WHAT'S HOT IN CHEMISTRY, May/Jun 2009

Surprising Steps Forward in Solar Cells Thanks to Nano Chemistry

by John Emsley

PDF

Papers #5 and #8 report on the benefits of nanomaterials—silicon and titanium dioxide (TiO_2), respectively—in boosting the performance of solar cells.

Miniature solar cells could power microelectronic systems, and downsizing to this scale requires nano-electronic components, but so far such cells have low efficiency and poor stability. However, the coaxial nanowires of paper #5 overcome these drawbacks. They are the work of Charles Lieber's group at Harvard University and they consist of a p-type silicon nanowire core surrounded by an n-type silicon sheath. Electrons and holes are generated by light in the layer of silicon between them and are swept into the n-shell and p-core, respectively, by a built-in electric field.

The coaxial wires were grown in three stages starting with a vapor-liquid-solid method for the 300 nanometer (nm) diameter core. This was coated by a chemical vapor deposition with a layer of pure silicon and finally with a phosphine-doped outer layer. Metal contacts were fabricated onto the p-core and outer n-layer. The new wires maintained their performance for seven months and the Harvard group connected them both in parallel and in series to demonstrate their versatility to drive large loads. The efficiencies of the devices were only 2-3%, but Lieber suggests this could be improved.

The research described in paper #8 offers

Chemistry Top Ten Papers

Rank	Papers	Cites This Period Nov-Dec 08	Rank Last Period Sep-Oct 08
1	Y. Kamihara, *et al.*, " Iron-based layered superconductor La[$O_{1-x}F_x$]FeAs (x = 0.05-0.12) with T_c = 26 K," *J. Am. Chem. Soc.*, 130 (11): 3296-7, 19 March 2008. [Tokyo Inst. Technol., Yokohama, Japan] *273SL	108	1
2	C. de la Cruz, *et al.*, "Magnetic order close to superconductivity in the iron-based layered $LaO_{1-x}F_x$FeAs systems," *Nature*, 453 (7197): 899-902, 12 June 2008. [6 U.S. and China institutions] *311WV	62	2
3	H. Takahashi, *et al.*, "Superconductivity at 43 K in an iron-based layered compound LaO_{1-x} F_x FeAs," *Nature*, 453 (7193): 376-8, 15 May 2008. [Nihon U., Tokyo, Japan; Tokyo Inst. Technol., Japan] *301AI	39	3
4	J. Peet, *et al.*, "Efficiency enhancement in low-bandgap polymer solar cells by processing with alkane dithiols," *Nature Mater.*, 6(7): 497-500, July 2007. [U. Calif., Santa Barbara] *184NH	35	†
5	B. Tian, *et al.*, "Coaxial silicon nanowires as solar cells and nanoelectric power sources," *Nature*, 7164(449): 885-9, 18 October 2007. [Harvard U., Cambridge, MA] *221LY	31	†

significant benefits to solar cells of the Grätzel type. In these cells, light is captured by dye molecules which release electrons into a metal oxide and holes into an electrolyte, and provided they successfully migrate to opposite electrodes they will produce an electric current; if they recombine before doing so they produce no current. To be effective, charge collection at the electrodes has to be much faster than recombination within the electrolyte. Paper #8 shows charge collection can be greatly boosted by means of TiO_2 nanotubes.

Arthur Frank of the National Renewable Energy Laboratory in Colorado led the group, and #8 reports both the microstructure and the way electrons behave in dye-sensitized solar cells which incorporate the TiO_2 nanotubes. These were prepared from electrochemically anodized titanium foil and were investigated by scanning and transmission electron microscopy. This showed them to consist of closely packed nanotubes which were several micrometers in length, with wall thickness of around 10 nm and pore diameters of around 30 nm.

A photovoltaic cell, the most basic building block of a PV system.

6	X.D. Wang, *et al.*, "Direct-current nanogenerator driven by ultrasonic waves," *Science*, 316 (5821): 102-5, 6 April 2007. [Georgia Inst. Tech., Atlanta] *153XD	27	†
7	X.L. Li, *et al.*, "Chemically derived, ultrasmooth graphene nanoribbon semiconductors," *Science*, 319(5867): 1229-32, 29 February 2008. [Stanford U., CA] *267SX	22	10
8	K. Zhu, *et al.*, "Enhanced charge-collection efficiencies and light scattering in dye-sensitized solar cells using oriented TiO_2 nanotube arrays," *Nano Lett.*, 7(1): 69-74, January 2007. [Natl. Renewable Energy Lab., Golden, CO] *124PK	20	†
9	N. Tian, *et al.*, "Synthesis of tetrahexahedral platinum nanocrystals with high-index facets and high electro-oxidation activity," *Science*, 316 (5825): 732-5, 4 May 2007. [Xiamen U., China; Georgia Tech, Atlanta] *163RR	19	†
10	A.I. Hochbaum, *et al.*, "Enhanced thermoelectric performance of rough silicon wires," *Nature*, 451(7175): 163-7, 10 January 2008. [U. Calif., Berkeley; Lawrence Berkeley Natl. Lab., CA] *249GA	19	†

SOURCE: Thomson Reuters Hot Papers Database. Read the Legend.

The nanotubes are all oriented in the same direction and perpendicular to the underlying titanium foil on which they were formed. The dye in these new cells was the same ruthenium complex used in many other Grätzel type cells, and this was adsorbed into the nanotubes. The electrolyte into which the holes were released was 1-hexyl-2,3-dimethylimidazolium iodide in methoxyproprionitrile. The cells were then illuminated with light. Transport times in the new cells was similar to the earlier cells which were based on randomly packed nanocrystallite films, but the recombination was 10 times slower so they generated more current. Also, the absorption of light by the ruthenium complex was enhanced due to stronger light scattering within the nanotube arrays compared to that of the traditional Grätzel cells with their nanocrystallite-based films.

More recently Frank has published a method of removing structural disorder from his nanotube arrays (K. Zhu, *et al.*, *Nano Lett.,* 7[12]: 3739-46, 2007) and a way of growing p-type semiconductors in the nano pores of n-type materials such as n-TiO_2 (Q. Wang, *et al.*, *Nano Lett.,* 9[2]: 806-13, 2009). Currently he is working to understand the electron dynamics in ordered mesoporous films with the aim of increasing the efficiency and stability of sensitized solar cells.

As Frank tells *Science Watch*, "The future is bright for the development of commercial high-efficiency, low-cost solar cells based on the sensitization phenomenon, and ordered nanoporous electrode architectures. I believe that by developing the scientific underpinning to exploit the unique properties of dye-sensitized mesoscopic systems, an efficiency of 15% is attainable for single-junction devices. We may even develop sensitized nanostructure systems with efficiencies beyond the theoretical (Shockley-Queisser) limit of 32% by incorporating third-generation concepts based on quantum confinement."

Dr. John Emsley is based at the Department of Chemistry, Cambridge University, U.K.

KEYWORDS: SOLAR CELLS, NANOMATERIALS, NANOCHEMISTRY, CHARLES LIEBER, NANOWIRES, SILICON, TITANIUM DIOXIDE, ARTHUR FRANK, MESOPOROUS FILMS.

PDF

Figure credit:
U.S. Department of Energy - Energy Efficiency and Renewable Energy> PC Systems. This image was obtained from the Wikimedia Commons. In-depth figure credit may be viewed here.

back to top

What's Hot In... : What's Hot In Chemistry Menu : Surprising Steps Forward in Solar Cells Thanks to Nano Chemistry