# Nanostructured Photovoltaic Materials for Enhanced Device Performance

Audrey M. Bowen Literature Seminar February 22, 2007

Worldwide consumption of energy is increasing, and with a forecasted 1 to 2% annual increase in energy demands, the availability of fossil fuels is expected to decline within several decades.[1] Renewable energy resources such as photovoltaic materials will become increasingly important. The sun provides an estimated $3x10^{24}$ joules per year to the earth's surface; if this energy were converted to electrical power at 10% efficiency, current worldwide energy needs would be fulfilled utilizing 0.1% of the land on Earth. Solar power is currently harvested chiefly by silicon-based solar cells that have power conversion efficiencies as high as 24%.[2] However, device performance is overshadowed by the cost of integrating such photovoltaic modules into homes and urban landscapes. For photovoltaics to be a viable alternative to fossil fuels, processing costs must be greatly reduced without sacrificing power conversion efficiency or long term device stability. Increased attention towards development of more cost-effective solar cells has led to novel device architectures and materials.

The dye sensitized solar cell is based on electrochemistry at the interface between a photosensitizing ruthenium based dye, which is chemisorbed onto a porous network of titanium dioxide particles, and a liquid electrolyte.[3] Due to its wide band gap, titanium dioxide ($TiO_2$) does not absorb much of the visible light provided by the sun; the photoexcited dye promotes ultrafast electron injection into the conduction band of the titanium dioxide, allowing for more effective photon absorption. To date, the highest reported efficiency reached by these cells is 10.4%.[2,4] Compared to the fabrication processes for silicon based solar cells, the production of dye sensitized solar cells requires lower process energy, which makes them attractive for both low cost and beneficial environmental factors.[5] While desirable in many regards, the feasibility of maintaining such a device is compromised by the highly corrosive liquid electrolyte; this has prompted the evolution of a solid-state dye sensitized solar cell, in which the liquid electrolyte is replaced with a solid layer of hole conducting material. The highest reported efficiency of such a solid-state cell is around 4%;[6] investigation of methods for improving this performance has elucidated the importance of nanostructuring photovoltaic materials, namely the titanium dioxide layer in dye sensitized solar cells.[7,8,9]

Arango *et al.*, reported an enhancement in external quantum efficiency (EQE) of a solar cell incorporating nanostructured titania. The enhancement was due to the substantial increase in surface area available for adsorption of the photosensitized dye.[7] Figure 1 illustrates this increase in EQE for a device with a nanostructured titania layer as compared to a device with a flat titania layer. The ideal $TiO_2$ nanostructure would have ordered features with uniform orthogonal pores 10 nm in diameter. Theoretically, this spacing allows for each charge carrier to consistently exist within a diffusion length of an electron acceptor. The electron and hole transport layers should each provide straight paths to one electrode, minimizing charge transport time, preventing carrier loss, and reducing the probability of scattering or recombination.[9]

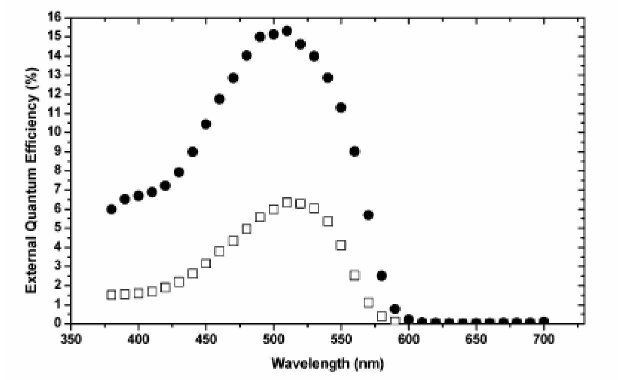

**Figure 1:** External quantum efficiency (EQE) plotted as a function of wavelength: devices with nanostructured $TiO_2$ (closed circles, top curve) and with flat $TiO_2$ (open squares, bottom curve)[10]

The development of novel processing strategies has enabled progress towards achievement of the ideal titania structure. The most promising of these methods control film structure by means of simple procedures with relatively low cost materials. McGehee et al., introduced an embossing technique, which draws on the principles of soft lithography and nanoimprinting, to mold $TiO_2$ into desirable structures, as seen in Figure 2.[11] Other structuring options include creating a porous titania web by poly(vinyl acetate) mediated electrospinning[12,13] and directing growth with a block copolymer surfactant template, such as Pluronic 123.[14,15,16] Incorporation of an ordered network of nanorods[17] or nanowires[18] into a flat titania layer will provide similarly beneficial structuring results.

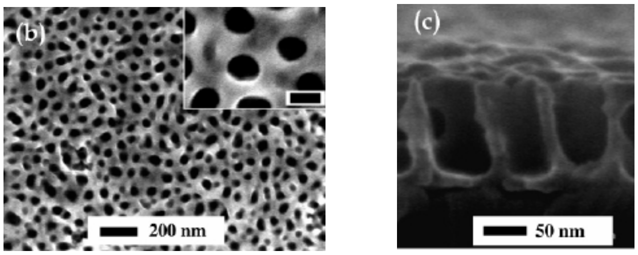

**Figure 2:** Typical embossed $TiO_2$ structures after mold removal[11]

Although the efficiency of solid-state dye sensitized solar cells is still too low to make this a feasible energy alternative, by optimizing the structure of the titania layer and studying the infiltration of the hole conducting material into that network, further increases in device efficiency are probable.

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