Pat McAdam Scholarship
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Report

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Contents

Motivation – CdTe Thin Film Solar Cells

While silicon remains the go-to material when people begin to discuss photovoltaic solar cells, it's not without its draw backs. High quality monocrystalline silicon is expensive to produce and requires large amounts of material to remain stable. Although cheaper polycrystalline silicon is available, much of the cells performance deteriorates within a very short time. Thin film cadmium-tellurite (CdTe) can be used as a lighter, cheaper alternative to traditional Silicon devices. Some of the major benefits of CdTe as a material is that despite being made of heavy metals it doesn't combust or dissolve in water, making it environmentally safe. CdTe is an excellent match for our sun's emission spectrum. CdTe has been known as a potential photoelectric material since 1959 and cells incorporating the CdS layer were first developed in the mid-1960s, although efficiencies of less than 5% were achieved. Now, with modern fabrication methods, efficiencies close to 20% are common. The Colorado School of Mines recently developed the Rapid Thermal Process activation of a ZnTe:Cu back contact material for cells which yielded a marked increase in efficiency, of around 5%, in both the cells created at the School of Mine and those at the nearby NREL (National Renewable Energy Laboratories).

During Summer 2015, while enrolled in the REMRSEC REU, under the auspices of the Pat McAdam Scholarship in Chemical & Bioprocess Engineering, I was assigned to Prof. Colin Wolden's Research Group at the Colorado School of Mines. I worked directly with Abdulaziz Alaswad, a PhD Student, assisting with his research into the properties of this new back contact material. Cells of this nature are typically stressed under Accelerated Lifetime Testing (ALT) conditions of 85°C, for long periods of time, normally days and weeks. I was tasked with measuring how the cells performed over a 24 hour period and how the characteristic curves for the devices changed during the testing. Figure 1 shows the front and back of a typical cell tested. Figure 2 schematically illustrates the multi-layered cell structure.

Figure 1. *One of the cells used for testing, Left: Back contact, Right: Front*

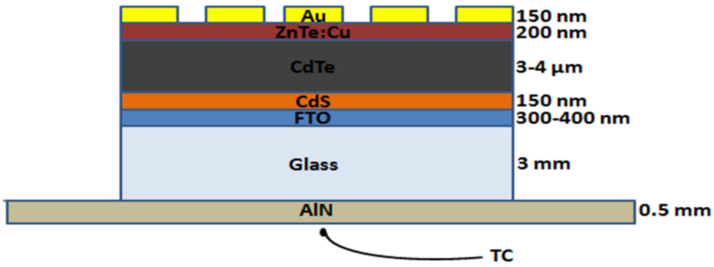

Figure 2. *Cross section of Solar Cell*

How It Works

The testing itself was quite straightforward, each sample was heat treated at 85°C under three conditions: darkness, illumination on the front of the cell, and illumination on the back contact of the cell. With an illuminated cell, a forward bias was introduced which allowed a comparison with the dark cells to see if a potential across the cell caused significant degradation. The illumination of the back contact was performed as a result of an interesting phenomenon discovered by Abdulaziz: a greater efficiency detected in cells stressed in this manner.

The first challenge I had to overcome was how to calibrate the illumination tests. The equipment used was a dark oven and a 0.7 Sun Halogen lamp. There was a stage below the lamp which could have its height adjusted to control the temperature, however this also affected the intensity of the light reaching the sample. To solve this, I constructed a variable speed fan using a Variac (variable transformer) to help control the temperature. Combining this with a thermocouple mounted on a spare sample unfit for testing I was able to get accurate measurements of the cell's temperature.

