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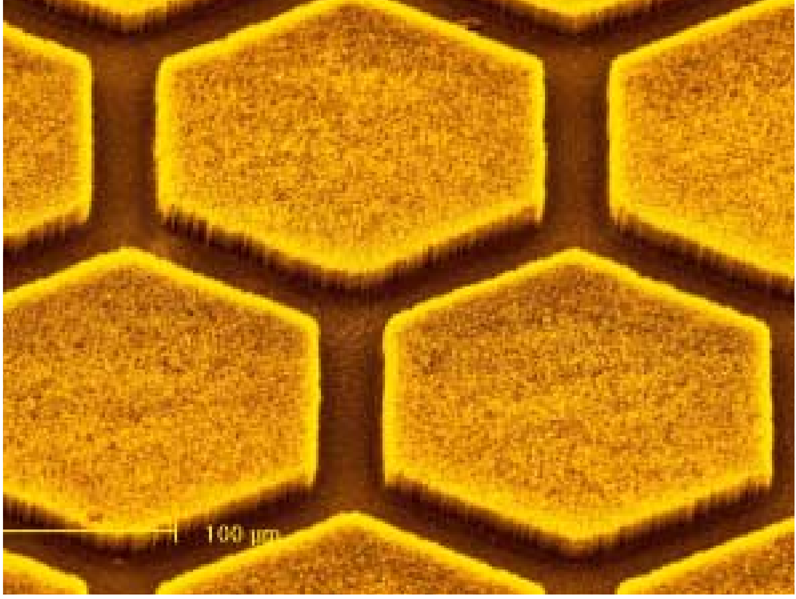
**Wendy Pyper enters a world where tiny structures perform Hurculean feats.**




# *Super* structures

Words like buckyball' and 'nanotube' sound as if they have been lifted from the pages of science fiction. But in fact, they describe tiny structures existing in a new realm of scientific inquiry – the nano-dimension.

The nano-dimension is a place where common materials, such as carbon or metal, form unusual structures only millionths of a millimetre in size, with properties distinct from their molecular and physical forms.

Carbon for example, exists as diamond or graphite in the physical world. In the molecular world, carbon atoms act as building blocks for molecules such as glucose or DNA. But in the nano-world, carbon exists as ball- and tube-shaped structures with unique electrical, mechanical, optical and magnetic properties.

These unique properties make carbon nanostructures such as buckyballs and nanotubes attractive for many potential applications: supercomputers the size of wall clocks, nanomachines that act as miniature surgeons, and artificial muscle, to name a few. Before such advances can be realised however, research into the basic properties of nanostructures and how to manufacture them in a controlled fashion is needed.

Dr Liming Dai of CSIRO Molecular Science and Professor Gordon Wallace, director of the Intelligent Polymer Research Institute at the University of Wollongong, lead groups researching the properties, production and uses of carbon nanotubes.

Carbon nanotubes are one of the more technologically promising nanostructures, although soccer ball-shaped buckyballs – the first nanostructures to be discovered – also have their place (see story opposite).

As the name suggests, carbon nanotubes are hollow carbon tubes enclosed at both ends. They can consist of one million or more carbon atoms and are three times stronger than steel per unit weight.

Humans have unwittingly been producing carbon nanotubes for years, through the burning of candles. When carbon molecules in candle wax are vaporised by the heat of a flame, some of them enter the yellow tip of the flame. Here, temperatures are high enough to split the carbon molecules apart, producing soot and carbon nanotubes. It wasn't until 1991 however, that Japanese scientist, Sumio Iijima, discovered nanotubes amid soot produced by heating graphite rods.

Recently, Dr Liming Dai's group developed a more sophisticated way of producing carbon nanotubes which involves heating metal-containing organic compounds. Using this 'chemical vapour deposition' method, the group has been able to align nanotubes either end-to-end – to form nanotube wires – or side-by-side into tiny clusters called 'micro-patterns'.

This ability to align similar or different types of nanotubes is a crucial step in the progression of nanotube theory into practical applications.

'For most applications, it is important that carbon nanotubes are either aligned or formed into patterns, so that the properties of individual nanotubes can be easily incorporated into devices,' Dai says.

One of the first devices, which Dai's group is developing in collaboration with the Austrian high-tech company, Electrovac, is a new flat screen for televisions and computers. The screens will utilise the electron conducting capacity of nanotubes to replace conventional cathode ray tubes.

'Depending on their diameter and the arrangement of carbon atoms in their walls, carbon nanotubes can act like metals, which are good electrical conductors, or like semiconductors, where their conductivity is intermediate between a metal and an insulator,' Dai says. 'So if we join individual nanotubes together, end-to-end, we can form different kinds of nanotube wires.'

Carbon nanotube wires, like cathode ray tubes, emit electrons that excite phosphor molecules on the surface of a television screen, producing light. Grouping nanotubes into micro-patterns, in contrast, focuses electrons onto tiny areas called pixels, which make up computer display screens.

While these applications have been proved, Dai says that actually transferring the technology into a working device is the tricky part. 'The television and computer screens need to be produced under vacuum, otherwise the electrons will collide with air

**Left: Carbon nanotubes can be aligned to form different patterns (micropatterns) for various applications, including flat panel displays for computers. These stars and hexagons were produced by 'chemical vapour deposition' on surfaces that had been physically masked and photo-patterned.**
**Photo-patterning involves masking specific areas (stars, hexagons) on a surface coated with a thin polymer. When the polymer is exposed to light it undergoes a chemical change that renders it insoluble in an appropriate solvent. But the covered areas of polymer (stars, hexagons) remain soluble. When a solvent is applied to the surface, the masked areas dissolve, forming pre-patterned pixels on which nanotubes can then be applied.**

molecules and won't have enough energy to excite the phosphor molecules. So we have to work out how to seal the screens under vacuum,' he says.

