Efficiency Enhancement of Dye-Sensitized Nanocrystalline Solar Cells Through Fabrication

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ABSTRACT

This paper reports results obtained from the investigation of electrical performance of blueberry-based DSSCs and makes recommendations regarding their fabrication, specifically optimal sintering temperature and optimal sintering time. Electrical characteristics (open circuit voltage, short circuit current, power max and fill factor) of 10mm X 10mm DSSCs under indoor illumination were measured and cell efficiency calculated from ratio of maximum power output to incident luminous power. It was found that DSSCs fabricated at higher sintering temperatures (~500 degrees Celsius) consistently exhibited efficiencies 2-3 times greater than those sintered at lower temperature (<300 degrees). Furthermore sintering times in the 10-12minute range produced the most solar efficient cells. TiO2 nanocrystals in the DSSCs were viewed using an Atomic Force Scanning Electron Microscope at Penn State's Nanotechnology Characterization Facility.

Keywords – solar cells, renewable energy, sintering, nanotechnology, organic dye sensitization

1. INTRODUCTION

Solar cells are solid state electrical devices that convert light energy directly into electricity through the photovoltaic effect. Modern solar cells are based on semiconductor physics – essentially the principle of pn junction photodiodes having large light-sensitive areas. Since silicon is the second most abundant element in earth's crust and has the advantage of being available in large quantities, over 95% of all solar cells produced worldwide are silicon-based. An alternative type of solar cell made from simple, common and relatively cheap materials is the DSSC - Dye sensitized solar cell invented by Michael Grätzel and Brian O'Regan in 1991. The first cells were only capable of using light at the Ultraviolet and Blue end of the spectrum but by the turn of the century, advances in technology were able to broaden the frequencies in which these cells were able to respond. The most efficient of the dyes were known as "black dyes" due to their very dark colors. Today's Gratzel cell [1-9] is composed of a porous layer of titanium dioxide nanoparticles, covered with organic/molecular dye that absorbs sunlight, similar to chlorophyll in green leaves.

Remarkably high quantum efficiency have been reported for this type of solar cell with overall conversion efficiencies up to 11%. This fact, in combination with the expected relatively easy and low cost manufacturing makes this newer technology an interesting alternative to existing silicon-based solar cell technologies. Recent work shows some important advances. Flexible Dye sensitized Nanocrystalline TiO2 Solar cells were investigated in [1] to determine performance and stability differences between glass-based and polymer foil-based DSSCs. In [2] Hinori et al studied a method for light harvest efficiency improvement in TiO_2 pastes containing varying particle sizes. Scattering of light by these particles in DSSC cells optimized for size and shape produced efficiencies of about 8.4%. In [3], experimental results were reported with DSSCs fabricated using a wide variety of organic dyes based on porphyrin - basic building block of hemoproteins (include plant chlorophyll, animal haemoglobin) . Efficiencies on the order of 5.6% using these low-cost dyes were reported. The objective of the work reported here is to investigate optimal fabrication conditions for manufacture of DSSCs , specifically sintering temperature and sintering time. Electrical performance and efficiencies of blueberry-based DSSCs was monitored for cells fabricated under a variety of temperatures and sintering times. It was found that DSSCs fabricated at higher sintering temperatures (>500 degrees Celsius) consistently exhibited efficiencies 2-3 times greater than those sintered at lower temperature (<300 degrees). Furthermore sintering times in the 10-12minute range produced the most solar efficient cells.

2. PROCEDURE

The standard procedure [4,5] for fabrication of DSSCs on conductive tin dioxide-coated glass slides was adopted. Emphasis was placed on careful and thorough grinding of the TiO2 powder using a mortar and pestle. The finer the TiO2 powder, the smoother the paste consistency – poor paste consistency was found to result in cracks in the TiO2 after heating. Special attention was paid to the following fabrication issues.

