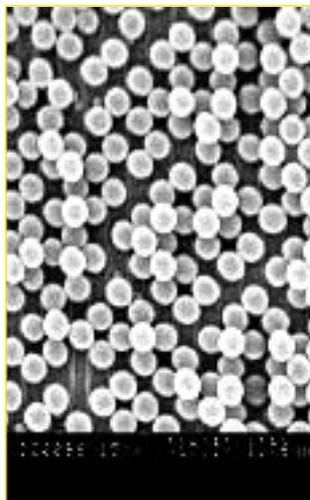


## Patterning photonics



Close-up of square lattice photonic crystal showing multi-layer deposition and propagation of the lattice through multiple layers. (Courtesy of Ted Sargent.)

Efforts to create photonic crystals without resorting to top-down lithography have problems reproducibly controlling the size and density of defects. Ordering monodispersed colloidal spheres

and then infiltrating high-refractive index materials is a particularly attractive option and has recently been shown to yield single-crystal structures when subject to confinement.

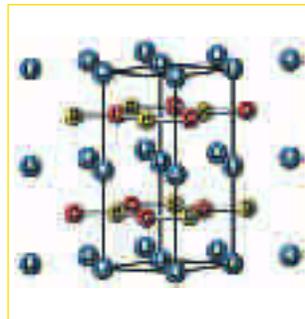
Researchers from the University of Toronto have now shown how confinement induces a transition from a disordered to a highly ordered state [*Adv. Mater.* (2002) **14** (3) 221-224].

By electrodepositing monodispersed charged colloidal spheres onto a substrate patterned with electroconductive grooves, the long-range order can be controlled. The planar pattern is on the scale of tens of microns, and so can be readily achieved by coarse lithography, laser micromachining or, as in this case, holography. Initially electrodeposition, driven by

coulombic interactions between the spheres and the electrode, and then electrohydrodynamic and capillary forces determine the organization of the colloidal particles. The density of packing and the number of deposited layers can be controlled by varying the time of deposition and the electric field strength, say the researchers.

Not only does the work provide a controlled growth method for large-scale colloidal crystals and a means for templating photonic crystals, but also a new way of studying confinement-induced order-disorder transitions in complex fluids. "Nature is still doing all the work in creating photonic crystals," explains Ted Sargent. "We're just politely asking it to do it in a particular location with a defined order and configuration."

## Class of MgB<sub>2</sub>



Crystal structure of LiBC. (Courtesy of University of California, Davis. © 2002 The American Physical Society.)

Physicists at the University of California, Davis, predict that lithium borocarbide (LiBC) could superconduct at temperatures up to 100 K [*Phys. Rev. B* (2002) **88** (12) 127001].

The material is usually insulating, but if LiBC is field-effect doped the researchers believe that it will become superconducting. Warren Pickett and his co-workers show that when LiBC is hole-doped the electron-phonon coupling effect, which gives rise to superconductivity in this type of material, is twice as strong compared with magnesium diboride (MgB<sub>2</sub>). This effect has already been shown to boost the superconductivity transition temperature of C<sub>60</sub>. If their predictions are right, LiBC could be the first of a new class of superconductors related to MgB<sub>2</sub>, but with a much higher operating temperature. "Hole-doped lithium borocarbide should be a terrific superconductor," says Pickett, "almost certainly better than magnesium diboride."

## Focus on the small and green

Delegates at the Spring Meeting of the American Chemical Society in Orlando, Florida, heard speakers from many areas of current chemical research covering a broad range of the disciplines. A number of presentations concerned control at the nanoscale. Andrew Lyon from the Georgia Institute of Technology announced a nanoparticle hydrogel he described as a 'photonic fluid'. The optical properties of the crystalline particles can be tuned by thermally controlling their water content. In other talks, John Margrave from

Rice University described the fluorination of polyfullerenes for subsequent formation of derivatized nanotubes and Erick Iezzi from Virginia Tech announced an organic derivative of a metallofullerene, possibly a step towards a drug delivery vehicle.

The conference also focused on 'green' chemistry and technologies. Two new processes for improving fuel cell performance were presented. Radoslav Adzic at Brookhaven National Laboratory reported on an electrocatalyst consisting of platinum deposited on

ruthenium crystalline particles that reduces carbon monoxide accumulation on the platinum. Chunsan Song at Penn State Energy Institute described a process that selectively absorbs organic sulfur and has potential for removing sulfur from fuels for fuel cells. Also, Mark McCleskey from the Los Alamos National Laboratory presented a method that uses supercritical carbon dioxide and water to remove hazardous metals from waste.

**For further information:**  
<http://chemistry.org>

## Defects in three-dimensions

Japanese researchers have found a new way of revealing defects in semiconductor crystals [*Optics Letters* (2002) **27** (5) 297-299].

