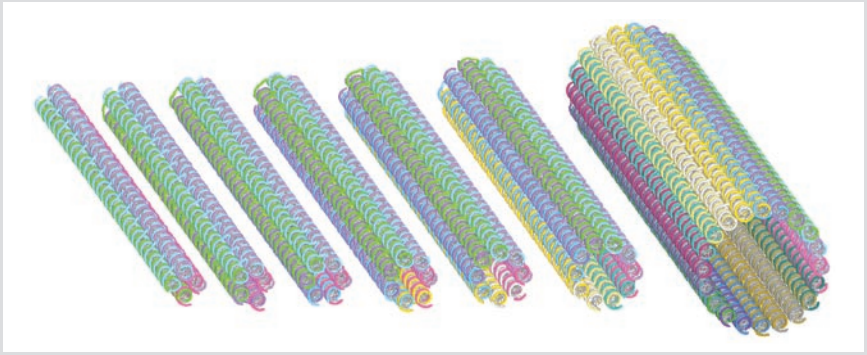
DNA NANOTUBES

Programming their design



Science **321,** 824–826 (2008)

Absolute control over the dimensions of a structure is a primary goal of nanotechnology. To this end, DNA is proving to be one of the most versatile building blocks. DNA can be used to form rigid tiles with 'sticky ends' capable of binding other tiles and directing the formation of a design. Using such methods, a range of two- and three-dimensional nanoscale architectures have been created, including tubes. However, controlling the circumference and uniformity of these nanotubes has proved difficult. Peng Yin and colleagues at the California Institute of Technology and Duke University now report the synthesis of molecular tubes with programmable circumferences by using flexible DNA motifs.

The research team used a 42-base single-stranded DNA motif with four modular domains. By pairing up complementary domains, it was possible to organize the motifs into DNA lattices made up of parallel helices with single-stranded linkages. In the lattice, the motif configures into a rectangular, tile-like geometry, which is connected to four adjacent neighbours. The circumference of a molecular tube can then be programmed by specifying the modular interactions between the motifs.

To execute this 'molecular programme', one-pot annealing of the DNA strands is all that is required, and monodispersed nanotubes with designed circumferences from four to twenty DNA helices can be synthesized.

NANOPARTICLES

Follow the ice tracks

Small **4,** 1210–1216 (2008)

Nanostructures in the form of wires and tubes have various applications in electronics, catalysis and medicine. These materials can be created using physical or chemical templating and laser-based processing. Researchers have now shown that ultralong nanorods can be formed by freezing and ageing an aqueous solution of nanoparticles.

Using water-based methods, Sudipta Seal and colleagues at the University of Central Florida, Pacific Northwest National Laboratory and the UK Defence Academy made cerium oxide nanoparticles of around 3–5 nm in diameter by oxidizing Ce(III) precursor salts to Ce(IV). They then subjected the solution of nanoparticles to subzero temperatures and aged it over a number of weeks. Within one day, rods and octahedral superstructures were formed. Subsequent ageing for a week lengthened the nanorods, which grew into yet longer structures after two weeks. Similarly to the solidification of an alloy, it was suggested that as freezing occurs, nanoparticles are expelled into the water phase, saturating the unfrozen solution. As the ice front develops, capillary forces drive the nanoparticles from the saturated solution into channels and capillaries at the ice-water interface. Control experiments using unfrozen solutions indicated that the templating geometry of ice assisted the evolution of the nanorods. Furthermore, freezing by immersing the solution in liquid nitrogen did not form nanorods.

By varying the freezing rates, particle concentrations and ageing temperature to alter the ice structures, this approach may offer a green route to fabricate nanostructures.

GRAPHENE

A perfect break

Science **321,** 385–388 (2008)

Even in a controlled environment it is hard to attain perfection in a material. This is because of the structural defects and flaws created during synthesis and processing. As a result, the mechanical properties of a material rarely exhibit their inherent values, and it is difficult to measure the intrinsic strength of a pristine material. Now, James Hone and colleagues at Columbia University have caught sight of this ideal with measurements on a single layer of graphene.

The researchers used an atomic force microscope to explore the elastic properties and intrinsic breaking strength of a layer of graphene that had been suspended over open holes. The holes were patterned into a silicon substrate and graphite flakes deposited over the top. Once areas of monolayer graphene had been identified, measurements were made by indenting the centre of a covered hole with the diamond-tipped atomic force microscope.

The strength of graphene was measured by pushing the suspended layer to breaking. The results suggest that the area of graphene near the microscope tip is free from defects, and hence the maximum stress the material can bear corresponds to its intrinsic strength. The experiments confirm graphene to be the strongest material ever measured.

ICE FORMATION

Squashed solid

Phys. Rev. Lett. **101,** 036101 (2008)

An object moving over a surface usually traps molecules from the surrounding air, which can either lubricate the motion or add to friction. Water molecules, in particular, may add to friction by forming into solid ice — but this has never been proven experimentally.

Now, K. B. Jinesh and Joost Frenken at Leiden University have provided the first direct evidence that ice can form when water is confined to a narrow layer, even at room temperature. The researchers used a friction force microscope to monitor the forces on a tungsten tip moving over a surface of graphite, under various levels of humidity. At low humidities, the tip showed a 'stick–slip' motion, getting stuck every 0.25 nm, which matches the spacing of carbon atoms in the graphite surface. When the humidity was increased, the stick–slip distance increased to 0.38 nm, closer to the lattice size of common ice structures.

The researchers believe that when there is more water in the air, ice attaches firmly to both the microscope tip and the graphite surface, and is continually broken and reformed during movement. Therefore, the conditions of confinement can overcome a major obstacle — the fact that water expands when it freezes.