(i) Overheating of glass slides while sintering on hotplate: causes dryness of paste and inability to absorb blueberry dye
(ii) Smoothness of extracted dye: Blackberries must be converted to fine juice with no coarse material
(iii) Hot Plate Preparation: thorough and

uniform pre-heating of hot plate prior to sintering

(iv) Excess electrolyte: oozing of excess electrolyte out of offset slides - dye stained electrode and graphite coated electrode – is to be avoided

Solar cells are electrically characterized (fig 1) by a maximum voltage at zero output current and maximum current at zero output voltage (fig 2). Power can be computed and other performance parameters for the cell can be determined. Electrical characterization involved measurement of 5 important parameters:

1. Open Circuit Voltage (Voc) - open circuit voltage occurs when there is no current passing through cell (cell resistance R--> ∞)

2. Short Circuit Current (Isc) - short circuit current corresponds to the short circuit condition when the resistance is low and is calculated when the voltage equals 0. (cell resistance R--> 0)

3. Max Power (Pmax) - Power produced by cell in watts calculated along the I-V sweep (see fig 2) by equation P=IV. At **Isc** and **Voc** points, power is zero. Maximum value for power occurs between the two. The voltage and current at this maximum power point are denoted as **VMP** and **IMP** respectively

4. Fill Factor (FF): Fill Factor (FF) is essentially a measure of quality of solar cell. It is calculated by comparing maximum power Pmax = IMP*VMP to available theoretical power PT = Voc*Isc that would be output at both open circuit voltage and short circuit current together. FF = Pmax/ PT. Optimal range for FF is 0.3 - 0.7.

5. **Efficiency** - Solar cell efficiency is the ratio of the electrical power output Pout to solar power input Pin to the cell. When Pout is assumed to equal Pmax, efficiency is considered maximized, equal to $\eta_{MAX.}$ (since solar cell can be operated up to its maximum power output). Therefore a maximum efficiency η_{MAX} = Pmax/ Pin can be calculated. Note that Pin is the solar input power observed directly using a luxmeter.

In this study, DSSC cells - fabricated on 10mmX10mm glass slides - were intended for indoor use, hence all tests were performed under indoor fluorescent lighting conditions (80-90 lux).

3. RESULTS & DISCUSSION

3.1 Effect of Sintering Temperature

The first set of investigations examined the effect of sintering temperature on cell performance. What is sintering? Sintering is a method of atomic diffusion used to create objects from powders. It occurs much faster at higher temperatures - atoms in the powder particles diffuse across the boundaries of the particles, fusing the particles together and creating one solid piece without first melting material. Melting point of TiO2 is above 1500 degrees, hence sintering at temperatures around 500 degrees works well. Cells were fabricated at five different sintering temperatures, 150, 250, 350, 450, and 500 Celsius. Each cell was fabricated using the same procedure except that sintering temperatures was varied. Sintering was carried out for 10minutes after a color change was observed. The open circuit voltage (Voc), short circuit current (Isc), fill factor (FF), Power max (Pmax) was measured for each cell.The Extech Instruments LT300 LuxMeter was used to record the light intensity during electrical characterization. Care was taken to ensure uniform lighting conditions during all tests (1 lux = 1.46 microwatts/ sq cm). Figures 4-7 shows results of open circuit voltage, short circuit current, Pmax and Fill Factor as a function of sintering temperature. Experimental results indicate (fig 4) that increased sintering temperature increases open circuit voltage at a roughly linear rate of 0.6mV per degree centigrade. Sintering at 150degrees produced DSSCs with Voc around 220mV while sintering at 500degrees produced Voc readings of approximately 430mV. A similar trend was observed for short circuit current. Isc ranged (fig 5) between 8 -10uA for cells sintered at 150 degrees to 18-20uA for cells sintered at 500 degrees. However changes observed for Isc were not as linear. Isc remained approximately constant at 8-10uA for sintering temperatures below 350 degrees; at temperatures 350-500 degrees, Isc jumped to about 18 uA and remained at this level. Max power available from each cell quadrupled (fig 6) when sintering temperature increased from 150degrees to 500degrees. Finally, fill factor improvements were less dramatic (fig 7) with increases in sintering temperature: a maximum fill factor of 0.5 was observed at 500degrees while a minimum of FF=0.2 was obtained at 150degrees. Fill factor at 350degrees (0.46) exceeded that at 450 degrees (0.41) an outcome that warrants additional investigation. Max efficiency (fig 8) increased with sintering temperature from 0.75% at 150 degrees to 3.13% at 500 degrees.