The presence of defects in semiconductor crystals determines the quality and performance of devices. This is especially so for laser diodes based on ZnSe and GaN materials. Observation of photoluminescence is commonly used to detect these defects, but is limited in deep regions of the crystal. To get round this problem, Yoshimasa Kawata, Shigetoshi Kunieda, and Toru Kaneko at Shizuoka University have developed a two-photon process. Based on laser-scanning microscopy, the technique uses near-infrared light instead of blue to excite photoluminescence. The

excitation light is focused to a single point in the crystal and can propagate into deep regions. Since the two-photon luminescence is confined to the spot region, defects can be observed in three-dimensions by scanning the spot across the crystal. To demonstrate the capabilities of the technique, the researchers imaged defects in ZnSe, 200  $\mu\text{m}$  below the crystal surface with submicron resolution. Sequential imaging yields what the researchers believe is the first observation of the three-dimensional structure of defects by two-photon excitation. According to Kawata, work is now underway to observe defects in GaN and investigate how optical damage observed in crystals subject to laser power output above 250 mW arises.

## The theoretical blacksmith

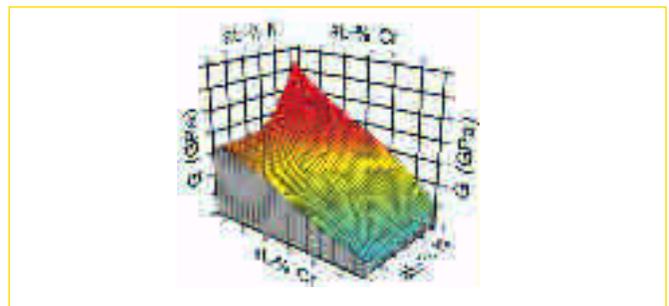
Understanding properties at the atomic scale is vital to the development of new materials. Despite the theoretical modeling and computer power devoted to alloy steels, a detailed description of these materials has remained elusive. The search for new alloy steels has relied on an empirical correlation of composition, manufacturing processes, and properties. Last year researchers at the Swedish Royal Institute of Technology and Uppsala University came up with a new approach to computational alloy theory [*Phys. Rev. Lett.* (2001) **87**, 156401]. Their method extends density

functional theory calculations from ordered structures to concentrated random alloys by implementing the coherent potential approximation (CPA) within the framework of the exact muffin tin orbitals (EMTO) theory. Börje Johansson and his colleagues have now applied their EMTO-CPA method to predict two new steel alloys with outstanding properties in terms of hardness and corrosion resistance [*Phys. Rev. Lett.* (2002) **88**, 155501]. The method combines the most efficient quantum level theories of random substitutional alloys with the most sophisticated numerical

## Shiny, coated insulators

A new metal-coating technique for insulating materials could have significant advantages over conventional methods. Existing electrochemical techniques to deposit metals from solution can be difficult to control *in situ* or require a conducting substrate. Now researchers at the École Polytechnique/CNRS and IUT de Chartres in France have developed an electroplating technique that overcomes these problems [*Nature* (2002) **416**, 716-719]. By exploiting the ability of a metal to grow progressively outward from an electrode over a substrate and choosing the growth conditions carefully, it is possible to coat insulating substrates. The resulting uniform metal coating has controlled grain size, thickness, and growth speed. The simple electrochemical cell

consists of a thin layer of electrolyte squeezed between two glass plates, one of which is to be metallized. An Au edge is deposited on the substrate that will act as the starting point for metallization. An anode at the other end of the cell also acts as a separator for the two plates. Key to the process is the fact that deposition starts at the Au edge and progressively coats the surface. The metal layer wets and adheres to the surface – allowing insulating materials to be coated. The researchers show examples of Ag and Cu on glass, and Cu on Teflon, and expect the technique to work on many metals. Coating fibers, ribbons, or organic materials could be possible, say the researchers. The only drawback of the new process is a slow coating rate.



Calculated shear modulus ( $G$ ) of austenitic stainless steel as a function of Cr and Ni percentage. Red corresponds to high  $G$ , yellow to intermediate, and blue to low.

techniques, says Johansson. It provides the 'quantum blacksmith' with a tool for computational alloy design. This means of obtaining a quantitative description of the electronic structure and physical properties of steels allows the creation of composition-elastic property maps. Mapping the elastic

properties of austenitic stainless steels as a function of chemical composition reveals the effect of alloying elements on properties and can be used to direct the search for new alloys. The researchers are now applying the method to ferritic and duplex steels, as well as nonferrous materials.

## Self-assembly made easy

Chemists at Harvard University have created cylindrical light-emitting diode (LED) displays by simply shaking LEDs and a patterned surface together. Their simple technique assembles micron-scale displays on non-planar surfaces within minutes [*Science* (2002) **296**, 323-325].

GaAs/GaAlAs LEDs of size 280 x 280 x 200  $\mu\text{m}$  with Au contacts are assembled on a patterned cylindrical substrate to give a well-defined array. This is achieved using a substrate with 280  $\mu\text{m}$  wide Cu squares coated in solder, which forms the bottom electrode for the display. By placing the LEDs and substrate together in water at 90°C and shaking, the LEDs assemble on the molten solder through their large Au anode. The assembly is driven by minimization of the

free surface energy of the liquid solder. Further agitation removes incorrectly attached components. The top electrode, which consists of solder-coated Cu wires on a transparent film, is introduced and fused to the Au LED cathodes, allowing the components to minimize the interfacial energy. By using solder-based assembly, the solder provides both the mechanical bond and the electrical connection. Any defects in the arrays are caused by imperfections in the components and not the assembly process. Having tested their displays by applying a potential of 2 V between the electrodes, the group are hopeful of fabricating more complex devices consisting of several types of components.