If successful, the technology will improve the energy efficiency and physical characteristics of display screens.

'A conventional cathode ray tube in a TV set works under about 10 kilovolt of voltage, while nanotubes use about 50 times less,' Dai says. 'The screens will also be lighter, thinner and more flexible. And the tiny size of carbon nanotube electron emitters could allow an unusually high resolution for the image displays.'

The success of Dai's group in aligning carbon nanotubes is of interest to Professor Gordon Wallace and his group at the Intelligent Polymer Research Institute. Wallace, in collaboration with a number of international organisations, is developing artificial muscles that will one day be used in small machines or robots.

'We're getting performance characteristics an order of magnitude greater than human muscle in terms of stress generation,' Wallace says. 'But there's a lot of room for improvement and if we can get the nanotube structures right, we'll greatly improve their strength.'

Wallace says nanotube alignment will go a long way to improving the strength and control of artificial muscles, such that they could be used as prosthetics in rehabilitation. Greater control at the nano level will enhance other products as well.

'When we learn to control things at the nano level, we'll get enhanced performance out of existing products. And we'll also be able to develop new, unforeseen products – things that have been talked about only in science fiction.'

# Nano **futures**

IN 1985, the scientific world was captivated by the discovery of tiny soccer-ball shaped carbon structures called 'buckyballs'. Named after the architect and engineer, R. Buckminster Fuller, who designed the 1967 Montreal World Exhibition geodesic dome, buckyballs consist of a combination of 60 carbon atoms arranged in a sphere of interlocking hexagons and pentagons.

The discovery came after British chemist, Harry Kroto, and US scientists, Richard Smalley and Robert Curl, tried to recreate the conditions thought to produce chains of carbon atoms in space. They vaporised graphite (sheets of carbon atoms) with a laser in an atmosphere of helium gas.

The experiment produced a variety of different sized and shaped carbon molecules although the buckyball or 'C60' structures predominated. Scientists soon began hypothesising potential uses for buckyballs, such as organic photoconductors, which conduct electricity when exposed to light, molecular ball bearings, or chemical sponges that absorb and contain fluids or gases within their hollow core.

In 1991, Japanese scientist Sumio Iijima discovered carbon nanotubes among the buckyballs, opening up a realm of new technological possibilities. For example, carbon nanotubes can be made with or without encapsulated metals, and in straight, curved or helical shapes. If different types of nanotubes are joined together, they can form molecular wires with interesting electrical, magnetic, optical and mechanical properties.

'Their diverse properties and unusual molecular symmetries make carbon nanotubes attractive for many potential applications,' Dai says.

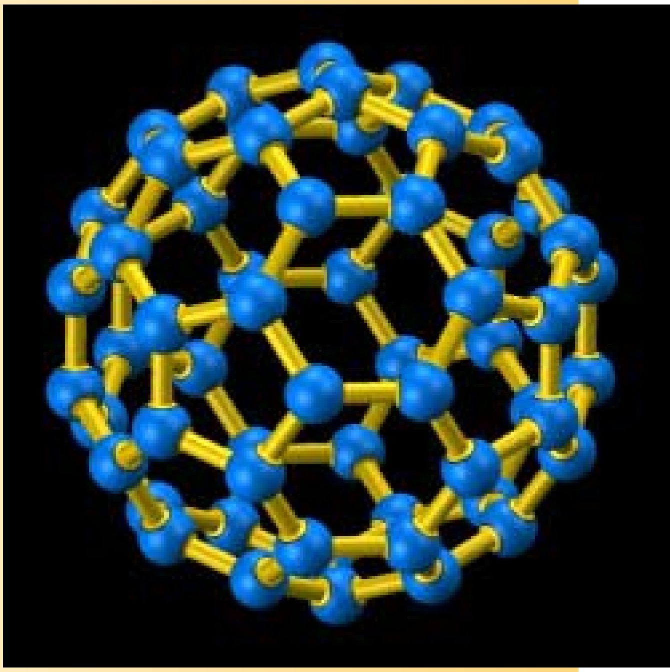
'These applications include their use in panel displays (see main story), molecular transistors, gas and electrochemical energy storage, protein or DNA supports, chemical or biological sensors, and molecular filtration membranes.'

As molecular filtration membranes, Dai says carbon nanotubes would adsorb some molecules, like poisonous gases, into their hollow core, while excluding others. Their affinity for certain gases, like hydrogen, could also be harnessed to store alternative energy sources.

'One of the problems in developing alternative energy sources for cars has been finding materials that can store hydrogen in large quantities. But carbon nanotubes can hold more hydrogen than most materials studied,' Dai says.

Carbon nanotubes could one day be used for controlled drug delivery as well.

'You could place a drug inside the nanotube, then close the tip with a temperature or pH responsive polymer. Then, by changing the temperature or pH, you could open or close the nanotube,' Dai says.



**Buckyballs have a combination of 60 carbon atoms arranged in a sphere of interlocking hexagons and pentagons. (Source: Joseph W. Lauher, Department of Chemistry, State University of New York.)**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