WHAT'S HOT IN... CHEMISTRY, January/February 2010

Sustainable Electrodes for Solar Cells

by John Emsley

PDF

To generate solar energy, a solar cell must have an electrode that is transparent. Currently there are two materials which meet this requirement: indium tin oxide (ITO), which is the preferred one, and fluorine tin oxide (FTO), which is less effective. However, indium is rare and has to be extracted from zinc and lead ores, of which it is a minor component; production is less than 500 tons a year.

ITO and FTO are not without their drawbacks. They lack transparency with respect to the infrared region of the spectrum, and this restricts their ability to gather a wider range of solar energy. They are unstable in the presence of acids and bases, and their metal ions are prone to diffusing into the polymer layers thereby reducing efficiency. Unless they are structurally perfect they suffer from current leakage.

Graphene, on the other hand, appears to have none of these drawbacks—and it is cheap and sustainable. Graphene films are transparent, electrically conducting, and can be made ultra-thin. Paper #9 describes such an electrode, and one that is suitable for solid-state dye-sensitized solar cells which harvest light over a wider range of the spectrum. What is particularly important for these titanium dioxide based solar cells is that the graphene films are chemically more stable, especially to strong acids. The paper comes from the Max Planck Institute for Polymer research at Mainz, Germany.

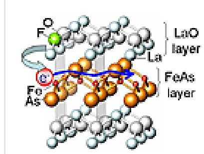
Graphene sheets are produced from graphite starting with the acid oxidation of graphite flakes. The oxygen-containing groups which are formed make the product dispersible in water in which it can be exposed to ultrasonification to separate it into thinner sheets. These are then deposited on to a substrate such as quartz, and this is done by simply dipping in the hot solution. The thickness of the film can be varied by changing the temperature of the aqueous medium.

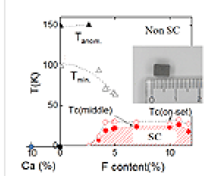
The graphite oxide so obtained is an insulator but can be reduced by heating to high temperatures in an atmosphere of argon and hydrogen gas. (The absence of oxygenated groups in the product was evidenced by IR spectroscopy.) The resulting graphene film was tens of layers thick. One such film, which was 10 nm in width, was observed to have transmittance of 71% at a wavelength of 500 nm which may be lower than that of ITO's 90% and FTO's 82%. However, compared to ITO and FTO, the graphene film is transparent to IR radiation. The films have a conductivity of 550 S cm-1 which compares to that of graphite's 1250 S cm-1 and so they have the potential to act as electrodes.

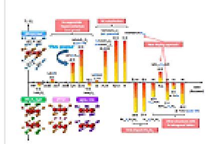
Currently leading the research at the Max Planck Institute are Xinliang Feng and Klaus Müllen, and their recent papers suggest more exciting developments. In *Nanotechnology* (Y.Y. Liang, *et al.*, 20[43]: no 434007, 2009) the group reports an improved way of making the films which involves using acetylene in the reduction of the graphite oxide, a method which not only repairs defects within the sheets but also increases the conductivity to 1425 S cm-1 while still maintaining high optical transmittance.

In *Advanced Materials* (Q. Su, *et al.*, 21[31]: 3191-5, 2009) they report the inclusion of large aromatic donor and acceptor molecules to functionalize the graphene. This approach stabilizes the graphene in aqueous dispersion and also enables it to be deposited

The figures below are from an interview with coauthor Hideo Hosono, in regards to paper #1. Click figures for a larger view & description.







in monolayer and double-layer on substrates in large quantities. When the graphene is then heated at around 1000° C, the aromatic molecules repair holes in the film, thereby contributing to an improved conductivity of 1314 S cm-1 which now exceeds that of ordinary graphene.

As Xinliang Feng tells *Science Watch*: "Our work is possibly the most attractive application of graphene in future electronics. We are currently improving the quality of graphene film in terms of transmittance and conductivity, because these are the crucial parameters for the window electrode replacement of traditional ITO. I think that we are leading in this area of large scale and cheap synthesis of transparent graphene electrodes. If graphene electrodes can be fabricated by easy and cheap methods in large quantities, then a big market for them can be expected."

A sustainable future for solar panels now seems assured.

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

Chemistry Top 10 Papers

Rank	Paper	Citations This Period (Jul-Aug 09)	Rank Last Period (May-Jun 09)
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	173	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	54	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	51	4
4	X.L. Li, *et al.*, " Chemically derived, ultrasmooth graphene nanoribbon semiconductors," *Science*, 319(5867): 1229-32, 29 February 2008. [Stanford U., CA] *267SX	44	4
5	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	40	5
6	A.I. Hochbaum, *et al.*, "Enhanced thermoelectric performance of rough silicon nanowires," *Nature*, 451(7175): 163-7, 10 January 2008. [U. Calif., Berkeley; Lawrence Berkeley Natl. Lab., CA] *249GA	36	7
7	S. Stankovich, *et al.*, "Synthesis of graphene-based nanosheets via chemical reduction of exfoliated graphite oxide," *Carbon*, 45 (7): 1558-65, June 2007. [Northwestern U., Evanston, IL; U. North Carolina, Chapel Hill] *185XJ	36	6
8	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	29	8
9	X. Wang, L. Zhi, K. Müllen, "Transparent, conducive graphene electrodes for dye-sensitized solar cells," *Nano Letters*, 8(1): 323-7, January 2008. [Max Planck Inst. Polymer Res., Mainz, Germany] *249VI	25	†
10	A.I. Boukai, *et al.*, "Silicon nanowires as efficient thermoelectric materials," *Nature*, 451(7175): 168-71, 10 January 2008. [Caltech, Pasadena] *249GA	24	10

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KEYWORDS: GRAPHENE, SOLAR CELLS, GRAPHENE ELECTRODES, GRAPHENE FILMS, XINLIANG FENG, KLAUS MULLEN.