INTERDIGITATED ELECTRODES FOR DYE-SENSITIZED SOLAR CELLS

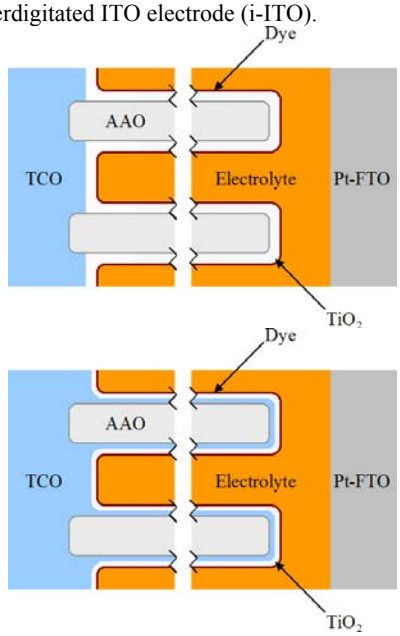
Alex B. F. Martinson[1,2], Jeffrey W. Elam[1], Jun Liu[2], Tobin J. Marks[2], Joseph T. Hupp[2], Michael J. Pellin[1,2]
[1]Materials Science Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439; [2]Department of Chemistry and Argonne-Northwestern Solar Energy Research (ANSER) Center, Northwestern University, 2145 Sheridan Rd., Evanston, IL 60208

INTRODUCTION

In the most efficient DSSCs to date, the superior light harvesting efficiency of photons throughout the visible spectrum is realized by a ~14 μm thick nanoparticle photoanode with roughness > 2000.[1] Given a charge collection time of milliseconds at the maximum power point,[2] efficient charge extraction is only made possible through the extraordinarily slow interception of electrons by adjacent I_3^-. Thus, what promises to be a *tour de force* in photoelectrochemical energy conversion has so far only offered a limited variable space in which efficient devices are realized. Particularly lacking is an assortment of redox couples that permit reasonable collection efficiency, the current number able to be counted upon one hand.[3-6] In order to accommodate the faster electron interception rates of alternative redox shuttles, the collection time of electrons traversing the photoanode must be reduced.

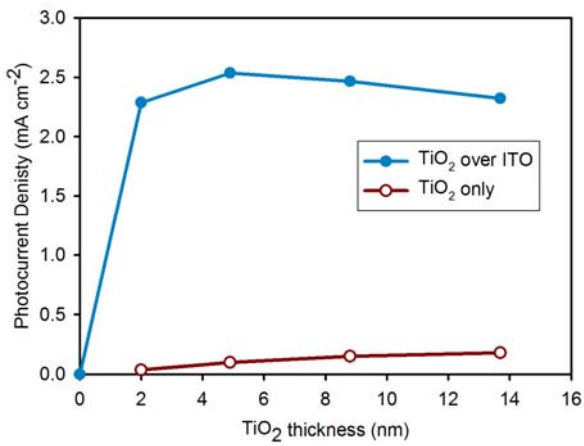
EXPERIMENTAL

We introduce a new device architecture in which the electron collection distance is reduced by orders of magnitude, without a significant reduction in surface area, by extending the transparent electrode deep within the semiconductor framework. Indium tin oxide (ITO) is grown within and upon AAO by atomic layer deposition (ALD) to produce a transmissive and conductive high-area electrode. Subsequent deposition of amorphous TiO_2 within the pores of the electrode yields a high-area photoanode suitable for implementation in DSSCs. A highly idealized schematic of the new architecture is shown as Figure 1b. In contrast to a conventional DSSC photoanode, Figure 1a, in which electrons diffuse the length of the microns-thick nanotube or nanoparticle photoanode, we hypothesized that electrons would flow *radially* through a few nanometers of semiconductor to be collected by the adjacent, interdigitated ITO electrode (i-ITO).



RESULTS

Figure 3 shows the short-circuit photocurrent densities (J_{sc}) measured for a series of samples prepared with increasing TiO_2 tube wall thickness, with and without i-ITO. The meager output of the control devices is not surprising since injected electrons, forced to traverse the microns-long amorphous TiO_2 tubes, are expected to be collected extremely inefficiently at the distant TCO (see Figure 1a). An additional control, in which only i-ITO is present in the pores, underscores the need for some thickness of semiconductor to rectify the dark current. Here the high surface area TCO exhibits exceedingly large dark currents that overwhelm any photocurrent. In striking contrast, the i-ITO DSSCs (idealized in Figure 1b), each with > 2 nm of TiO_2 over 7 nm of ITO within the pores, show larger J_{SC} values (10- to 60-fold) than the controls. Indeed, the current densities approach that of the best ZnO nanotube DSSCs to date.[7]



REFERENCES

1. Nazeeruddin, M. K.; De Angelis, F.; Fantacci, S.; Selloni, A.; Viscardi, G.; Liska, P.; Ito, S.; Takeru, B.; Gratzel, M. G. *Journal of the American Chemical Society* **2005**, *127*, 16835.
2. Wang, Q.; Ito, S.; Gratzel, M.; Fabregat-Santiago, F.; Mora-Sero, I.; Bisquert, J.; Bessho, T.; Imai, H. *Journal of Physical Chemistry B* **2006**, *110*, 25210.
3. Nusbaumer, H.; Moser, J. E.; Zakeeruddin, S. M.; Nazeeruddin, M. K.; Gratzel, M. *Journal of Physical Chemistry B* **2001**, *105*, 10461.
4. Wang, Z. S.; Sayama, K.; Sugihara, H. *Journal of Physical Chemistry B* **2005**, *109*, 22449.
5. Wang, P.; Zakeeruddin, S. M.; Moser, J. E.; Humphry-Baker, R.; Gratzel, M. *Journal of the American Chemical Society* **2004**, *126*, 7164.
6. Gorlov, M.; Pettersson, H.; Hagfeldt, A.; Kloo, L. *Inorganic Chemistry* **2007**, *46*, 3566.
7. Martinson, A. B. F.; Elam, J. W.; Hupp, J. T.; Pellin, M. J. *Nano Letters* **2007**, *7*, 2183.

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