## Nanotubes left hanging

Siegmar Roth and colleagues at the Max-Planck-Institut in Stuttgart, Germany, have developed a general method for producing suspended nanofibers that does not involve either an etching process or chemical vapor deposition [*Appl. Phys. Lett.* (2002) **80** (10), 1815-1817]. The method starts with a Si/SiO<sub>2</sub> substrate with coordinate markers that is spin-coated with a poly(methylmethacrylate) PMMA layer. Onto this layer carbon nanotubes are deposited and mapped relative to the coordinate markers. A further two layers of PMMA are then added. Electron beam

(e-beam) lithography is used to expose defined sections of the nanotube, and Au/Pd is evaporated at an angle to embed the exposed areas of the nanotubes in metal. The PMMA layers are then removed by a lift-off process to leave a suspended nanofiber between two metal posts. The researchers imaged the suspended nanotube ropes using atomic force microscopy and obtained a Young's modulus of 0.4 TPa for the carbon nanotube from a force-displacement curve. The suspended fibers could find use both in research and applications, suggest the researchers.

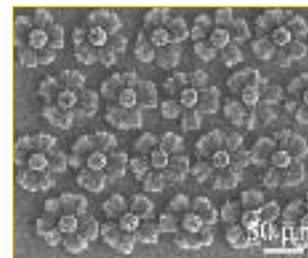
## Flexible hybrid solar cells

Researchers at the Lawrence Berkeley National Laboratory and the University of California, Berkeley, have combined nanorods with an organic polymer to give a hybrid solar cell that is cheap and easy to produce [*Science* (2002) **295**, 2425-2427]. The technology should allow the production of flexible solar cells suitable for coating any surface, even clothing for wearable electronics. Standard semiconductor photovoltaic cells have high efficiencies, but require expensive fabrication methods. Cheaper organic polymer cells have been investigated as an alternative, but typically have low solar power conversion efficiencies largely because of the low carrier mobilities. By combining inorganic semiconductor nanorods with an organic polymer,

Paul Alivisatos' group has overcome some of the charge transport problems. Using 7 x 60 nm CdSe nanorods, which form the electron transport material, combined with poly(3-hexylthiophene) (P3HT), an effective hole transporter, the solution is spin-cast onto a glass substrate. The diameter of the nanorod tunes the absorption spectrum of the solar cell, and its aspect ratio improves directional charge transport. They report initial solar efficiencies of 1.7% with the opportunity for further improvement. With interested companies already making approaches, Alivisatos says they have shown that "semiconductor nanorods can be used to fabricate readily processed and energy-efficient hybrid solar cells together with polymers."

## A beautiful nanotube

Researchers from Rensselaer Polytechnic Institute and Motorola can control nanotube growth in three-dimensions [*Nature* (2002) **416**, 495]. The patterns of multiply-orientated, organized carbon nanotubes are grown by a chemical-vapor deposition method on Si/SiO<sub>2</sub> substrates. The nanotubes grow preferentially on or normal to the SiO<sub>2</sub> and not at all on the Si. Lithographic patterning of the substrate provides a growth template – controlling sites of nucleation and direction of growth. Gas phase delivery of xylene/ferrocene metal catalyst makes the new



Patterns of carbon nanotubes. (Courtesy of P.M. Ajayan, Rensselaer Polytechnic Institute, and *Nature*.)

process both flexible and scalable.

"It's a simple and elegant process that provides unprecedented control over nanotube growth," says Pulickel Ajayan from Rensselaer. The implications are more wide-reaching, says Ganapathiraman Ramanath. "This is the first step toward making complex networks comprised of molecular units."

## A zoo of flexible ceramics

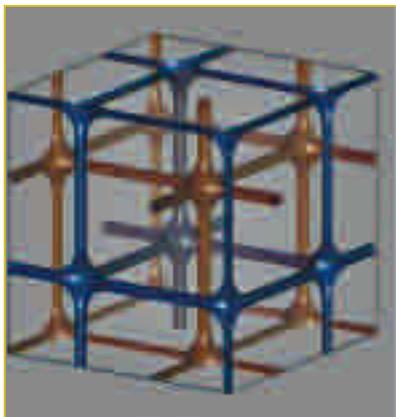


Diagram shows the molecular architecture of the flexible ceramic. (Courtesy of the Wiesner Research Group, Cornell University.)