3.2 Effect of Sintering Time

The second set of investigations examined the effect of sintering time on cell performance. During standard fabrication, the glass slide coated with TiO2 paste is placed directly on a hot plate for typically10 minutes to sinter the film. During this process, slides turned yellow and then white again, the surface turning brown as the organic solvent dried and burnt off to produce a sintered titanium dioxide coating. Once sintered, slides were allowed to cool slowly to room temperature. The resulting TiO2 layer is *nanoporous*, meaning that it has pores, like a sponge,which are only a few nanometers wide. The TiO2 particles themselves are about 20 nm wide, the film about 7-10 micrometers thick. In order to investigate the effect of

sintering time on cell performance, sintering temperature was fixed at 500 degrees C. Glass slides were kept on hot plate at 500 degrees for 10, 15, 20 and 25 minutes respectively beyond color change. The resulting Voc and Isc of the cells were then measured. Results are presented in figures 9 and 10. Empirical results indicate that optimal sintering time is approximately 8-10 minutes (i.e. beyond color change). Open circuit voltage peaks at 450mV but is drastically reduced if cell is sintered beyond 10 minutes. The rate of decline in Voc of approximately 30mV per additional minute of sintering was observed (fig 9). Similarly for short circuit current, peak Isc of 22uA was observed after 10min of sintering (fig 10); this quickly decreased to zero when cells were sintered for 25 minutes. Isc decreased at a rate of 1.5uA per additional minute of sintering above 10 minutes.

4. CONCLUSIONS

The effect of sintering temperature and time on electrical performance of DSSCs was investigated. The investigations employed TiO2 - a wide band gap semiconductor and blueberry dye which acts asa photochemical pump exciting electrons to a mobile (conductive) state.It was found that DSSCs fabricated at higher sintering temperatures (~500 degrees Celsius) consistently exhibited efficiencies 2-3 times greater than those sintered at lower temperature (<300 degrees). Furthermore sintering times in 10-12 minute range produced the most solar efficient cells at sintering temperatures of 500 degrees celsius. TiO2 nanocrystals in the DSSCs fabricated were viewed using an Atomic Force Scanning Electron Microscope available through Penn State's Nanotechnology Remote Characterization Facility.

5. FIGURES

Figure 1 Circuit Set Up for Electrical Characterization

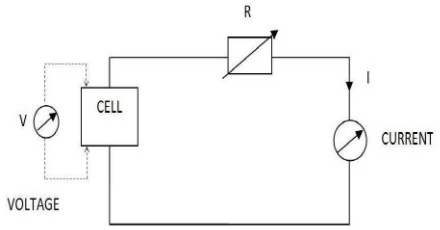
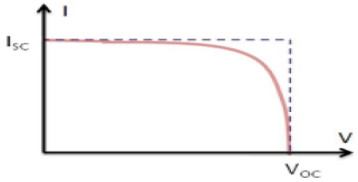