The cells were initially tested unstressed to get a base-line reading and were then stressed for periods of 1, 3, 5, 8, 16, 20 and 24 hours, after which stressing was carried out over periods of 24 hours. After each stress test the sample was allowed to cool to ambient temperature and the characteristic data were collected using a one sun Solar Simulator, by exposing the cell to the lamp for a brief period of time (> 0.5 s). A potential was placed across the cell and was swept from -0.5V to 1.0V, which allowed the machine to measure the Fill Factor (FF), Efficiency, Voltage Open Circuit (VOC) and the Current Short Circuit (JSC). By plotting and comparing the data an increase or decrease in efficiency could be attributed to a change in one or more of the cell's characteristics (FF, VOC, and JSC). With three or more cells undergoing testing at any one time, I was kept very busy testing and analysing the data.

In addition to the FF, VOC, and JSC, the Electron Quantum Efficiency (EQE) of the cell was measured at the end of the testing. Very few universities have access to an EQE machine and it was quite exciting to get to use such a rare piece of equipment. EQE is a measure of how many of the photons that strike the cell are converted to electrons. Figure 3 shows the machine I used for EQE measurements, which employed a xenon lamp (with an emission spectrum very close to that of the sun), a monochromator, collimator, focusing lenses and a stage. The device had to be calibrated each time it was switched on, due to the sensitivity of the equipment.

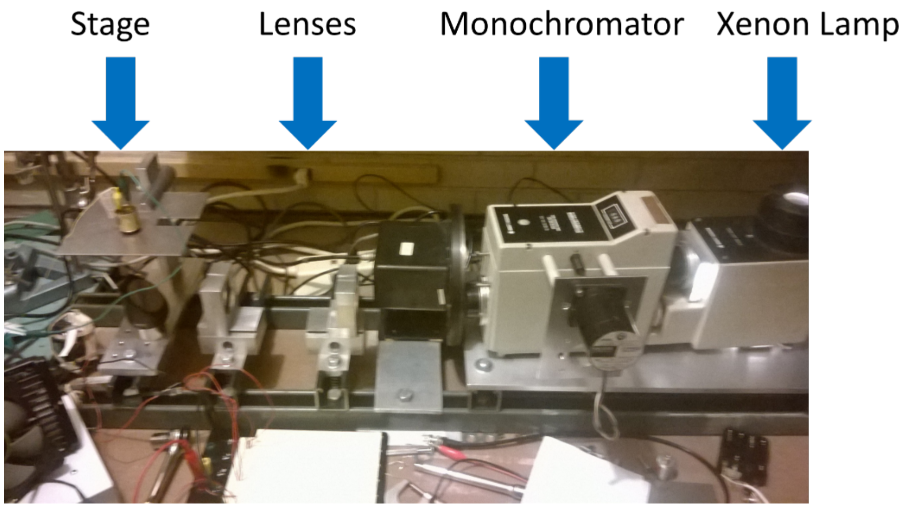

Figure 3. *The EQE machine*

Each week Prof. Wolden, held a meeting with Abdulaziz, Jiao Jiao Li (a post-doctoral student examining new manufacturing processes), Jason Trevithick (a masters student examining a new CdCl deposition method) and myself to discuss our work. It was at these meeting I was able to see what other work was being done in the group and hear about the work of other groups outside the university. In addition to these meetings, I had one-to-one meetings with Abdulaziz to discuss the work we were doing and to review my results and findings

Unfortunately over the 4^{th} of July weekend, the building where the Solar Simulator was located was subject to a severe act of vandalism; as a result, the police and University authorities kept all personnel out of the building while they investigated the crime scene and remedied the damage. This halted my work with Abdulaziz for about 10 days. However, during this time I got the opportunity to work with Jason and his undergraduate student on a new CdCl deposition method on which they were working. The undergraduate student had previous training with the scanning electron microscope (SEM) and the X-Ray Diffraction machine and she trained me in their use. I was tasked with undertaking CV (Capacitance-Voltage) and EQE analyses of this group's cells. During my time working with Jason, I produced the most reliable data from the EQE machine to-date.

The CV analysis was tricky, to say the least: the computer itself ran on Windows '95 and there was only a floppy disk drive for data export. The voltage generator was prone to give false readings if the contacts were slightly misaligned. This was my first real experience of dealing with what could be described as 'real lab' equipment i.e. the original person who had developed the testing criteria and associated settings had long left the lab and the equipment had sat idle for several years.

