Complex Porous Metal Nanostructures: self-assembled from block copolymers

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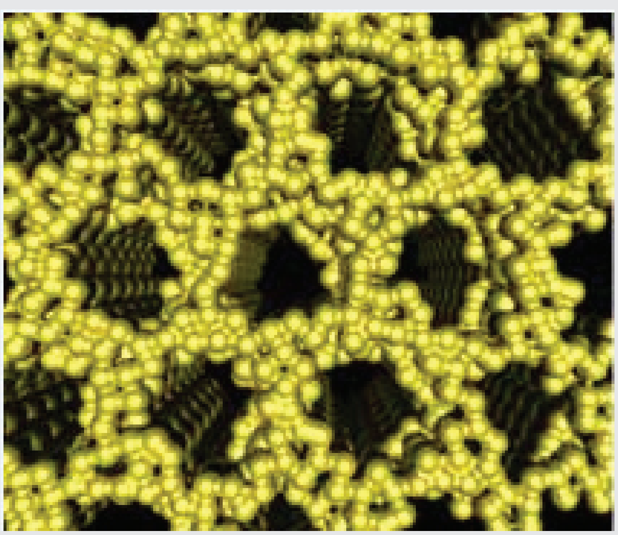
Uli Wiesner (Dept. of Materials Science & Engineering, Cornell University) and coworkers have pioneered a novel way to use block copolymers to make nanoporous structures for catalyst, battery and fuel cell applications. The self-assembly of nanoparticles using block copolymers depends largely on the ability to design the right polymers and ligand-stabilized nanoparticles. Ligands can be used to achieve a high solubility in an organic solvent and allow particles to flow at high density. The layer of ligand needs to be thin around each particle so that the final structure has a volume of metal large enough to maintain a microstructural shape when the organic materials are removed[1]. The metal particles may then be sintered or calcined into a metal or metal oxide framework that has structure directed by the parent copolymer system and high porosity.

A structure made of platinum, which is the best catalyst for fuel cells, can now be created with uniform hexagonal pores. The neatly ordered pores create a large surface area within a very small volume of material. Fuel cells and solar cells also both benefit from nanoscale pores: For a fuel cell, pores offer increased surface area at which a fuel can interact with a catalyst, making it more efficient. Similarly in certain types of solar cells, more surface area means that more light can be absorbed and generated charge carriers can be collected, converting more of the incident light energy into electricity. Porous films of titanium oxide, used in Grätzel-type solar cells, and niobium oxide, a fuel cell catalyst support, are obtained by mixing the chemicals that react to form the metal oxides with a polymer solution of PI-b-PEO (poly isoprene-block-polyethylene oxide). As the reaction proceeds, the PI portion of the copolymer forms cylinders surrounded by metal oxides. Subsequent heat treatments leave uniform, crystalline metal oxide with cylindrical pores[2]. The exceptional properties make them excellent candidates for solar cells but also valuable in many other areas.

In addition to making porous materials, this technique could be used to create finely structured surfaces. In the field of plasmonics, waves of electrons move across the surface of a conductor with the information-carrying capacity of fiber optics, but in spaces small enough to fit on a chip. The self-assembly of nanoparticles with block copolymers may enable the formation of porous materials made of a range of elements, alloys, or intermetallics. This may enable mixtures of distinct metal nanoparticles to be combined into a single nanoporous material. Nanoporous metals made from nanoscopic particles of distinct compositions may have unique electrical, optical, and catalytic properties. There is great promise for future energy applications. Control over the structure of metals is crucial for energy conversion, sensing, and information processing. Self-assembly of nanoparticles with block copolymers provides a natural entry point to materials structured on this length scale[3].



Computer simulated image of how platinum nanoparticles fuse into a structure with tiny pores after the polymers that guided them into position are removed. Figure from the Wiesner Lab.

Related information by the Wiesner Research Group, Department of Materials Science at Cornell University can be found at http://people.ccmr.cornell.edu/~uli/. CHESS was used to characterize the nanoporous structures at various steps along the processing sequence in order to understand the formation process, thereby enabling future materials improvements.

References:

1. B.Steele; *"In 'novel playground', metals are formed into porous nanostructures for better fuel cells and microchips"*, Cornell Chronicle Online (June 26, 2006)

2. B.Steele; *"'One-pot' process can make more efficient materials for fuel cells and solar cells"*, Cornell Chronicle Online (January 28, 2008)

3. S.C. Warren, and U. Wiesner; "Self-assembled Ordered Mesoporous Metals", Pure Appl. Chem **81**(1), pp. 73-84 (2009)