Figure 2 Solar Cell I-V Curve



Source: National Instruments 2009

Figure 3 I-V Sweep showing Max Power Point

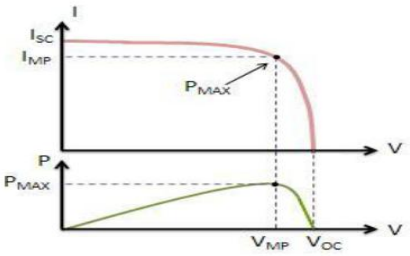


Figure 4 Variation of Voc with Sintering Temperature

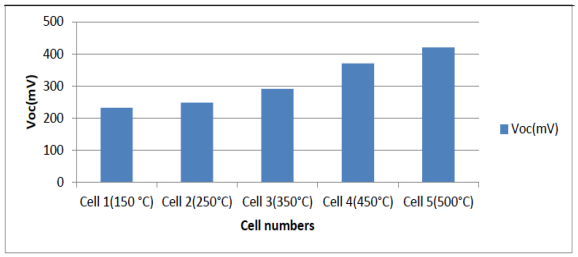


Figure 5 Variation of Isc with Sintering Temperature

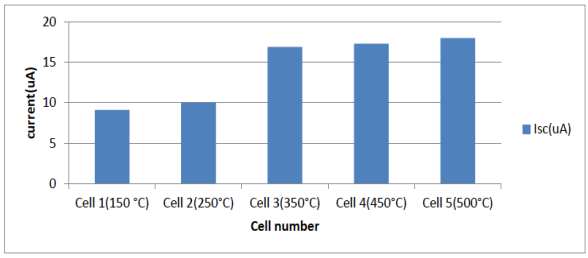


Figure 6 Variation of Pmax with Sintering Temperatur

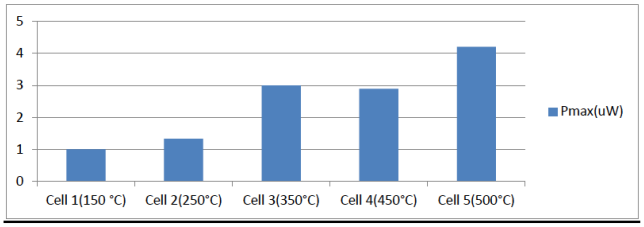


Figure 7 Variation of FF with Sintering Temperature

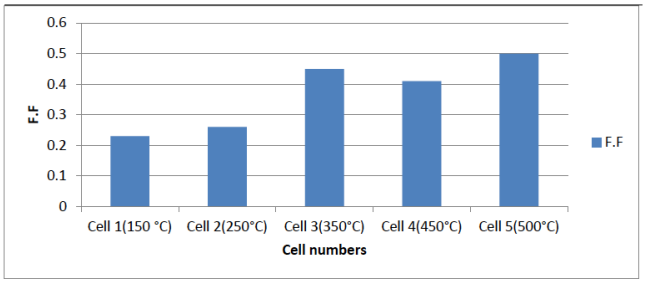


Figure 8 Variation of Max Efficiency with Temp

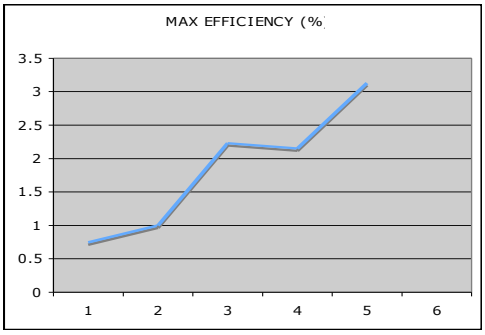


Figure 9 Variation of Voc with Sintering Time

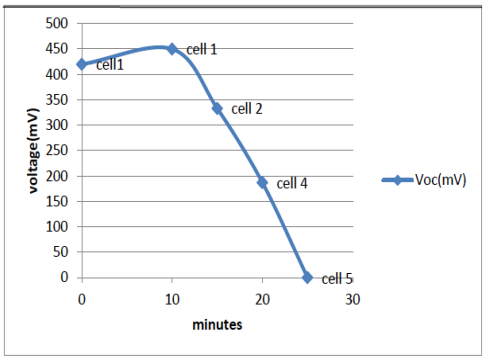


Figure 10 Variation of Isc with Sintering Time

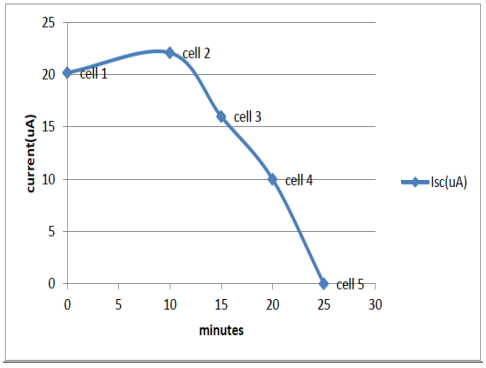
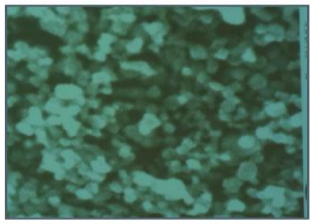


Figure 11 SEM Photograph of TiO2 nanocrystals (100nm scanning)



Source: Penn's state's Nanotechnology Remote characterization Facility

6. Acknowledgment

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