>
</tr>
<tr>
<td>Geothermal</td>
<td>12 TW</td>
</tr>
<tr>
<td>Wind Power</td>
<td>2-4 TW</td>
</tr>
<tr>
<td>Incident Solar Energy</td>
<td>120,000 TW</td>
</tr>
</tbody>
</table>

*Table 1: Potential Sources of Renewable Energy*
The main goal in the research of solar cells is to develop more efficient solar cells at a cheaper price than the ones already commercially available. The Shockley-Queisser limit places maximum solar conversion efficiency around 33.7% assuming a single p-n junction with a band gap of 1.34 eV (using an AM 1.5 solar spectrum). Solar panels are currently selling for as low as US$0.70c a watt (7-April-2012) in industrial quantities. Large wind turbines cost about $2 a watt. Natural gas-fired peaking power plants are around $6 a watt.

**Project summary:**

How a solar cell works:

- Light from a xenon lamp (closest spectrum to natural light) is passed tough 1.5AM filter onto cell
- The light (E=hv) is absorbed by the sensitizer (perovskite) which leads to the excitation of electrons from the valence band to conduction band. As a result an electron hole pair is formed. The electron being in the conduction band and the hole formed in the valence band.

![Energy Diagram](image)

- The excited electrons are then transferred to the TiO₂ conduction band which is lower in energy. These electrons are further transferred onto the FTO conduction band and finally into an electrical circuit.

The goal I was set at the beginning was to develop a solid state solar cell using Carbon 60 as the electron acceptor. The sensitizer/absorber (perovskite) and hole-conductor (spiro-OMeTAD) had already been used in conjunction with titanium dioxide (TiO₂) as the electron acceptor. The published record efficiencies of these cells had grown from 12% to 15% in my time at Notre Dame. In the standard TiO₂ based perovskite solar cells, a blocking layer of TiO₂ is deposited on the fluorine doped tin oxide (FTO) substrate by spray pyrolysis. Then a nanoparticle TiO₂ active layer is deposited by spin coating. On this nanoparticle TiO₂ layer, the absorber (perovskite) and the hole conductor are subsequently deposited by spin coating. Finally a layer of gold was deposited by metal evaporation.
My challenge was to replace the nanoparticle TiO$_2$ active layer with C$_{60}$ clusters as fullerenes are widely used to capture and transport electrons in organic solar cells. This also necessitated that I replace the TiO$_2$ blocking layer with a SnO$_2$ blocking layer. The reason tin oxide was used instead of titanium oxide is illustrated in the diagram below. The conduction band in the TiO$_2$ is actually higher than the conduction band of C$_{60}$. Therefore SnO$_2$ was used as the compact layer because of its lower conduction band compared to C$_{60}$ to allow electron transfer.

The key duties undertaken in the first period of research was to become familiar with the techniques used to make the perovskite solar cells using TiO$_2$ and also the development of knowledge on key aspects of photoelectrochemistry and electrochemistry. The fabrication of solar cells using solar paint was also explored during the first week of research to become familiar with the laboratory and a variety of solar cell fabrication procedures. In weeks two to four I made TiO$_2$/perovskite solar cells. This gave me the ability to deposition perovskite and the hole conductor on my C$_{60}$/perovskite solar cells.

The second period of research focused on developing methods to deposit a SnO$_2$ compact layer and an active layer of C$_{60}$. This was done to effectively replace the TiO$_2$ active layer with C$_{60}$ clusters and as a result the TiO$_2$ layer with SnO$_2$. In an effort to create an even layer of SnO$_2$ approximately 100nm in thickness we attempted methods of deposition such as spin coating, spray pyrolysis and drop cast.
**Deposition of SnO2 compact layer and C$_{60}$ layer:**

- Figure 3 shows the SEM image shows first attempt of making C$_{60}$ cells by spin coating SnO$_2$ layer at 2000 rpm for 30 seconds (4ml SnO$_2$ and 350 mg of polyethylene glycol (PEG)) and electrophoretic deposition (EPD) of C$_{60}$ for 30-60 seconds (tried different ratios of C$_{60}$ dissolved in toluene to acetonitrile (MeCN)). This process was tried first as our lab had previously developed a method of deposition C$_{60}$ clusters using EPD.

