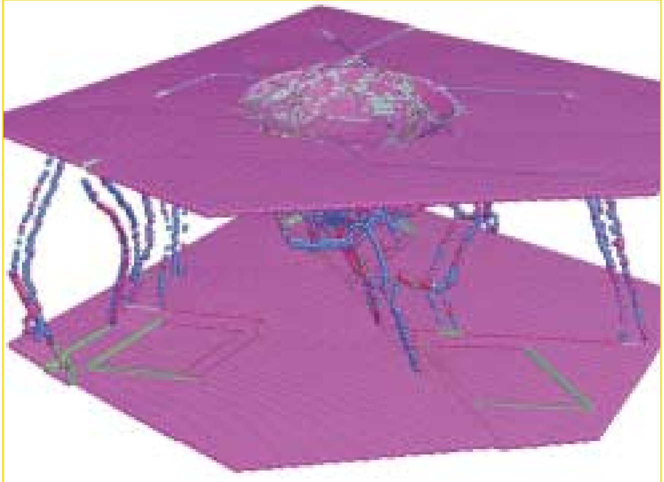
Surprising behavior in aluminum

MODELING



This image, created by AtomicEye software, simulates the result of a nanoindentation experiment on a thin slice of Cu. The crater represents the indentation formed by the diamond tip. To simplify the view, Li only made visible the Cu atoms that were dislocated during the experiment, unaffected atoms are invisible. (Courtesy of Ju Li, Ohio State University.)

New theoretical calculations indicate that Al may behave more like a ceramic or semiconductor than a metal under certain conditions [*Science* (2002) 298, 807-811].

Even though the minimum shear stress required to produce deformation in an imperfection-free material is central to materials science, it is not generally feasible to measure the ideal shear strength of crystals. Ju Li from Ohio State University, along with coworkers Shigenobu Ogata at Osaka University and Sidney Yip at Massachusetts Institute of Technology, used first-principles calculations to investigate Al on an atomic scale. With density functional theory (DFT) calculations, the researchers modeled the behavior of one-atom thick layers of Al and Cu under shear strain. Contrary to previous work, they found that Al has an ideal pure shear strength 32% higher than Cu. "These are pretty shocking conclusions," says Li. "We know Cu is three times heavier than Al and significantly stiffer than Al under normal conditions. But when we looked at large shear strains, Al won hands down. Cu started out stiffer, but it softened much earlier than Al."

To explain their surprising findings, the researchers looked at the electronic structure of the metals. In Cu under shear strain, layers of atoms slide over each other horizontally. But in Al under the same conditions, the atoms tend to 'hop' rather than slide. The reason for this difference in behavior could be that Al has 'directional bonding' like Si or SiC. The hinged-rod-like nature of Al bonds means that the material can endure much larger shear strains than Cu, which has isotropic 'sphere-in-glue' bonding, before beginning to soften. "You wouldn't expect to find significant directional bonding in a metal like Al," says Li. "This could mean that Al behaves more like ceramics in certain ways than anyone previously thought."

These new findings could also explain the puzzle of abnormal intrinsic stacking fault energy in Al. "From what we've seen, the high strength that Al shows under uniform shear strain and its abnormal intrinsic stacking fault energy may be two sides of the same coin," explains Li. Intriguingly, it seems that Al may not be alone in its surprising behavior. Recent results show similar behavior in Ni, albeit to a lesser degree. "It's as if Ni occupies a spot on a spectrum halfway between Al and Cu," says Li.

A better understanding of the behavior of metals at the atomic scale could be profoundly important for nanotechnology. Accurate interpretation of nanoindentation studies will require a closer look at what is going on at the atomic level. As Li explains, "There are some approximations that make the calculations easier. Now it seems those approximations will likely give the wrong interpretation for Al and Cu."

Nano-approach unites strength and ductility

METALLURGY

Combining the opposing characteristics of strength and ductility in a material is a tricky business, but researchers from The Johns Hopkins University have done just that. A novel thermomechanical treatment of Cu results in extraordinarily high ductility, while retaining strength [*Nature* (2002) **419**, 912-915]. "We were able to get the strength of the pure Cu up to and beyond that of Cu alloys without adding any other metals to it and without sacrificing ductility," says En Ma.