A new class of hybrid – a flexible ceramic – has been developed by researchers at Cornell University in collaboration with the Max-Planck-Institut for Polymer Research. Reporting at the American Physical Society March Meeting, Ulrich Wiesner described the new material as "an exciting,

emerging research area offering enormous scientific and technological promise." Following the example of unicellular algae that form diatoms with perfectly replicated silica pores, the researchers used diblock copolymers, with an associated silica component, to self-assemble hybrid structures

## Harder than diamond

A team at the Lawrence Livermore National Laboratory has made the surprising discovery that osmium (Os) has a lower compressibility than diamond [*Phys. Rev. Lett.* (2002) **88** (13) 135701]. Compressibility, which is the reciprocal of the bulk modulus, is an indicator of a material's strength, chemical bonding, and electronic structure. The hardest known material – diamond – has a bulk modulus of 443 GPa, which translates to a compressibility of  $0.226 \text{ Mbar}^{-1}$ . However, Hyunchoe Cynn and co-workers' diamond-anvil cell compression studies of

5d transition metals reveal a bulk modulus of 462 GPa for Os at ambient conditions. First principles calculations based on the local density approximation (LDA) confirm that Os has the largest bulk modulus of the transition metals and is comparable to diamond. Although the theoretical bulk modulus of diamond comes out higher than Os, the researchers say that the difference is within the range of uncertainty in the LDA. This experimental measurement of the lowest compressibility yet in Os gives a new impetus to the search for superhard materials.

## Nano-strain

combining the flexibility of a polymer with the functionality of a ceramic. "The resulting material has properties that are not just the simple sum of polymer plus ceramic, but maybe something quite new," says Wiesner. In one form the material acts as an ion conductor and could serve as a battery electrolyte or in fuel cells. The cubic biocontinuous structure of the material has pores of 10-20 nm, which means it could also be used to separate proteins. "We can structure the material down to the nanoscale with unprecedented control," says Wiesner. "We now know how to make a suite of structures of assorted shapes and pore sizes. There is a good chance that we will find a whole zoo of other biocontinuous structures that people didn't know existed in polymers."

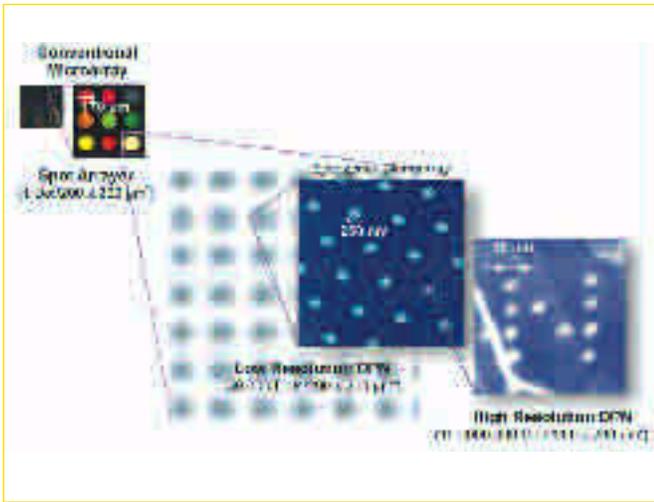
Nanocrystals of germanium on a silicon-on-insulator (SOI) substrates can act as nanomechanical stressors [*Nature* (2002) **416**, 498]. Researchers from the Universities of Utah and Wisconsin deposited ten monolayers of Ge onto an SOI substrate consisting of a thick Si layer, 400 nm  $\text{SiO}_2$  layer, and a 10 nm of crystalline Si. The resulting Ge nanocrystals (100 nm at base, 10 nm high) form in register with the crystalline Si and produce local bending of the Si layer. Calculations show that the bending depends on the nanocrystal density and shape – and can be suppressed on a thick substrate. The local stressor modifies both the mechanical and electronic properties of the Si layer and could allow band gap engineering on the nanoscale.

## Charge ordering revealed

For the first time, researchers from NEC Research Institute and Rutgers University claim to be able to link tunneling spectra with distinct phases at the atomic scale [*Nature* (2002) **416**, 518-521]. Gabriel Aeppli and co-workers used scanning tunneling microscopy (STM) to look at the manganite  $\text{Bi}_{1-x}\text{Ca}_x\text{MnO}_3$ . Transition metal perovskite oxides can exhibit exotic properties like high-temperature superconductivity or colossal magnetoresistance. These properties are associated with order-disorder transitions – which are hard to measure. STM, however, enables charge

ordering and phase separation to be resolved in real-time with atomic-scale resolution, say the researchers. By taking images and current-voltage spectroscopy data, the local metallic and insulating state can be correlated with structural order. Despite using very simple sample preparation (cleaning in ethanol), the researchers were able to find enough clean areas to routinely achieve atomic resolution. The technique demonstrates many of the phenomena associated with manganites such as charge ordering, and promises to reveal more about these unusual materials.

## Protein nanoarrays



Dip-pen nanolithography (DPN) generated nanoarrays. (Courtesy of Chad Mirkin.)

