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Novel TiO_2 Microstructures for Low Cost Dye Sensitized Solar Cells

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Abstract A critical component of the dye sensitized solar cell (DSSC) is the nano-structured wide bandgap semiconductor (typically TiO_2). The particle size, crystal structure, orientation, and scale of interconnected porosity are all critical to cell performance. In our lab, we have engineered and produced ceramic pastes including a hierarchy of nano- to micron-sized particles of varying morphologies and texture which yield novel, hybrid microstructures. We assert that while the nano-material provides the surface area, the micro particles provide conduits for easier diffusion of photo-generated electrons through the titania and also a pore structure for percolation of dye and electrolyte, giving enhanced photo-current and power output. The pastes also are of practical benefit, as they avoid shrinkage cracks during drying, and result in high quality thick films.

Keywords dye sensitized solar cells (DSSC), titanium dioxide, hierarchical microstructures, nanomaterials

Introduction

The vision of low cost, ubiquitous solar power systems requires a paradigm shift in photovoltaic (PV) materials and manufacturing. Any new energy source must use abundant, non-toxic materials. It must be produced in a scalable process requiring low capital investment. The goal of our work is to conduct the science required toward the design of a material coating system which can be applied on site by skilled labor that will generate electricity for a fraction of current PV cost. The technology of focus is the dye sensitized solar cell (DSSC), a hybrid organic/inorganic device with proven efficiencies of 10%, and estimated costs at just 10 to 20% of state of the art silicon devices [1-3]. The DSSC is a 3rd generation PV just beginning commercialization [4-5].

The role of the dye (typically bipyridyl complexes of Ru^{2+}) in DSSC is to absorb visible light, pump an electron (e^-) into the wide band gap semiconductor of the anode, and accept an e^- from the redox couple (I^-/I_3^-) to repeat the cycle [2]. One limitation of the DSSC is the tortuous e^- percolation path between weakly linked nano-anatase particles giving high internal resistance and low current output. Li *et al.* [6] has recently verified, via impedance spectroscopy and numerical simulation, that e^- transport and recombination dominate operation of DSSC, and an optimal bimodal distribution of nanoparticles can benefit performance. Several research groups (examples given in references [7-10]) have taken the approach of growing oriented TiO_2 and ZnO nano-rods or -tubes to enable easy transport of e^-s to the anode, however; the height of nano-pillar arrays is limited to a few tens of nanometers, which limits the amount of light absorption in the cell. In addition, growing very large areas in an economical fashion is difficult to envision.

Percolation of electrons is not the only issue. Diffusion of the electrolyte, whether the typical low viscosity organic solvent type or newer higher viscosity polymers, to and from the dye-covered TiO_2 surfaces is critical to maintaining high current. In the case of iodine solutions, I_3^- must quickly diffuse from the surface during operation to reduce recombination events and the undesirable dark current.

An optimized film structure has been shown to be one containing meso-porous channels aligned perpendicular to the substrate [11], which again justifies the fervor over using aligned nano-tubes or rods. A more novel and potentially practical idea was recently reported where an "inverse opal" microstructure was produced from commercially available titania nanoparticles giving DSSC with efficiencies greater than 4% [12].

It has been suggested that optical effects resulting from the nano-structured semiconductor provide opportunities for increasing the total efficiency of DSSC [13-18]. As in the well known textured single crystal Si solar cell, surface roughness can reduce specular reflectance. Enhanced internal light scattering may increase the average photon path length, increasing the probability for photon capture by the dye, an idea similar to the dependence of opacity of paint coatings and paper on multiple scattering from large numbers of particles comparable to wavelength [20]. Moreover, light should be absorbed over the widest possible range of wavelengths, and interaction of the dye with varying surfaces may