WHAT'S HOT IN... CHEMISTRY , July/August 2008

Making Viruses Make Nanowires to Make Anodes for Batteries

by John Emsley

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Rank	Papers	Cites Jan-Feb 08	Rank Nov-Dec 08
1	X. Huang, *et al.*, **"Cancer cell imaging and photothermal therapy in the near-infrared region by using gold nanorods,"** *J. Am. Chem. Soc.*, 128(6): 2115-20, 15 February 2006. [Georgia Inst. Tech., Atlanta; U. Calif., San Francisco] *014AX	28	†
2	Z.L. Wang, J. Song, **"Piezoelectric nanogenerators based on zinc oxide nanowire arrays,"** *Science*, 312(5771): 242-6, 14 April 2006. [Georgia Inst. Tech., Atlanta; Peking U., Beijing, China] *032HK	25	†
3	K.T. Nam, *et al.*, **"Virus-enabled synthesis and assembly of nanowires for lithium ion battery electrodes,"** *Science*, 312 (5775): 885-8, 12 May 2006. [MIT, Cambridge; Korea Inst. Sci. Tech., Seoul] *041JQ	21	†
4	I. McCulloch, *et al.*, **"Liquid-crystalline semiconducting polymers with high charge-carrier mobility,"** *Nature Materials*, 5(4): 328-33, April 2006. [Merck Chem., Southampton, U.K.; Palo Alto Res. Ctr., CA; Stanford U., CA; Stanford Synchrotron Radiat. Lab., Menlo Park, CA] *029AO	19	†

Four of the current Hot Ten papers relate to nano chemistry: #1 and #7 are about gold nanorods and #2 is about zinc oxide nanowires. However, it is paper #3 which is the most innovative, reporting how cobalt oxide (Co_3O_4) nanowires have been assembled with the help of a virus.

The paper comes from a team headed by Angela Belcher of the Department of Materials Science and Engineering at MIT. It also describes how these nanowires can form a monolayer which can act as the anode for an ultra-thin lithium ion battery. Not surprisingly, Belcher's work has attracted a lot of media attention. In 2004 she was rewarded with a prestigious MacArthur Fellowship and in 2006 was named by *Scientific American* magazine as its Research Leader of the Year.

Employing a virus to carry out an *inorganic* chemical process requires a quantum jump of scientific intuition, although some living species have evolved to do just that. For example, sea snails can manipulate calcium carbonate to construct their protective shells. In fact it was these tiny creatures which Belcher says gave her the idea that microscopic life forms might be able to construct other inorganic materials.

She was proved right when her group used the M13 virus, which has 2,700 helical proteins wrapped around its DNA, to grow crystalline nanowires of Co_3O_4. The virus was modified by attaching tetraglutamate groupings to it, and these acted as templates for the nanowires which grew within 30 minutes from a dilute (1 mM) aqueous cobalt chloride solution at room temperature. They were then reduced with sodium borohydride followed by spontaneous oxidation in water to yield the desired product. Their authenticity as nanowires was proved using transmission electron microscopy which revealed their genuinely crystalline nature.

The anodes for the lithium battery were made by mixing the nanowires with 15% of carbon black and 11% of poly(vinylidene fluoride)-hexafluoropropylene binder. (The electrolyte was lithium hexafluorophosphate in ethylene carbonate and dimethyl carbonate.) The capacity of the new batteries was twice that of the normal carbon-based anode batteries. Belcher was also able to show that the virus itself was stable within the battery anode and there was no decomposition when the battery went through a sequence of charging and discharging. The inclusion of gold in the process led to hybrid Au-Co_3O_4 nanowires, and these increased the storage capacity compared to Co_3O_4 nanowires alone.

Paper #3 also reports that M13 viruses can form very ordered two-dimensional liquid crystalline layers of nanowires on top of conducting films and that these can be as large as 10 cm2 in area. The thickness of the multilayered polymer can be varied from 10 nm to several micrometers and is independent of the substrate.

Talking to *Science Watch*®, Belcher says her current research is being conducted with MIT colleagues Paula Hammond and Yet-Ming Chiang: "We have been working on high specific capacity cathode materials using biological processing and getting very good results. We now have full virus-based battery cathodes as well as anodes. We are also working on materials for solar cells, catalysts, fuel cells and carbon sequestration."

Belcher's collaborative work on multilayers assembled with the aid of viruses has recently been published—see P.J. Yoo, *et al.*, *ACS Nano*, 2(3): 561-71, 2008; and P.J. Yoo, *et al.*, *Nano Letters*, 8(4): 1081-9; 2008.

And what does she see in the future?

5	M. Dinca, *et al.*, "**Hydrogen storage in a microporous metal-organic framework with exposed Mn2+ coordination sites,"** *J. Am. Chem. Soc.*, 128 (51): 16876-83, 27 December 2007. [6 U.S. institutions] *118KQ	19	†
6	J. Song, Y. Wang, L. Deng, **"The Mannich reaction of malonates with simple imines catalyzed by bifunctional cinchona alkaloids: Enantioselective synthesis of ß-amino acids,"** *J. Am. Chem. Soc.*, 128(18): 6048-9, 10 May 2006. [Brandeis U., Waltham, MA] *041PU	18	†
7	N.L. Rosi, *et al.*, **"Oligonucleotide-modified gold nanoparticles for intracellular gene regulation,"** *Science*, 312(5776): 1027-30, 19 May 2006. [Northwestern U., Evanston, IL] *043UX	18	†
8	D. Enders, *et al.*, **"Control of four stereocentres in a triple cascade organocatalytic reaction,"** *Nature*, 441(7095): 861-3, 15 June 2006. [Aachen U., Germany] *052SL	17	7
9	J.E. Green, *et al.*, **"A 160-kilobit molecular electronic memory patterned at 1011 bits per square centimetre,"** *Nature*, 445(7126): 414-7, 25 January 2007. [Caltech, Pasadena, CA; U. Calif., Los Angeles; Ohio St. U., Columbus] *128WD	17	†
10	A.G. Wong-Foy, A.J. Matzger, O.M. Yaghi**, "Exceptional H_2 saturation uptake in microporous metal-organic frameworks,"** *J. Am. Chem. Soc.*, 128(11): 3494-5, 22 March 2006. [U. Michigan, Ann Arbor] *025XD	16	8

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Belcher: "I think in the next few years new kinds of interdisciplinary approaches to the synthesis and assembly of high-value, high-performance materials will be much more acceptable. I also think that environmentally friendly processing and environmental compatibility will become increasingly important."

Belcher has opened up a completely new era of chemical synthesis by using viruses to create and design inorganic nano-sized materials. One day we may all benefit from her batteries which are not only efficient but transparent and capable of powering all kinds of nano devices. And just as living things with inorganic components are able to repair these themselves, so might this ability even become a feature of nano components.

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Keywords: Angela Belcher, MIT, cobalt oxide nanowires, nanowires, M13 virus, lithium batteries, nanotechnology.

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