Researchers at Northwestern University and the University of Chicago have come up with a new technique for producing nanoarrays of proteins [*Science* (2002) **295**, 1702-1705]. Precise arrays of different proteins are extremely important in proteomics (the study of the entire protein library of cells and organisms, analogous to genomics, which

is the study of all genes) where screening for biologically relevant protein interactions is desirable. In a series of proof-of-principle experiments, the group not only show the production of ordered protein arrays, but screen for specific protein-protein interactions on the array using atomic force microscopy (AFM). Dip-pen nanolithography (DPN),

developed at Northwestern University, is used to pattern the nanoarrays. The technique uses an AFM tip coated with the molecules that are to be patterned on the surface. A solvent meniscus forms naturally between the AFM tip and the surface in air, which, Chad Mirkin explains, "provides a conduit for the delivery of the molecules to the surface." DPN is used to produce a grid of 16-mercaptohexadecanoic acid (MHA) features on an Au thin-film substrate. Features can be as small as 100 nm. The surrounding areas are then passivated, and the substrate immersed in a protein solution. The high affinity of proteins for MHA produces a precisely patterned protein array. The reaction of these arrays with solutions of different proteins can be observed using the AFM. The researchers do not observe non-specific binding of proteins to the array, which could produce

significant background signals on this nanoscale. However, binding of a protein to its specific antibody from a mixture of antibodies is observed as a large change in height profile. This interaction appears to be independent of the orientation of the protein absorbed on the array, showing activity is retained. The group goes on to show whole cell adhesion to arrays of a cell receptor. This technique holds great promise for the study of functional interactions between biological structures and proteins patterned on a surface. The advantages of DPN technology for producing protein arrays include, according to Mirkin, "making structures on a scale that was previously inaccessible, giving a much greater density of protein structures. This has led to the development of new screening methods as this is beyond the resolution of optical methods."

## What tangled webs we unweave

Spider dragline silk has a tensile strength comparable to steel and elasticity like rubber. The molecular organization of the individual silk proteins gives rise to these unique mechanical properties, but despite many structural studies is not yet fully understood. Researchers at the University of California, Santa Barbara, are using AFM and single-molecule force spectroscopy to unravel, literally, the structural organization of a recombinant spider silk protein [*PNAS Early*

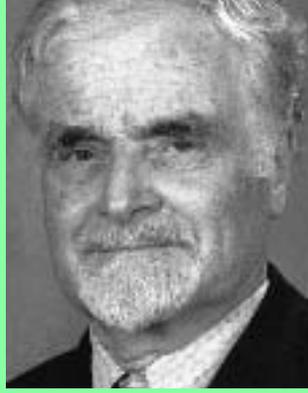
*Edition* 10.1073/pnas.082526499]. Spider dragline silk can be considered as a composite material consisting of a semi-amorphous matrix filled with nano-crystalline particles. Within the amino acid sequence of silk proteins, poly-alanine motifs organized in  $\beta$ -sheets (a standard protein fold) are thought to form the nano-crystalline particles. Glycine-rich sequences form the semi-amorphous matrix. In these studies, lead by

Helen G. Hansma, a recombinant protein consisting of repeated modules of poly-alanine and glycine-rich motifs was used. This protein has been shown to have similar properties to natural spider silk proteins. AFM of the synthetic silk protein reveals nanofiber aggregates. Each fiber also shows a regular segmented structure, with the size of each segment suggesting it contains 20-35 silk protein monomers. Such fiber formation has

important implications for the process of silk production. Pulling apart molecules in these fibers using single-molecule force microscopy shows a series of ruptures of protein modules. It appears that multiple repeated units may be released in one rupture event. The insight gained into the organization of these repeated modules should enhance the understanding of the remarkable mechanical properties of spider dragline silk.

## Cahn's Column

# Platinum in fuel cells



As hydrogen-fed fuel cells, especially the low-temperature designs using solid polymeric electrolytes, edge closer to widespread automotive use, every aspect of their design (and the design of their essential accessories) becomes vital. Small improvements in efficiency may make all the difference between failure and success. These include the formulation and manufacture of the electrolyte sheets, alternative ways of storing hydrogen fuel, keeping the cells cool, control procedures including hybrid systems with regenerative braking – and the essential electrocatalyst. This is the noble-metal powder adhering to both anode and cathode, which is essential to accelerate the kinetics of the electrode reactions and permit reasonably high current density at each electrode without too much loss of electric efficiency.

The best popular account I know of the genesis and development of automotive fuel cells is a book by Tom Koppel (*Powering the Future: The Ballard Fuel Cell and the Race to Change the World*, 1999, John Wiley & Sons). Here we learn that the Ballard Company, of Vancouver, Canada, which has an impressive lead in fuel cell technology, in 1994 entered into an agreement with Johnson Matthey, the British noble-metal company. The aim was to improve the platinum electrocatalyst, and within five years the required platinum loadings had been reduced by a factor of ten. This, in turn, converted a prohibitive cost into something that could be lived with. Koppel explains that the new approach substituted the layers of platinum black (already a very fine powder) with much smaller metal particles still, a very few nanometers in diameter, attached to fine pieces of carbon, which in turn were set in close contact with both electrodes – but the cathode is crucial. Use of platinum-ruthenium alloys also mitigates poisoning by CO impurity (unavoidable if hydrogen is made from a methanol precursor).