The process starts with the rolling of commercial grade Cu at liquid nitrogen temperatures. The plastic deformation produced by the rolling creates a dense network of dislocations, which are prevented from moving by the low temperatures. A further heat treatment at around 450 K starts a recrystallization process. "New, ultra fine crystal grains form that are almost dislocation-free," explains Yinmin Wang. "The higher the stored dislocation density after rolling, the finer the re-crystallized grains during heating." Careful control of the temperature allows 20-25% of the crystals to undergo abnormal grain growth. This results in a final 'bimodal distribution' of larger grains embedded in a matrix of nanocrystalline material (<300 nm). The nanoscale grains block the movement of dislocations, improving strength, while the larger grains stabilize the tensile deformation. "A real significance of this project was that we showed what traditional metallurgical processing can do in a new era of nanotechnology," says Wang. "Our work demonstrates that extraordinary properties can be derived from a nanostructured material by first creating and then tailoring the ultrafine grain structures," adds Ma. One advantage of this simple process is that it does not introduce porosity or contamination, unlike the creation of nanomaterials by compacting powders. The researchers believe that the treatment could be successfully applied to other metals as, such as Ni. These strong and tough pure metals could be ideal for microelectromechanical systems or biomedical devices.

Understanding transformation

METALLURGY

The properties of steel depend upon the microstructure, produced by austenite decomposition during processing. Although this phase transformation is one of the most studied, the mechanism is not fully understood and models are largely empirical. A team of European researchers has come up with a new way to investigate the kinetics of phase transformations in steel using X-ray diffraction at a synchrotron source [*Science* (2002) **298**, 1003-1005].

The *in situ* technique allows a new insight into the nucleation and growth of ferrite grains in bulk steel, which govern the kinetics of phase transformations during processing.

High energy X-rays provide information about individual grains in a bulk material because the intensity of each resulting diffraction spot is proportional to the grain volume. The researchers recorded diffraction spots sequentially to build up a picture of grain nucleation and growth over time. The number of diffraction spots indicates the number of ferrite grains as a function of temperature. One of the most striking results, say the researchers, is that the maximum nucleation rate occurred at a higher temperature than predicted by classical theory.

The researchers were also surprised to find that the activation energy of ferrite nucleation is at least two orders of magnitude lower than previously predicted. Although the results confirm the classical picture of diffusional growth, the new technique also reveals three other, more complex growth regimes that were previously unknown.

Current models of phase transformation kinetics in polycrystalline materials are not accurate, conclude the researchers, and should incorporate the interactions between neighboring grains.

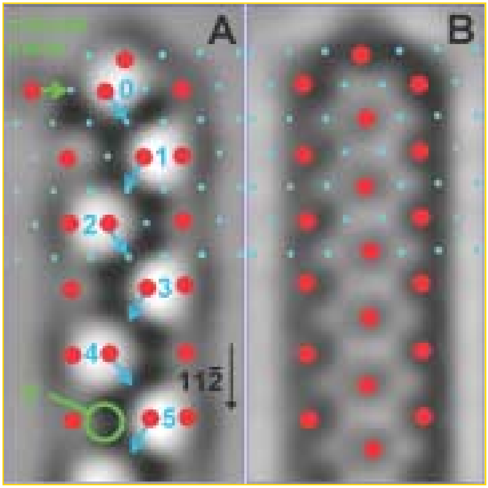
Playing dominoes with molecules

MOLECULAR ELECTRONICS

Researchers at IBM's Almaden Research Center have developed a simple computation scheme based on molecular cascades [*Science* (2002) 298, 1381-1387].

Molecular cascades are atomically precise arrangements of molecules where the motion of one causes subsequent motion, like a row of toppling dominoes. The IBM researchers constructed staggered chains of carbon monoxide (CO) dimers on a Cu(111) surface with a low temperature scanning tunneling microscope (STM). A nudge with the STM tip forms a bent-line configuration of molecules (or 'chevron') which decays after a few seconds to form another and so on in a cascade. Each time the molecule hops to a new site on the surface the energy of the system is lowered, driving the cascade forward.

Investigating the effect of temperature and local environment on the hopping rate reveals that below 6 K the motion is due to quantum tunneling between neighboring binding sites on the surface. This rate can be engineered by controlling hopping direction and interaction with neighboring molecules. Above this temperature, thermally activated hopping is observed, which the researchers attribute to tunneling of the CO molecule from a vibrationally excited state.



A linked-chevron cascade shown in STM. (a) Manual move with the STM tip of a CO molecules starts the cascade. The cascade proceeds one hop at a time until all the chevrons have decayed (b). (© AAAS 2002.)

Intriguing though this might be, the researchers also suggest that molecular cascades could be used for the one-time transition of single bits of information from one location to another. They go a step further and create simple AND and OR logic gates. Though these may be exceedingly slow, the size of molecular cascade devices warrants further investigation, say the researchers.