Once the Solar Simulator was again available for use I completed my testing and began to put my final presentation together.

Results

My results (Figures 4 & 5) were quite interesting! They showed that the decrease in efficiency was due to a decrease in Fill Factor, while the JSC and VOC remained largely unchanged. I was able to identify that there was Current-Voltage rollover present in the dark testing, but not in the illuminated testing. This was attributed to electro-migration in the cells due to the forward bias imposed on them during the stress testing. The quantum efficiency remained largely unchanged which indicated that the spectrum of light the cell could convert to electricity remained unchanged over its life time. The simulated lifetime testing for the cells was 16 years for the cell in the dark and 8 years for the illuminated cells. Our cells met the performance criteria for solar cells of achieving a decrease in efficiency of <0.2% per annum.

Most interesting was the increase in efficiency of the cell up to 10 hours of stressing. This would imply a 'self-healing' characteristic of the cell. This is most apparent in the J-V curves where they 'fix' themselves after the initial stressing.

Research into new back contact materials such as ZeTE:Cu could have significant implications for the adoption of Thin Film Solar Cells. If these new materials can sufficiently increase efficiency or the life time of a cell, then CdTe or other thin film cells could potentially replace traditional silicon. Advancements at facilities such as the Colorado School of Mines, NREL and First Solar are paving the way for this to become a reality.