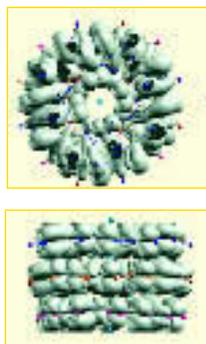
Two senior scientists at Johnson Matthey's research center, T.R. Ralph and M.P. Hogarth, have now published a very detailed paper (*Platinum Metals Review* [2002] **46**, pp. 3-14) that sets out research they have done in recent years to further improve the already highly efficient platinum-based electrocatalyst. There are indications that constantly increasing the surface area per unit mass (by making the platinum particles ever smaller) eventually becomes ineffective; it turns out that careful attention to cathode design, in particular, to enhance catalyst contact with both the hydrogen gas and the related ions, is more important. Extensive research has been done on alloys of platinum with solutes such as iron and chromium; the end-result is a further improvement of electrical efficiency by about 2% – which is undoubtedly significant.

Johnson Matthey is a firm with an unusually interesting history, going back to 1777 in London. John Johnson at that time made his fortune by refining large quantities of imported Brazilian gold, which was too brittle. It turned out that the brittleness was caused by an admixture with platinum group metals, so Johnson won plaudits both for refining the gold and for producing stocks of platinum and palladium. George Matthey joined the firm in 1838 and performed wonders in the production of malleable platinum and palladium, and even supplied Michael Faraday with these metals for his researches. The research-intensive story of the firm is stylishly retailed in a recent book (D.R.F. West and J.E. Harris, *Metals and the Royal Society* (1999) IOM Communications Ltd., London, pp. 64-68).

Robert W. Cahn,  
rwc12@cam.ac.uk

## A biomolecular semiconductor Making use of a virus

A helix composed of guanine molecules has electronic properties like those of a wide bandgap semiconductor, say researchers at the Università di Modena e Reggio Emilia and the CNR ISOF in Bologna, Italy. Results to be published in *Applied Physics Letters* (2002) suggest these helices could be useful as biomolecular nanowires. Guanine (G) molecules can form a number of self-



Top (top) and side (bottom) views of a HOMO isosurface for the G-quartet helix. (Courtesy of Arrigo Calzolari.)

assembled structures. One particular planar structure called a G-quartet is formed from four hydrogen-bonded G molecules arranged in a square. Many of these G-quartets can stack on top of each other to form a stable helix with a central channel. This channel accommodates monovalent ions that are located between the tetramer layers, coordinating carbonyl groups in the G molecules. The researchers show that these extended structures are stable in the presence of potassium ions. Calculation of the electronic properties of the G helices show a band structure comparable to wide bandgap semiconductors, with a gap of 3.5 eV. These long helical structures can, therefore, be considered as nanowires and may have potential in molecular electronics.

Researchers at the University of Basel have developed a way of packaging DNA into a polymeric nanocontainer [*PNAS Early Edition* 10.1073/pnas.062654499]. The DNA-loaded particles could have potential applications in gene therapy through targeted delivery of DNA to specific tissues.

The group, headed by Wolfgang Meier, used an ABA-triblock copolymer that spontaneously forms vesicles in water. These polymer shells prove to be more stable than conventional lipid vesicles. Further stabilization is achieved by including end groups that can be polymerized once assembled in the vesicle.

The researchers were able to introduce a bacterial transmembrane protein, LamB from *Shigella sonnei*, into the self-assembled structure and show that it retains biological

activity. LamB serves as a receptor for the  $\lambda$  bacteriophage, a virus that infects bacteria by 'injecting' its DNA genome into the host bacterial cell. By including this receptor in the polymeric vesicle, the  $\lambda$  bacteriophage is able to bind and inject its DNA into the artificial shells. Electron microscopy reveals the formation of bacteriophage-polymer vesicle complexes. The transfer of DNA was observed in solution by labeling the DNA with a fluorescent dye. This neat use of a viral system to package DNA inside a polymer container could be used as a model system to understand transport of foreign genes into cells. By optimizing the block copolymer chemistry of the biocompatible particles, the shells may also find applications in drug delivery and gene therapy.

## Ordered nanoparticles separate DNA fragments

Separation of large DNA fragments has been, until now, a slow process. However, scientists at the Institut Curie and Ecole Supérieure de Physique et de Chimie Industrielles (ESPCI) in France have developed an original approach using self-organizing nanospheres to separate large DNA molecules in a matter of minutes. Their technology, called Ephesia and described in *Science* [(2002) **295**, 2237], has potential applications in separating or identifying many biomolecules in biochemistry and medical diagnostics.