Mind the surface

MECHANICAL PROPERTIES

Surface roughness could be the key to the mechanical failure of polysilicon devices, such as microelectromechanical systems (MEMS), according to new findings [*Science* (2002) **298**, 1215-1218]. "Over the past few years there has been a debate about the roles that moisture and mechanical stress play in the fatigue failure of polysilicon devices," explains Roberto Ballarini of Case Western Reserve University. The researchers looked at various failure scenarios, including stress corrosion cracking. "This failure mechanism is associated with the propagation of a sharp crack under an applied stress too low for immediate catastrophic failure and in the presence of a corrosive environment like humid air." But, says Ballarini, "Our research shows that polysilicon under constant stress is not susceptible to stress corrosion."

Instead, the researchers found that the fatigue strength of polysilicon is strongly affected by the ratio of compression to tension experienced during each cycle. They suggest that surface roughness, such as asperities and microcracking (although the latter was not actually observed), is the root cause. Under compressive loading the surfaces come into contact and the 'wedging' action of surface ridges generates microcracks. These propagate and grow during subsequent tension and compression cycles. "The microcracks extend from the surface into the miniaturized structures, weakening the material and causing failure," explains Arthur Heuer. Ambient conditions can, however, exacerbate the process for high-cycle fatigue conditions. Air could cause the thickening of surface oxide on asperities or cracks, leading to additional wedging and crack extension during compression. "The research," says Heuer, "tells us to be mindful of the manner in which we create the surfaces of polysilicon chips so that devices that experience significant mechanical stresses like gyroscopes and optical devices can be rendered less susceptible to fatigue failure."

Molecular insulation

POLYMERS

A team of European researchers have devised molecularly insulated polymer chains with better light-emitting properties [*Nature Materials* (2002) **1**, 160-164].

By threading α- or β-cyclodextrines (six or seven glucose rings) onto semiconducting polymers such as poly-para-phenylene (PPP) or poly(4,4'-diphenylenevinylene) (PDV) like beads on a string with stoppers to prevent unraveling, intermolecular interactions are reduced. The molecularly insulated polymer chains retain fundamental semiconducting properties, but show improved stability and light-emitting efficiency. By insulating the polymers, the molecules are kept at a fixed minimum separation, which avoids the problems of aggregation or concentration quenching. Encapsulation of the active groups increases the molecule's stability and makes it more resistant to impurity quenching. This is good news for polymer light-emitting devices, because intermolecular interactions red-shift and partially quench luminescence. The researchers observed a greater blue-shift of the photoluminescence spectrum from β-CD threaded onto PVD cores, and in general saw a higher photoluminescent efficiency in the rotoxinated forms.

Using the insulated polymers, the researchers constructed standard light-emitting diodes (LEDs), which although not optimized for operation clearly show the advantages of the new supramolecular architecture. Device architectures with more advanced charge-injection schemes could have electroluminescent efficiencies at least two orders of magnitude better. A final benefit is that the insulated polymers are more soluble in water – enabling spin-coating without toxic solvents and paving the way for biocompatible processes and structures.

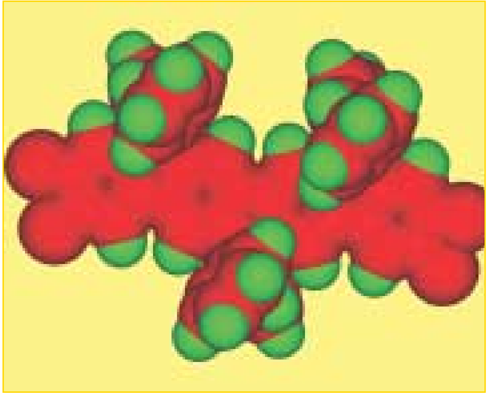
Dark states of light

POLYMERS

A German-Austrian group of researchers has found a way to improve the light efficiency of conjugated polymers [*Phys. Rev. Lett.* (2002) 89 (16), 167401].

The potential of conjugated polymers for optoelectronic applications is starting to be realized, but the role of triplet excitons remains a puzzle. When charge carriers are injected into a light-emitting diode (LED), excitons form in either the singlet or triplet state. In the absence of triplet-harvesting dyes, only singlet excitons contribute to the visible luminescence. "The accumulation of long-lived triplet states is a well known problem with organic dye lasers, which find many applications in research and industry," explains John Lupton from the Max Planck Institute for Polymer Research. Instead of producing light, the triplet 'dark' states generate heat, reducing the efficiency and stability of LEDs.

Lupton worked with Ullrich Scherf from the Universität Potsdam, who synthesized the polymer, and Emil List at Graz University of Technology on the phosphorescence measurements, as well as collaborators from the Institute of Nanostructured Materials and Photonics in Weiz. They found that covalently bonding a few metal atoms to the polymer backbone overcomes the problem.



Chemical structure of the polymer. The backbone is structured in the shape of a ladder which is substituted with phenyl rings on the side. (Courtesy of John Lupton.)