![SEM image of first attempt of C$_{60}$ cell]

- It can be seen from the image that the SnO$_2$ layer is larger than the desired 100nm layer. We wanted it small just to act as a blocking layer. The layer of C$_{60}$ from EPD gave an uneven layer also.
- As a result various methods of applying C$_{60}$ solution to FTO such as drop cast, spin coating and spray method were explored
- Spray pyrolysis gave even looking layer. The drop cast and spin coating methods failed to deposit C$_{60}$ on FTO substrate.
Tried spraying on tin oxide (2 grams of SnCl\(_2\).2H\(_2\)O, 0.7 ml of conc. HCL, 0.3 ml of Methanol and 7ml of H\(_2\)O) and EPD of C60 as shown in graph below.

As a result of figure 4 the 1:4 ratio of C\(_{60}\) in toluene to acetonitrile was only used
Also tried spin coating tin oxide (8ml SnO\(_2\) and 350 mg of PEG) and spray pyrolysis of C60 but didn’t work.
In all of the attempts mentioned above there was roughly no voltage (~0.005V)

New tin oxide layer made from SnO\(_2\) paste (1 gram of SnO\(_2\) paste and 1 gram of ethanol). Spin coated onto FTO
10 and 20 coats of C\(_{60}\) sprayed on new SnO\(_2\) layer.
Different thickness of Spiro and Copper iodide then applied as the hole conductor
Solar cells with 10 coats of C\(_{60}\) and 1 cycle of Spiro spin coat had an open circuit voltage and short circuit current of ~0.15V and ~0.4mA/cm\(^2\) respectively.
Measuring Solar Cell Performance:

Once the fabrication of the various cells was complete, the voltage and current of the solar cells were measured in order to calculate the efficiency. Figure 5 shows the solar simulator set-up. The light on the left is a 300W xeon lamp with an AM1.5 filter in front of it. The box in the foreground is a power meter that tells the power per square centimeter (usually 100mW/cm²). On the right is the solar cell attached to a stand and connected to a potentiostat with alligator clips.

Three tests were conducted on each cell. A voltage-time graph (V-t), current-time graph (I-t) and a current –voltage graph (IV) were all recorded. The next step was to measure the masked area on each cell. This could be done in a number of manners but the most accurate method is to take a photo of the masked cells beside a ruler. Then using an image analysis software (imageJ), the areas could be calculated. The current values were then multiplied by 1000 and divided by the area to obtain the current density of the solar cell in milliampere/cm². The power is the calculated by multiplying the current density by the voltage. Figure 6 shows the location of P_max along the I-V curve below.

\[
FF = \frac{P_{\text{max}}}{P_T} = \frac{I_{\text{MP}} \cdot V_{\text{MP}}}{I_{\text{SC}} \cdot V_{\text{OC}}}
\]

Figure 6: Equipment used to Measured Voltage and Current in Solar Cell

Figure 7: Calculating Fill Factor
The fill factor is calculated as shown above in figure 6. The maximum power is divided by the open circuit voltage and the short circuit voltage. Typical commercial solar cells have a fill factor greater than 0.70. The efficiency is calculated by dividing a cell's power output (in watts) at its maximum power point \( P_m \) by the input light \( E \) (in W/cm\(^2\)) and the surface area of the solar cell \( A_c \) (in cm\(^2\)).

\[
\eta = \frac{P_m}{E \times A_c}
\]

**Conclusion**

Overall the research was partially successfully for a 10 week period. In the first set of C\(_{60}\)/perovskite cells made the current density was \(~1.2\text{mA/cm}^2\) with a voltage below 0.01V. The second set of C\(_{60}\)/perovskite cells had a higher voltage of 0.15V but a lower current density of 0.06mA/cm\(^2\). If I had more time I would take SEM images of solar cells after each layer is deposited to gain a better understanding of the interaction of layers and to optimize the cell efficiency.