The device, developed by Jean-Louis Viovy at the Institut Curie and Jérôme Bibette at the ESPCI, makes use of low-cost silicone rubber wafers 4 cm in diameter, into which microchannels have been molded. An aqueous suspension of magnetic nanospheres is injected into a channel in the absence of a magnetic field. By then applying a field, the particles form ordered columns in the microchannel, giving an obstacle course for the separation of DNA. So far, they have reproducibly separated DNA in the size range

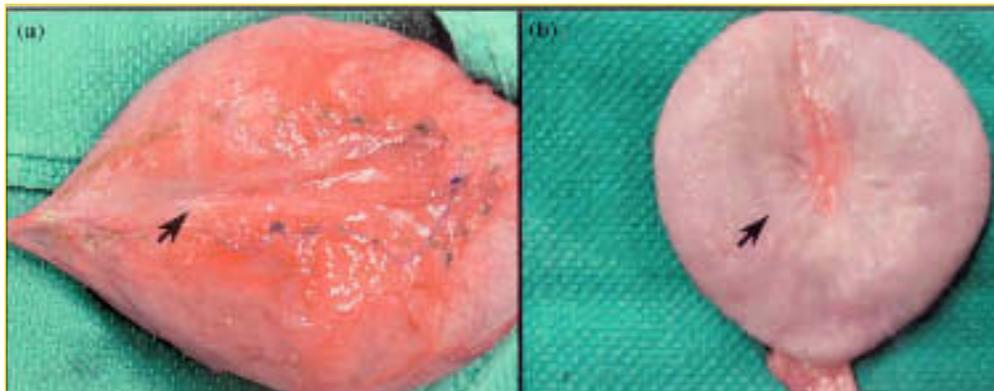
10-200 kbp. There are many advantages of this technique over previous separation methods. These include the speed of separation, Ephesia's size, which lends itself to lab-on-a-chip technologies, and the possibility of replacing the magnetic particles in between runs to avoid contamination. The separation of large DNA fragments is increasingly important in searching vast DNA libraries resulting from genomics projects. The device could also be developed to rapidly detect specific molecules or cell types in samples, for example residual

cancer cells that have survived an initial treatment.



Introduction of the liquid containing magnetic nanospheres into a microchannel in a silicone rubber wafer. (Courtesy of the Institut Curie.)

## Bladder augmentation material



Explanted bladder at 22 weeks. Arrows show scar at centre of BAMA. (a) Serosal view and (b) luminal view. [Reproduced with permission from *Biomaterials* (2002) **23**, p. 2182.]

A wide range of urological problems result in the need for bladder augmentation or substitution. Although various synthetic and natural materials have been evaluated both in the lab and the clinic, the success of these technologies has been limited. Many synthetic devices fail as a consequence of complications associated with infection,

calculus formation, inadequate healing, and graft contracture. Previous studies involving the reconstruction of porcine bladder with bladder acellular matrix allograft (BAMA) provided promising results in relation to graft shrinkage and cellular repopulation at 12 weeks [Reddy, P. P., *et al. J. Urol.* (2000) **164**, 936-941].

In an attempt to evaluate the long-term performance of BAMA, Brown and co-workers have undertaken an extended 22 week study of the use of BAMA for bladder augmentation in a porcine model [*Biomaterials* (2002) **23**, 2179-2190]. Although the peripheral regions of the grafts become extensively repopulated with cells, the centers of the

grafts are devoid of organized smooth muscle tissue and developed urothelium. In addition, histological examination of the center of the tissue shows significant fibrosis caused by alterations in the amount and organization of collagen fibers. This is reflected in the rupture strain and elastic modulus of the BAMA region compared with the native bladder tissue and the contraction of the BAMA (as shown).

The molecular mechanisms by which stomal, epithelial, and extracellular components interact to form a functional bladder have yet to be fully elucidated. Given the results of this and previous studies, it seems likely that the elucidation of these mechanisms will form an essential component of the future development of novel functional bladder materials.

## Enhancing biointegration

Although various materials have been developed in recent years with enhanced mechanical properties, the use of these materials in certain biological applications is often limited by poor tissue integration. In particular, the use of carbon composites as prostheses can be limited by poor osteointegration. However, Fu and co-workers show that this can be overcome through the use of titanium oxide coatings (TiO) [*J. Inorgan. Mater.* (2002) **17**, 189-192]. The researchers deposited a layer of TiO onto

carbon/carbon composites using ion beam enhanced deposition. To increase the surface area through the generation of a microporous structure, the researchers alkali-treated the TiO layer. Incubation of this porous coated substrate in simulated body fluid leads to the formation of biological apatite. This technique will undoubtedly have application in improving the osteointegration of other novel substrates enhancing the spectrum of materials which may be employed in prosthetic devices in the future.

## Polyimide biocompatibility

Low surface energy fluorinated materials have previously been shown to have improved haemocompatibility over other materials used in blood contacting applications such as membrane-oxygenators and hollow fibre dialyzers. In a recent publication, Kanno and co-workers describe an investigation into the biocompatibility of fluorinated polyimide membranes [*J. Biomed. Mater. Res.* (2002) **60**, 53-60]. The researchers investigated protein adsorption, neutrophil adhesion, and complement activation *in vitro* under static conditions.