A concentration of only 80 ppm of Pd atoms is sufficient to enable luminescence from the dark states. This is the first time that electrically-induced phosphorescence has been observed in a common conjugated polymer, poly(para-phenylene), at room temperature, say the researchers. The trace metal atoms have no effect on the material's electronic or structural properties either.

"Using conjugated polymers we can create tiny solid state lasers, which can now be improved by controlling the troublesome triplet excitations," says Lupton. "This could be an important step forward for designing organic laser diodes." The findings could also, say the researchers, provide a novel tool to study the intrinsic properties of triplet excitations in conjugated polymers.

Fast rate control

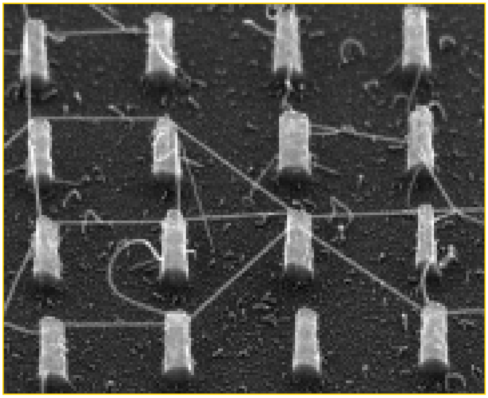
POLYMERS

The most efficient way to transport large amounts of data is by infrared light through optical fibers. Research is under way to increase optical bandwidth to accommodate growing traffic, but many challenges remain including the encoding of electronic signals onto a lightwave carrier by modulating light at very fast rates. An electro-optic (E-O) moderator, where a signal voltage changes the refractive index of a dielectric optical waveguide to modulate the phase of a guided lightwave, is generally used for this purpose. Lithium niobate is the most widely used E-O material, but its response deteriorates because of the resistance of the voltage guide electrodes, absorption by the optical waveguide dielectric, and velocity mismatch between the signal and carrier waves.

In recent years, interest has focused on polymeric materials and now researchers from Lucent Technologies' Bell Labs may have come up with an optimum combination [*Science* (2002) **298**, 1401-1403]. By choosing polymers carefully, the researchers almost entirely eliminate the factors leading to response decay at high frequencies. The modulator consists of commercially-available chromophore disperse red-1 (DR1) in a PMMA host as the optical core, sandwiched between glass resin cladding layers. A ridge optical waveguide is etched into the core and an Au microstrip guides the voltage modulation signal. The device modulates light with a bandwidth of 150-200 GHz, and has a detectable signal at 1.6 THz. This broad bandwidth operation, coupled with low voltage operation and cheap fabrication, could be ideal for next-generation optical communications.

Nanotube suspension bridge

NANOTECHNOLOGY



Scanning electron micrograph of carbon nanotubes suspended from Si pillars, grown using a Fe thin film catalyst. Pt was deposited to highlight the nanotubes. (© AIP 2002.)

Like thousands of tiny suspension bridges, researchers from NTT Basic Research Laboratories and Tokai University in Japan have grown networks of nanotubes between Si pillars [*Appl. Phys. Lett.* (2002), 81 (12), 2261-2263].

Yoshikazu Homma and his coworkers prepared a patterned Si substrate using synchrotron-radiation lithography. A thin film of Fe or Co was deposited on top of the Si pillars to catalyze the growth of single-walled carbon nanotubes (SWNTs) using chemical vapor deposition with methane. “A very interesting thing,” says Homma, “is that nanotubes originated from the pillar top tend to form suspended bridges between pillars.” More than 80% of these suspended nanotubes show nearest-neighbor connections when the pillar spacing is comparable to the pillar height.

These self-assembled nanotube networks could be used as interconnections for nanoscale devices, say the researchers. “By utilizing the self-assembly of nanotube networks, we are hoping that without using lithography we would obtain interconnection,” explains Homma. Nano-probes could be used to send electrical currents along the nanotube networks, and analyze their properties.

“If we achieve control of the nanotube properties through the control of chirality and diameter, we could fabricate nanotube device networks, which would be applicable to an artificial neural network,” adds Homma. Photonic applications could also be attractive, suggest the researchers.

Gaining on silicon devices

MOLECULAR ELECTRONICS

As Si devices scale down in size, high-κ dielectrics to replace SiO_2 have become vital to provide high capacitance without the disadvantages of ultra-thin films. But with the limits of Si technology in sight, molecular electronics is attracting interest as an alternative strategy. Researchers from Stanford, Cornell, and Purdue Universities, led by Hongjie Dai, have combined these two technologies in a carbon nanotube transistor with a high-κ dielectric layer [*Nature Materials* (2002) doi:10.1038/nmat769].

