

conduction in the perovskite plays a significant role in the electrode process, or whether surface diffusion of adsorbed species from the fuel will be a rate-controlling step. Furthermore, long-term experiments under real SOFC conditions still need to be performed. Nevertheless, Irvine and Tao provide a new direction for improving SOFC technology, possibly bringing it a step closer towards commercialization.

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NANOSCALE PHOTONICS

Nanoshells: gifts in a gold wrapper

Researchers in the field of ‘nanophotonics’ are attempting to fabricate the smallest possible structures with optical functionality. The ability to engineer silica–gold nanoshell particles may increase the importance of metals in a range of nanophotonic and biological applications.

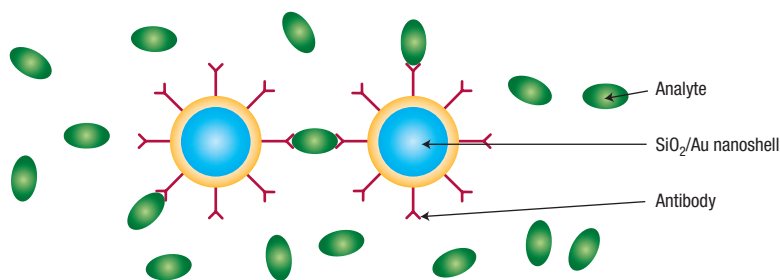
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In the past few years, metallic nanoparticles have emerged as powerful building blocks for photonic devices in which electromagnetic waves can be controlled at the nanometre length scale. Structures such as metal nanoparticle waveguides exploit the unique properties of collective electron oscillations, known as plasmons¹. At the March 2003 symposium* on *Photonics and the Nanoscale* at the American Physical Society Meeting in Austin, Texas, Naomi Halas and Jennifer West from Rice University reported their efforts to take plasmonic nanoparticles into the bio-arena. In a series of clever experiments, they demonstrated how silica–gold nanoshells are uniquely suitable for use in ‘instantaneous’ whole-blood immunoassays, optically triggered drug delivery², and targeted photothermal destruction of cancer cells.

*American Physical Society, Focus session: *Photonics and the Nanoscale: Devices, Materials and Chemistry* Austin, Texas, USA, March 3–7, 2003.

Figure 1 Formation of a nanoshell dimer through the interaction of antibodies immobilized on the nanoshell surface with the analyte. The formation of such dimers causes an easily detectable change in the plasmon-related absorption.



The use of metallic nanoparticles dates back to the Renaissance. In that era, artists handcrafted vibrantly coloured church windows and glass vases by dissolving minute amounts of noble metal impurities in a glass melt to induce precipitation of nanometre-size metallic clusters³. In 1908, Gustav Mie provided the theory explaining this phenomenon⁴. This theory predicts that metallic nanoclusters strongly absorb visible light at a well-defined plasmon-resonance frequency. At this frequency, electromagnetic energy is efficiently converted into a collective motion of the free electrons in the metal. The resonance frequency of the particles depends on the particle size and shape, the presence of other particles, and the dielectric environment⁵.

At the APS meeting, George Schatz from Northwestern University demonstrated how the resonance frequency of two-dimensional metallic nanoparticle arrays can be tuned over a wide range of frequencies from blue to near-infrared by controlling the electromagnetic interaction between the particles⁶. Experimental and theoretical work by Naomi Halas and Peter Nordlander at Rice University showed that silica–gold nanoshells offer enormous flexibility to tune the resonance frequency by varying the relative dimensions of the silica core and gold shell^{7,8}. In contrast to solid-core metallic nanoparticles, the resonance of a silica–gold nanoshell particle can easily be positioned in the ‘water window’ in the near-infrared (800–1,300 nm), where absorption by biomatter is low. Together with the high degree of biocompatibility of gold nanoshells, this result opens the door to a wide variety of biological applications.