POLYMER FILMS

Shot from within

Appl. Phys. Exp. **1,** 087001 (2008)

Laser irradiation is widely used for cutting a material or modifying its properties. Alterations to a material on the nanoscale are substantially more challenging, and ultra-short wavelength laser light has been studied for such purposes. However, the ultimate size of structures produced by laser processing is restricted by the diffraction limit of the light, and the spatial resolution is usually in the order of a few hundred nanometres. Now, Yasuyuki Tsuboi of Hokkaido University and colleagues at the Kyoto Institute of Technology and AIST have developed a laser-based approach that can create holes with diameters of less than 100 nm, which is significantly smaller than the wavelength of the light.

The fabrication process involves first immobilizing gold nanoparticles on glass substrates using a self-assembled monolayer. An organic polymer film, with a thickness similar to the diameter of the gold particles, was then spin-coated on top. Finally, the functionalized substrate was irradiated with pulsed laser light, with a wavelength of 532 nm. The laser irradiation 'superheats' the gold nanoparticles, by a process known as resonant plasmon absorption. This leads to an explosive vaporization of the gold particles, which penetrate the polymer film, generating the nanoholes.

Such polymer films could eventually prove useful in the synthesis of novel biomaterials and in the development of electronic devices.

QUANTUM TUNNELLING

Switching states

Nano Lett. **8,** 2393–2398 (2008)

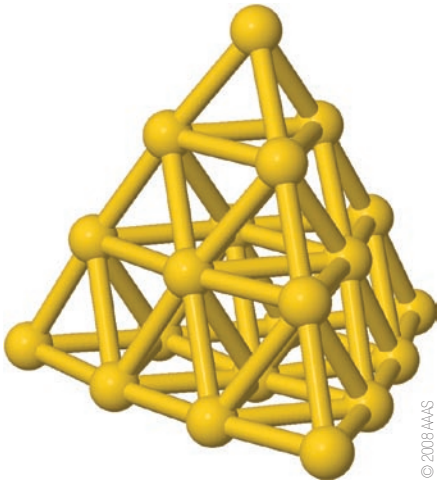
Devices consisting of a single molecule trapped between two electrodes may have interesting applications in molecular electronics. For example, the degrees of freedom of the molecule can be exploited to produce a switching effect. Thomas Bjørnholm of the University of Copenhagen and co-workers in Sweden and Germany have demonstrated one such switch in which the quantum motion of the entire molecule plays a role in the process.

The researchers trapped a C_{60} molecule between two silver electrodes and observed switching between two states with different conductances. They analysed the distribution of switching voltages at different temperatures and currents in order to calculate the barrier separating the two states and the rate of switching. They found that a voltage-dependant barrier separates the two states and suggest that quantum tunnelling, current-induced excitations and thermal effects are responsible for the mechanism.

The energy relating to the tunnelling is found to be the most dominant and corresponds to an object of the mass of C_{60}. The switching frequency is too small to be assigned to any internal vibrational modes so it must be for the rotation or displacement of the entire molecule.

GOLD CLUSTERS

Freely understood



Science **321,** 674–676 (2008)

Although bulk gold is relatively inert, nanoparticles of the metal, dispersed across the surface of a support, have been found to be exceptionally active catalysts in a range of reactions. The origins of this reactivity are widely disputed, but the geometric structure of the gold is undoubtedly a significant factor. However, obtaining three-dimensional structural information about such clusters is challenging. Now, André Fielicke of the Fritz-Haber-Institute and colleagues have been able to determine the exact geometries of an array of minute gold species by using clusters that are free in the gas phase.

Previously, gas-phase gold clusters have been investigated using a number of techniques, but these approaches have been restricted to looking at charged species. Fielicke and team have managed to examine neutral gold clusters by measuring vibrational spectra in the far-infrared, and by comparing the experimental data with spectra predicted by density functional theory. They first looked at Au_7, revealing a two-dimensional triangle-based structure. The researchers then identified a pyramidal structure for Au_{20} and a truncated pyramidal structure for Au_{19}.

With improved sensitivity, the technique could be used to explore larger clusters, and perhaps to study ligand-induced structural changes.

TOP DOWN BOTTOM UP

Commercial graphene

Researchers have set up a company to sell graphene samples to other researchers.

It was back in 2004 at Manchester University that graphene — a layer of carbon atoms bonded in a honeycomb lattice — was isolated for the first time by a process known as micromechanical cleavage. Although the flakes produced with this method were used in a number of high-profile experiments, they were too small for many other experiments. Since then the Manchester group, working with electron microscopists at the Daresbury Laboratory and theorists at Radboud University Nijmegen, has learned how to make bigger flakes with better yields (*Nano Lett.* **8,** 2442–2446; 2008). Moreover, three members of the team — Tim Booth, Peter Blake and Da Jiang — have set up a company called Graphene Industries (www.grapheneindustries.com) to sell the flakes.

"Our aim was to help speed up the pace of research by providing the highest quality graphene flakes to researchers on a commercial basis, giving our customers a head-start in the field," says Booth. "It also allows us to work with more people than would be possible through collaborations." The biggest challenge, according to Booth, was ensuring that the idea was protected with a patent before publishing. "The close relationship between the company and Andrei Geim's group at Manchester has been mutually beneficial."

What advice does he have for other researchers? "If a spin-out company seems to be a viable option, I would recommend the experience because the peripheral benefits to research are enormous." And what is next for Graphene Industries? "We have had a number of enquiries from investors, and offers from venture capital funds, which are still under discussion," says Booth. "However, we feel it is best at this stage to continue to add to our stored potential, so that we can capitalize quickly on great ideas — there is no shortage of them in graphene research."

The definitive versions of these Research Highlights first appeared on the *Nature Nanotechnology* website, along with other articles that will not appear in print. If citing these articles, please refer to the web version.