The field-effect transistors (FETs) consist of individual, semiconducting single-walled nanotubes (SWNTs) bridging metal source (S) and drain (D) electrodes on SiO_2/Si substrates. A thin film of ZrO_2 is formed on top of the SWNT-FET by atomic-layer deposition (ALD), followed by patterning of local top-gates. The ALD process produces layers of ZrO_2 with excellent crystallinity and is benign to carbon nanotubes. Electrical transport measurements on more than 30 devices, taken from different production batches, reveal that ZrO_2/SWNT-FETs have properties approaching – and sometimes exceeding – those of Si. *P*-type transistors show subthreshold swings, of S ~70 mV per decade, which approaches the theoretical limit for FETs. A key parameter in miniaturization, a low value of S is central to low threshold voltage and low power operation. Transconductance and carrier mobility reach 6000 Sm^{-1} and 3000 $cm^2V^{-1}s^{-1}$, respectively, higher than *p*-type crystalline Si by a factor of ten for transconductance and eight for carrier mobility. While the values are somewhat less for *n*-type transistors (S ~90-100 mV per decade, 600 Sm^{-1}, and 1000 $cm^2V^{-1}s^{-1}$) these values still far exceed previous devices.

Using the *p*- and *n*-type FETs, Dai and his coworkers constructed a NOT logic gate, or inverter, which shows a voltage gain of up to 60. This is the highest gain ever achieved with organic materials, including SWNT and conjugated organic materials, say the researchers. This approach combining the electronic properties of molecular materials with advanced gate dielectrics could open a new route towards advanced, miniature FETs.

Getting a better image

NANOTECHNOLOGY

Carbon nanotubes are known to have potential as electron-beam sources. But now a team from Philips Research Laboratories in Eindhoven, the Ecole Supérieure de Physique et de Chimie Industrielles de la ville de Paris, and Leiden Institute of Physics shows that carbon nanotube-based sources are ten times better than state-of-the-art sources for electron microscopes [*Nature* (2002) **420**, 393-395].

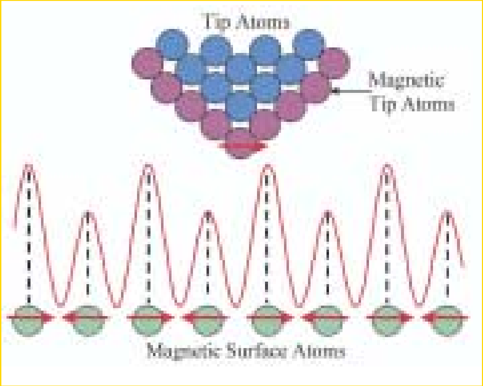
Reduced brightness, which depends on the angular current density and virtual source size, and the energy spread of emitted electrons determine the resolution of electron-beam instruments. Compared with Schottky emitters and cold field-emission guns, which have reduced brightness values of 10^7 to $2x10^8$ A $sr^{-1}m^{-2}V^{-1}$, the carbon nanotube electron emitter shows values greater by at least a factor of ten. Although atomically sharp emitters have reduced brightness values that are higher than those of nanotube emitters, they have very short lifetimes.

Consisting of individual multi-walled nanotubes (MWNTs) mounted on tungsten tips, the devices emit a single narrow beam. A small bundle of MWNTs shows the same result as individual nanotubes. The energy spread of the electron beam is 0.3 eV, which is smaller than that of a Schottky emitter and comparable to a cold field-emission gun.

Niels de Jonge and his coworkers believe that carbon nanotube sources could significantly improve the performance of high-resolution electron-beam instruments. Carbon nanotubes electron sources could benefit both the spot size and electron current that determine spatial resolution and the time to form an image, respectively, in probe-forming, electron-beam instruments.

Profile of spin-polarization

MICROSCOPY



A schematic representation of the SP-STM set-up used to image the magnetic transition metal nitride. (Courtesy of Arthur Smith.)

Researchers at Ohio and Case Western Reserve Universities have used a spin-polarized scanning tunneling microscope (SP-STM) to reveal a surprising amount about the unique structure of $Mn_3N_2(010)$, a magnetic transition metal nitride [*Phys. Rev. Lett.* (2002) 89 (22), 226101].

Although SP-STM has been demonstrated as a powerful spin imaging technique, it was thought that no chemical contrast could be viewed in constant current (CC) mode. Arthur R. Smith and colleagues, however, show that magnetic and nonmagnetic atomic-scale information can be obtained simultaneously. Working in ultra-high vacuum (UHV) conditions and at 300 K, the researchers found that the surface spin structure is manifested as a modulation of the normal atomic row height profile. With very sharp W tips coated with Mn or Fe, individual Mn atoms on the Mn_3N_2 surface can be resolved. The row structure of the atoms, as well as modulations of the row height induced by spin-magnetization, can be observed. Reproducible results with different magnetic tips confirm that the observations of profile modulation are consistent with a spin-polarization effect. "It's the best technique we have for measuring magnetic structure at the atomic scale," says Smith.