These studies demonstrate that the biocompatibility of this material is critically dependent on the curing temperature, suggesting that surface rearrangement occurs on curing, reducing the surface free energy which leads to reduced protein adsorption, neutrophil adhesion, and complement activation. This material also performs better than polystyrene or polydimethylsiloxane in these assays, suggesting that this material may have potential use in a wide range of blood contacting applications.

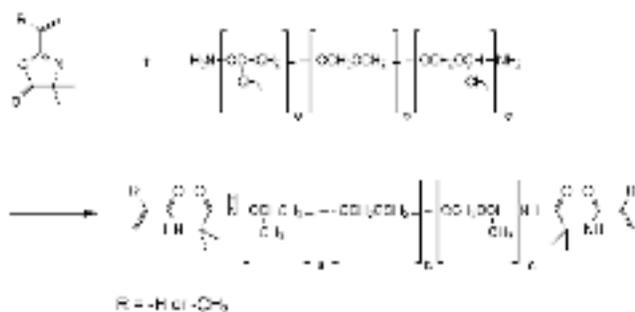
With the growth in the aged population and the need to extend average individual healthspan, biomaterials have an increasingly important role in the development of new generation medical devices, drug delivery systems, and medical diagnostic technologies. This column seeks to provide an insight into the latest developments in biomedical materials and related technologies through brief synopses and expert commentaries of recent presentations, publications, and patents. Andrew Lloyd, University of Brighton.

## Macromonomer synthesis

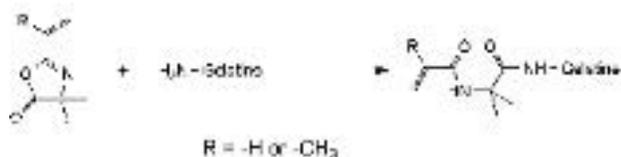
The wider application of biomaterials has led to the need for novel synthetic and semi-synthetic polymers that form stable hydrogels under physiological conditions. Zimmermann and co-workers [*Biomaterials* (2002) **23**, 2127-2134] report the use of azlactones for the preparation of (meth)acrylamido-peptide macromonomers for the synthesis of hydrogel supports for *in vitro* cell growth. The macromonomers are prepared by the conversion of terminal amines of  $\alpha,\omega$ -bisaminopropyl-terminated poly(ethylene glycol) (PEG) and gelatine with vinyl-functionalized azlactones at room temperature, under physiological conditions (Schemes 1 and 2).

Copolymerization of these macromonomers results in the formation of novel hydrogel networks. As expected, the compression modulus is proportional to the equilibrium water content, which is in turn controlled primarily by the PEG concentration. A comparison of human fibroblast adhesion to hydrogels prepared with and without the gelatine macromonomer demonstrates that its incorporation improves cell adhesion and spreading. No cytotoxicity is observed for any of the hydrogel systems. This approach, therefore, offers a useful means of preparing macromonomers under mild conditions for the tailoring of hydrogels for tissue engineering applications.

Scheme 1



Scheme 2



## Novel elastic biomaterial

There is increasing interest in the molecular basis of elastic properties of natural materials to allow the development of biomimetic materials for tissue replacement. Rapoport and Shadwick report an interesting study of the elastic properties of the egg capsules of marine snails [*Biomacromolecules* (2002) **3**, 42-50].

The researchers examined the acellular structural protein, which comprises the capsule, to understand the molecular basis for the protective function of this material. The protein demonstrates long-range elasticity with an unusual recoverable yield associated

with a significant decrease in elastic modulus above 3-5% strain. This protein, therefore, differs significantly from other structural proteins such as collagen and elastin. The data suggest that this protein may have a similar structural organization to that of keratin and, the researchers suggest, may be related to vertebral keratins such as intermediate filaments. The bimodal tensile properties of this material may, therefore, be potentially useful for tissue replacement. Further work on the biological properties of this protein should provide insight into other potential applications.

## Coatings for prostheses

Pluripotent bone marrow associated human mesenchymal stem cells play an important role in the regeneration of tissues such as cartilage, bone, muscle, ligament, and stroma. The use of these cells in tissue engineering is, however, limited by the need to support the appropriate differentiation of the cell on support materials. Thin films of titanium nitride (TiN) provide both corrosion and wear resistance when coated onto metallic substrates and may, therefore, have application in the coating of hip and knee prostheses. These materials' electrical properties could enable electromagnetic stimulation of cell differentiation. Manso-Silvan and co-workers have investigated the

development of human mesenchymal stem cells on TiN thin films [*J. Mat. Sci.: Mater. in Med.* (2002) **13**, 289-293]. The 1  $\mu\text{m}$  films were prepared by DC magnetron sputtering Si. Examination of adhesion and proliferation of the human mesenchymal stem cells, isolated from adult bone marrow, on the TiN films show a larger number of cells adhering to the TiN films compared with standard TiAlV substrates. This, combined with the electrical properties of TiN, offers the potential to stimulate *in vitro* differentiation of cells into functional osteoblasts using electrical pulses. Such a cellular pre-treatment could enhance bone-substrate integration at early stages of device implantation.