Illumination

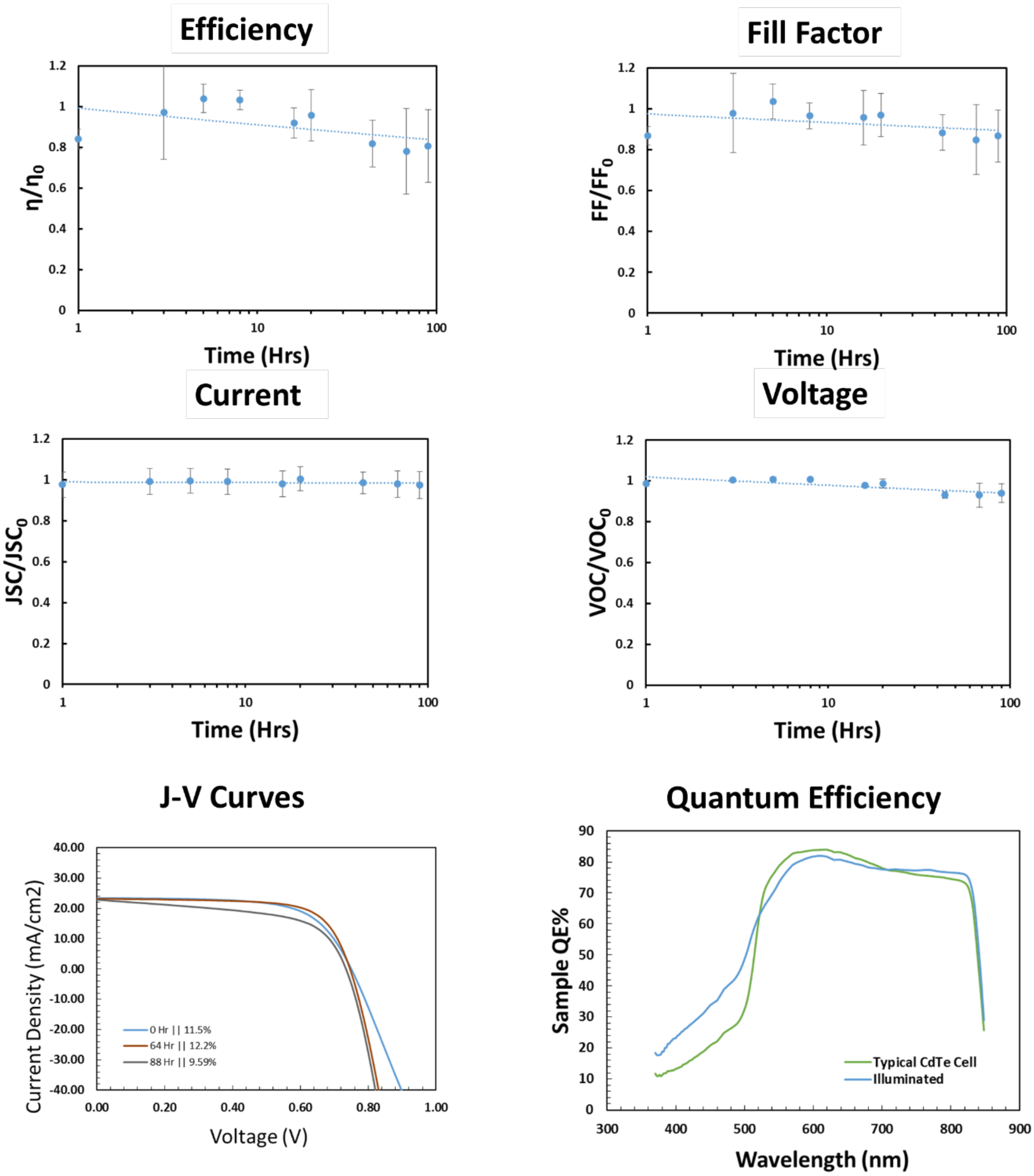

Figure 4. *Summary of Cell Characteristics under Illuminated Conditions*

Dark

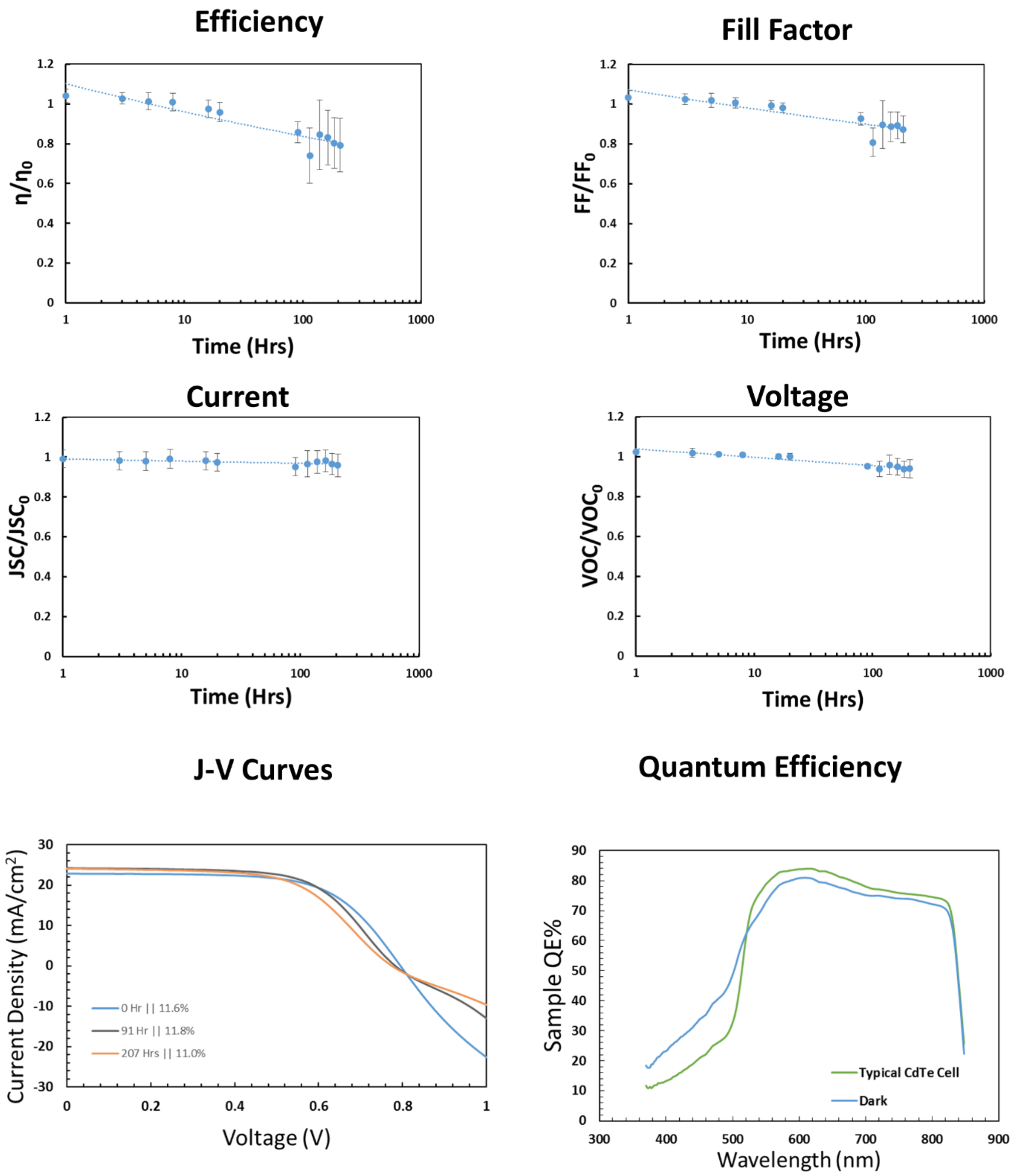

Figure 5. *Summary of Cell Characteristics under Dark Conditions*

Outside of the Lab

Almost every weekend I was able to go somewhere new and I spent most of my weekends hiking. I was able to visit the Flat Irons and Rocky Mountain National Park. I hiked to Sky Pool where we had to trek across mid-June snow and boulder up beside a waterfall to reach our goal. I climbed the 14,000 ft Greys Peak and Torreys Peak and camped in the Rio Grande National Park. It was en route to the Rio Grande National Park that I saw one of the most amazing sights: after a rise in the road a vast plain flanked by the Rockies on either side just appeared. We also found time to pay a visit to the Coors Light brewery in Golden, Colorado, which is the largest single brewery facility in the world.

The School of Mines organised a visit to the National Renewable Energy Laboratories facility (NREL) nearby where we were given a guided tour. It was really quite fascinating to see where some of the leading research into renewable energy is being conducted.

The school also arranged for the REU students to tour the University College Boulder campus, the engineering facilities there and the Fiske Planetarium (one of the best planetariums in the US).

Each week the REU students were treated to two guest speakers who spoke on a wide array of topics ranging from the differences between doing research in a university and in an industrial lab to the ethics behind engineering and the core tenets that dictate a person’s fundamental beliefs.

During my time in Colorado, I was also able to reconnect with my second cousin, Chester Van Tyne, FIERF Professor in the Department of Metallurgy at the University of Mines, whose grandfather immigrated to the US from Ireland in the 1920s and who hadn’t been in contact with my family for more than 25 years, since his last visit to Ireland!

Conclusion

In conclusion, the experience was more than I could have ever predicted: meeting other students dedicated to renewable energy research and making new friends; undertaking out research in a lab environment where I was trusted to work autonomously (which I prefer); exploring a part of the world that I would never have considered visiting before going to Colorado; being exposed to the Material Science side of Chemical Engineering, where previously I had only considered the Pharmaceutical and Petrochemical aspects.

I am truly grateful for this incredible scholarship and experience. I wish to sincerely thank Martin McAdam and his family, the staff in the UCD School of Chemical & Bioprocessing Engineering and the staff at the Colorado School of Mines, particularly Prof. Colin Wolden and Prof. Chuck Stone, for providing this wonderful opportunity. I am not sure I will ever experience something as unique or as rewarding as the 10 weeks spent in Golden Colorado, generously supported by the Pat McAdam Scholarship in Chemical & Bioprocess Engineering 2015.

Colm Ó Tuama