The profiles consist of two parts – a normal nonpolarized part and another magnetic, spin-polarized part. Smith and coworkers also show a procedure to separate these two parts, which can then be compared to simulations based on integrated local density of states (LDOS) calculations. The experimental profiles agree well with those calculated theoretically. "It's a very important technique for nanotechnology," suggests Smith, which could provide a means for modifying the surface of magnetic compounds as well as imaging them.

Clearly memorable materials

DATA STORAGE

John T. Fourkas of Boston College, along with coworkers Christopher E. Olson and Michael J. R. Previte (of Massachusetts Institute of Technology) have discovered a new class of materials that could be ideal for storing data [*Natural Materials* (2002) doi10.1038/nmat766].

The molecular glass cresolphthalein dimethyl ether becomes highly fluorescent on multiphoton absorption (MPA), making it a suitable material for three-dimensional optical data storage. This method has attracted attention because of its potential to allow a higher density of information storage than comparable magnetic systems. Laser light is used to initiate a photochemical or photophysical process, which alters the local optical properties in a controlled and position-sensitive manner. Until now, most MPA-suitable materials have shown readout degradation. But the new material shows excellent robustness during the readout of data, even at scan rates as high as 2400 bits s^{-1} – twice as fast as any other fluorescence-based MPA storage technology to date.

Fourkas and his colleagues also achieved storage densities densities of 870 MB cm^{-2} on a thin sample of the molecular glass. Although this is an order of magnitude larger than conventional DVDs, the researchers believe that it should be possible to further improve the storage density of their new material at least sixfold. Writing times could also be improved, they say. At the moment, a 40 mW Ti: sapphire oscillator can write a single bit in 100 ms. But with higher-powered bursts of light on shorter timescales, writing times an order of magnitude faster could be achievable.

The molecular glasses are inexpensive and would be easy to process. They are of high optical quality and can be molded into any shape. Although the underlying photochemical process involved is not yet known, the researchers believe that there is plenty of room for further optimization.

A shape worth remembering

NANOCOMPOSITES

Researchers from the University of Colorado, Boulder, and Composite Technology Development, Inc. have created a material that combines the ability of polymers to recover from large mechanical strains with the strength of a ceramic [*Acta Materialia* (2002) **50**, 5115-5126].

By reinforcing a shape memory polymer (SMP) matrix with 300 nm SiC nanoparticles, Ken Gall and his coworkers have created a nanocomposite with much improved properties. The simple micro-casting fabrication technique that the researchers use yields a uniform and well-dispersed nanocomposite.

The composite material (with 40 wt% SiC) has a microhardness and elastic modulus three times greater than the base resin. For weight fractions of SiC below 40%, the material shows perfect recoverability (i.e. the ability to recover from a mechanical strain with the application of heat). Above this weight fraction, the researchers found permanent strain bends.

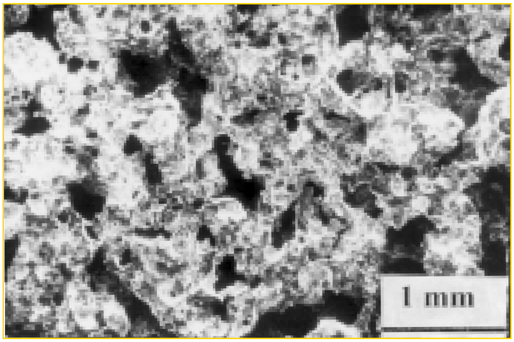
The addition of SiC to the SMP was also found to increase the constrained bending recovery force by 50% for a SiC weight fraction of 20%. This increase in the force exerted by the material as it recovers from a mechanical strain could be of great benefit to microelectromechanical systems (MEMS) technologies. Polymer materials are particularly attractive for MEMS sensors, actuators, and bio-MEMS because of their suitability for medical applications.

For all these observed improvements to the nanocomposite material's properties, the weight fraction of SiC has a profound effect. This suggests, say the researchers, that recovery parameters could be tailored for specific applications or requirements.

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.

Biomimetic supporting materials

SHAPE MEMORY ALLOYS



Scanning electron micrograph showing the pore morphology of the porous nickel-titanium shape memory alloys. (© Elsevier Science 2002.)

