

## Focusing on left-handed materials

The first reports of left-handed materials (LHM) created much excitement a few years ago. In theory, LHM (also known as negative-index materials) bend light the opposite way

to positive-index materials, and a flat slab of LHM could be used as a 'perfect lens' for near focusing beyond the diffraction limit. But the experimental evidence for LHM was open to interpretation, and there was much theoretical uncertainty about whether such materials actually existed. A report by MIT researchers, Andrew Houck, Jeffrey Brock and Isaac Chuang, at the American Physical Society meeting in March 2003, confirms negative refraction in LHM, at least in the microwave regime. Their material follows the same design as earlier

LHM — a composite structure of metallic wires and split-ring resonators in a periodic array — but they succeed in recording a complete profile of the electric field in the device, conclusively showing that microwave beams are refracted with a negative index (*Physical Review Letters*, in press). They also provide preliminary evidence that a flat slab of LHM can focus a point microwave source, and if similar materials can be designed for visible and other wavelengths, there are potential applications in photolithography and NMR.



## Electron microscopy of soft matter

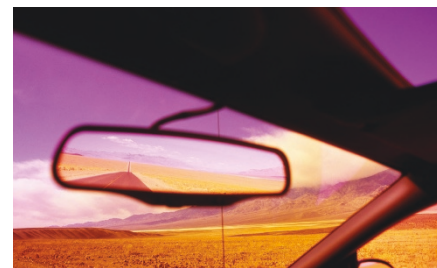
High-resolution electron microscopy (HREM) is a versatile tool for studying the structure of materials at the nanometre level. But conventional HREM requires fairly high electron doses, at which organic and soft materials cannot be imaged without incurring significant damage. David Martin and colleagues at the University of Michigan are developing techniques for low-dose HREM of polymers and molecular crystals. As they reported at the March 2003 meeting of the American Physical Society in Austin, Texas, the high contrast obtained using low-energy electron microscopy enables organic and polymer films to be imaged without the need for heavy-metal staining. Using this technique, the researchers are able to image the grain structure of the organic semiconductor pentacene, and to study the electron-beam-induced phase transformation of diacetylene from a molecular to a polymer crystal in real time.

## Sensors muscle up

Actuators — devices that couple sensing with action — are made up of several sensors working in parallel to synchronize sensing and movement. Researchers at the University of Cartagena, Spain, have built an "artificial muscle" in which the sensing and actuating capabilities are integrated in a single component, so the only connections required are two wires (*Advanced Materials* 15, 279–282; 2003). The authors exploit the conversion of electrochemical energy into mechanical energy in polypyrrole — a conducting polymer whose volume is easily controlled by applying a voltage. They connect two polypyrrole films to a cathode that swells one film and to an anode that shrinks the other film. The efficiency of the energy conversion process is such that the artificial muscle has sufficient strength to move an object up to 1,000 times its weight. If this happens at constant current, the electrical energy consumed is directly proportional to chemical or physical variables, such as the weight of the object, so the actuator simultaneously works as a sensor and a muscle.

## Plastic electrochromic devices

Electrochromic devices are transparent materials that become coloured when an electric potential difference is applied to them.



This property has already been exploited commercially for applications as diverse as rear-view mirror systems in cars, thin flat-panel displays and smart paint. Most of these devices are made from inorganic components based on metal oxides, but there is interest in using polymeric materials because of their useful mechanical properties, flexibility and low cost. Allen Bard and colleagues describe in *Chemistry of Materials* (<http://dx.doi.org/10.1021/cm0210445>) the electrochromic properties of phenothiazine–phenylquinoline donor–acceptor polymer films that show reversible electrochemical oxidation accompanied by a colour change (black–red and yellow–red). The colour switches as a function of the potential applied. These devices operate stably for days during potential cycling, and have better colouration efficiency compared with previous inorganic and organic materials. Their promising characteristics suggest they would make flexible, all-plastic alternatives to conventional devices.

## LOW-ENERGY SWITCHES

One of the promised advantages of molecular electronics is its potential to reduce the energy consumed by power-hungry laptops, and other devices based on solid-state circuits. Researchers in France and Switzerland have directly tested this idea by measuring the energy required to operate a single molecule switch (*Physical Review Letters* 90, 066107; 2003). Current solid-state transistors can be operated with less than a femtojoule of energy. The new molecular switch requires less than 100 zeptojoules —  $100 \times 10^{-21}$  J — some four orders of magnitude lower. The switching mechanism corresponds to the rotation of a single C–C bond in a porphyrin-based molecule placed in a tunnel junction. When the switch is 'off', one of four legs of the molecule lies parallel to the copper surface, and when it is 'on' the leg is perpendicular to the surface. The authors use the oscillating tip of a non-contact atomic force microscope/scanning tunnelling microscope to both rotate the leg and to record the forces involved. The ultralow switching energy suggests it may be possible to build molecular switches that approach the thermodynamic limit.

## Responsive surfaces

Thin films spread onto a surface have applications in many areas, for example, cosmetics, pharmaceuticals, agrochemicals and sensing devices. In most cases the films are subject to changing conditions. Anastasiadis *et al.*, writing in *Macromolecules* (<http://dx.doi.org/10.1021/ma0211129>), report a methodology for creating polymer surfaces that can respond to their

environment. They take an AB block copolymer — formed from covalent linkage of two chemically distinct A (polyisoprene) and B (polystyrene) polymer chains — which have a hydrophilic end group attached to the A block. When mixed with the homopolymer B and spin-coated onto a silicon wafer, the A block partitions to the free surface, while the B block forms an anchor into the

matrix polymer. In a humid environment, the hydrophilic group rises to the surface, enabling it to reduce the surface tension and therefore the contact angle of water drops. With a zwitterion containing both  $N^+$  and  $S^-$  ions as the hydrophilic group, the contact angle can switch between  $82^\circ$  and  $46^\circ$ , when the surface is placed in dry and humid environments, respectively.