Halas and West showed how near-infrared resonant nanoshells could be used to enable fast whole-blood immunoassays. For conventional blood immunoassays, optical tests are performed at visible wavelengths. Because a purification step needs to be

performed to separate out a variety of unwanted biomaterials that absorb visible light, the whole procedure can take several hours or days. In the immunoassay procedure proposed by Halas and West, nanoshells are conjugated with antibodies that act as recognition sites for a specific analyte. The analyte causes the formation of dimers (Fig. 1), which modify the plasmon-related absorption feature in a known way. The presence of analyte can then be determined by a fast absorption measurement in the water window, circumventing the time-intensive purification step.

Halas and West also showed how nanoshells can be incorporated into temperature-sensitive hydrogels to synthesize a new type of composite material that collapses on laser irradiation. Plasmon excitations are quickly damped, and the electron kinetic energy is converted into heat through electron-phonon interactions. This fast damping is usually undesirable, but here the efficient light-to-heat conversion in metallic nanoshells is used to shrink the volume of the hydrogel from a remote location. The absorption cross-section of a nanoshell is about a million times larger than that of a typical molecular chromophore, and hydrogel collapse thus occurs at relatively low pump-power densities. By incorporating nanoshells with different resonance frequencies, one can selectively collapse specific hydrogel volumes. Such remotely addressable hydrogels may find application in drug delivery and microfluidic valves or pumps.

Last but not least, it was speculated that nanoshells could play a role in future cancer treatments. These particles are small enough to find their way through the human circulatory system on injection. Bioactive molecules can be attached to the nanoshell surface to cause selective binding or accumulation of these particles within a tumour. Using a near-infrared laser, carcinoma tissue can then be destroyed by local thermal heating around the nanoshells.

As shown by the talks presented at the APS symposium, the design and fabrication of new types of plasmonic nanostructures has seen a flurry of activity. In particular, the unique properties of nanoshells promise a golden future for metallic nanostructures in biology. It will be fascinating to see what other applications arise in the near future.

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ACTUATOR MATERIALS

Towards smart artificial muscle

Intercalation of ions in vanadium oxide is a well-known process that causes this material to swell. Researchers have now used this mechanical deformation effect to build a vanadium oxide artificial muscle that is stronger than human skeletal muscle.

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Vanadium oxide, V_2O_5 , has been used for a long time as a catalyst. It is also known to exhibit a wide range of electronic or ionic properties and is already used to make microbatteries, electrochromic display devices and sensors. On page 316 of this issue, Gu and co-workers¹ show that sheets made of entangled vanadium oxide nanofibres behave like artificial muscles (actuators) that contract reversibly on applying an electrical signal. In conjunction with its many physical and chemical properties, the electrochemically driven deformation of vanadium oxide holds promise for the development of multifunctional devices.

Actuators are based on materials that change in shape and dimension when a potential is applied.

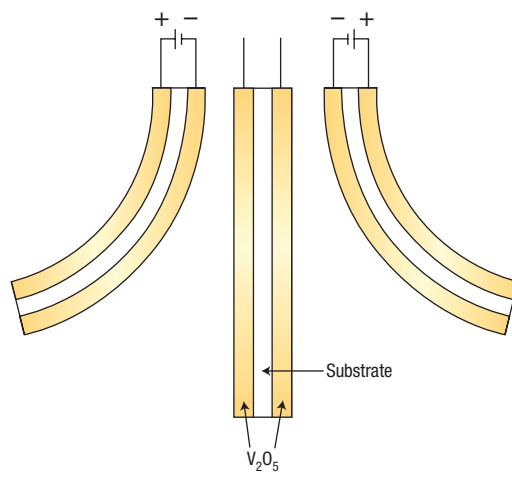


Figure 1 A cantilever actuator operating in an aqueous solution of $LiClO_4$. The actuator is made of two V_2O_5 sheets separated by double-sided scotch tape. Applying a voltage leads to the intercalation of Li^+ ions in the sheet connected to the anode and their de-intercalation in the sheet connected to the cathode. One layer then swells, while the other one shrinks, leading to the bending of the whole device.