Many biological systems, such as cancellous bone, consist of low density porous structures with high mechanical strength. Biomimetic porous materials are of particular interest in the field of biomaterials as these structures allow effective nutrient diffusion to support to support human tissue integration. As mismatch between the mechanical properties of implant materials and the host tissues cause effects such as stress-shielding, which may result in device loosening or inappropriate biological responses, consideration is increasingly being given to ensuring the mechanical compatibility of implanted materials.

Ni-Ti shape memory alloys have attracted considerable interest as biomaterials in recent years as a consequence of their biocompatibility and superelasticity. More recently, various groups have investigated the use of porous Ni-Ti shape memory alloys for a wide range of orthopedic, vertebral column, and maxiofacial applications. These materials also offer the ability to engineer the mechanical properties of the material to match those of the tissue surrounding the device.

Researchers at the Chinese Academy of Sciences' Institute of Metal Research in Shenyang have recently reported a study of the compressive properties of porous Ni-Ti shape memory alloys [*J. Alloys Compounds* (2002) 345, 271-274]. Yong-Hua Li and coworkers prepared the materials from elemental Ti and Ni powders using combustion synthesis. The materials have a three-dimensional interconnected pore structure (as shown), an average porosity of 49-65%, and pore size of 120-600 μm – and would, therefore, be capable of supporting tissue integration. The ultimate compressive strength and strain decrease with increasing porosity. Although the porous Ni-Ti shape memory alloys of the same porosity met the compressive strength of human cancellous bone, unlike bone the porous Ni-Ti shape memory alloy was found to have a stress-strain curve independent of the strain rate. Despite this difference in mechanical behavior, these porous materials seem to offer potential as tissue integrative materials for the fabrication of orthopedic devices.

Resisting bacterial adhesion

COATINGS

The longevity of modern urological prostheses is still limited by the common occurrence of device-associated urinary tract infections. In particular, ureteral stents, which are implanted to assist drainage of the kidney into the bladder, often act as a focus for infection through the attachment of bacteria and formation of resistant biofilms. Ultimately, this can result in kidney damage.

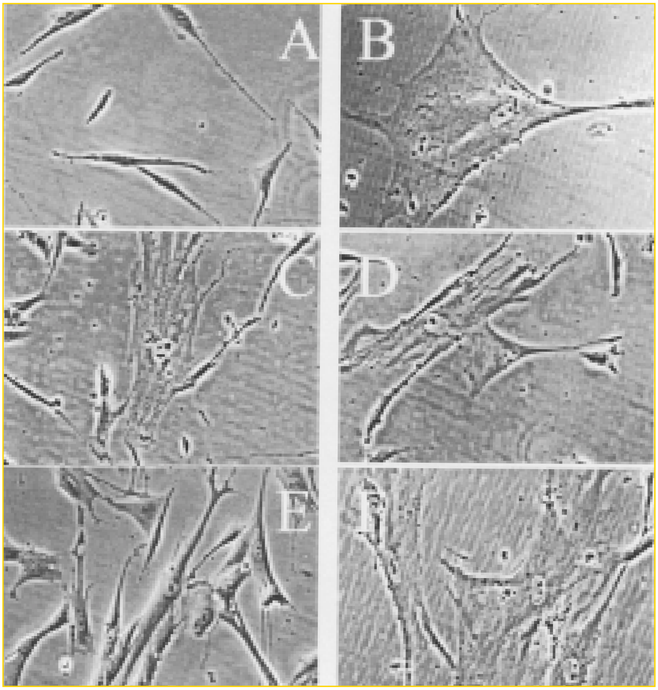
Previously, various groups have sought to address this problem by developing new materials and coatings that resist bacterial adhesion. In a recent report, Peter Cadieux and coworkers from St. Joseph's Health Care and the University of Western Ontario in Canada describe an alternative approach using a *Lactobacillus* protein-based coating [*Colloids Surfaces B: Biointerfaces*, available on-line 25 October 2002]. Their approach utilizes the ability of some probiotic organisms to produce metabolites that inhibit the growth and virulence of pathogens. *Lactobacillus fermentum* RC-14, which normally colonizes the vagina and intestine, has previously been shown to produce a biosurfactant that adsorbs to polymeric substrates and is capable of inhibiting the binding of urological pathogens. Further work has isolated a collagen-binding protein (p29) from this organism and shown it to inhibit bacterial adhesion to polystyrene. In this latest paper, the researchers have investigated the use of recombinant p29 as a biomimetic coating for reducing the adhesion of urological bacteria to polyisobutylene-polystyrene block copolymers, which are also presently under evaluation as an alternative to silicone for the manufacture of ureteral stents.

Although the coating was found to significantly reduce the adhesion of *Escherichia coli* 67 and *Enterococcus faecalis* 1131 *in vitro*, treatment with urine abolished the effect of the protein. This probably reflects either the displacement of the p29 from the surface or masking of the p29 by a coating layer of urinary proteins.

The future immobilization of the protein at the surface may, however, offer a means of overcoming this problem and provide a useful anti-adhesive biomimetic coating for urological devices.

Rejuvenating aged cells

SURFACE MORPHOLOGY



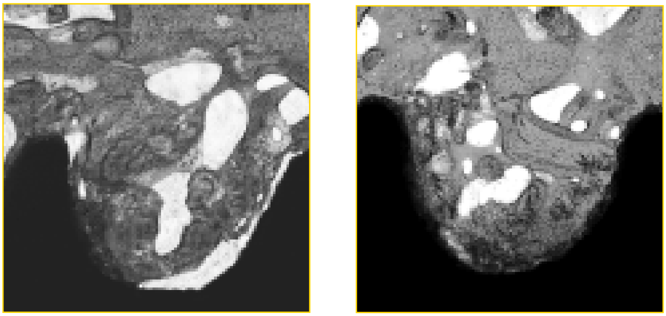
Growth of IMR90 fibroblasts (a) young and (b, c, d, e and f) aged cells after 6 days on (a), (b) tissue culture dishes; (c) film of 5 mg/ml denatured collagen; (d) film of 3 mg/ml denatured collagen; (e) film of 0.5 mg/ml denatured collagen; (f) film of 0.5 mg/ml native collagen. (© Elsevier Science 2002.)

The surface morphology and chemistry of biomaterials is known to influence the response of cells associated with these surfaces. These changes include effects on cell adhesion, remodeling of the extracellular matrix, and the activation of various biochemical pathways. The aging of cells represents a significant challenge for the development of materials for tissue engineering applications, as the aging of the cell within constructs may limit the development of a fully-functional tissue engineered product. A team from the Tufts University Bioengineering Center in Massachusetts has demonstrated that the use of denatured collagen Type I, a major extracellular matrix protein, as a cell support appears to reduce the rate of aging in cultured cells [*Matrix Biology* (2002) 21 (6), 533-543]. Using IMR90 human primary fibroblasts, Vladimir Volloch and David Kaplan show that growth on a denatured collagen matrix results in aged cells adopting a more 'youthful' appearance, while the rate of aging, determined by morphological analysis, of young cells appears to be reduced compared with controls. Examination of β-galactosidase expression, an established marker for cellular aging, shows that growing cells on Type I collagen reduces expression by aged cells and delays or prevents expression by younger cells. As oxygen-derived radicals are known to have a role in cellular aging, the researchers examined the oxidation of a subset of cellular proteins. The results demonstrate a reduction in the oxidation of these particular cellular proteins in aged cells. Finally, they examined the effect of collagen Type I on the expression of the major stress response protein Hsp70, which is normally attenuated in aged cells. These thermal stress studies show that the attenuation of this protein expression by aged cells can be reversed by culturing the fibroblasts on denatured collagen. Further elucidation of the basis for this phenomena may allow the development of surface-modified materials that will interfere with cellular aging, allowing the use of a wider range of autologous cell types for tissue engineering applications.

Improving bone fixation

SURFACE COATINGS

The incidence of osteoporotic vertebral fractures is increasing with the growth in the aged population. In many cases, such fractures require internal fixation and stabilization of the spine. The pedicle fixation technique often used currently requires effective integration of the screws, which hold the instrumentation in place, with the bone. Although there have been a number of approaches proposed for improving the bone-screw interface, for example the use of hydroxyapatite (HA) coatings, to date there have been no *in vivo* studies of the effectiveness of these coatings in osteoporotic bone. A recent study by Italian researchers has sought to address this by evaluating the performance of uncoated and HA-coated screws implanted into the pedicles of long-term ovariectomized and control sheep [*J. Orthopaedic Research* (2002) **20** (6), 1217-1224]. After four months there was a significant decrease in the bone-screw strength for the uncoated screws compared with the normal sheep. The HA coating led to improved bone apposition and bone-screw strength in the normal and osteopenic animals, indicating the advantages of using HA-coated screws for pedicle fixation.



*(Left) An uncoated stainless steel screw in the pedicle bone of an ovariectomized sheep showing some areas where bone is not in direct contact with metal surface of the device. (Right) A HA-coated stainless steel screw in the pedicle bone of an ovariectomized sheep illustrating that the presence of HA coating improves the bone apposition at the screw-bone interface. (Reprinted by permission of Elsevier Science from 'Pedicular fixation in the osteoporotic spine: a pilot in vivo study on long-term ovariectomized sheep', by Aldini, N.N. et al., Journal of Orthopaedic Research, **20**, 1217-1224 © Orthopaedic Research Society 2002.)*