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nanozone news

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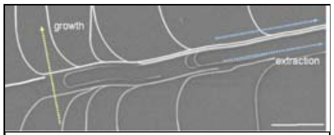
Unravelling the nanotube

Multiwalled carbon nanotubes are assemblies of several nested nanoscale cylinders. These can be separated from one another simply by tugging.

PHILIP BALL



Scanning electron microscope image of nanotube patterns produced by AFM manipulation of the initial MWNT. Scale bar = 10 µm. Reprinted in part from ref. 1. Copyright 2005 National Academy of Sciences, USA.

Carbon nanotubes consisting of several concentric shells can be pulled open layer by layer, researchers in the USA and South Korea have shown.

They have used the needle tip of an atomic force microscope (AFM) to pull out the nested tubes like a retractable telescope[1]. Because nanotubes are so long relative to their width, and because they don't break easily even when highly deformed, this telescoping extension means that the nanotubes can be reeled out over very long distances.

And because the nanotubes stay stuck to the AFM tip, they can be pulled across empty space to create bridging threads, or 'extruded' into crisscrossing patterns, rather like the strands of a spider's web being reeled out by the spider.

Kwang Kim of Pohang University of Science and Technology in Korea and his co-workers have found that their method also enables them to produce carbon nanotubes much thinner than those grown by conventional methods, by extruding the innermost shell from multiwalled structures. The thinnest of these are just 0.4 nm across — barely more than the spacing between each concentric layer — whereas single-walled carbon nanotubes grown by the usual methods tend to be no thinner than about 1 nm.

The key to opening up nanotubes this way is twofold. First, nanotubes deposited on a solid surface tend to be stuck there by intermolecular forces that, if the tube is long enough, impose strong frictional resistance to their being dragged, by an AFM tip say, over the surface. This means that a tip pushing against a nanotube at right angles to the long axis will deform and eventually break the outer shell(s), exposing inner layers.

Second, the friction between the concentric shells themselves is rather small. (This is often attributed to 'graphite-like' lubrication, although in fact graphite's lubrication properties owe more to intercalated gases between the sheets than to an intrinsic 'slidiness' of the sheets themselves.) This low friction means that the shells will readily telescope out from one another when pulled by the AFM tip.

Such inter-shell slipperiness in multiwalled carbon nanotubes (MWNTs) has

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been exploited previously by Alex Zettl and John Cumings at the University of California at Berkeley to make nanodevices that rotate on nanotube bearings[2]. Zettl's group has also exposed the inner shells of a MWNT by peeling away the outer layers by vaporization[3].

Kim and colleagues have now shown that the inner shells can be exposed without chemical modifications of this sort. They simply pull out a sharply kinked length of inner tubes from a break in the middle of a MWNT. They have extracted lengths of over tens or even hundreds of micrometres, for they have perfected a method of growing MWNTs more than 10 cm long.

When they perform the telescoping operation for MWNTs resting on a silica surface, the extruded tube becomes progressively thinner as each layer becomes impeded by friction once it gets long enough, so that it breaks afresh to release a further inner shell. These step-like decreases in width can be seen by measuring the nanotube height with an AFM. The steps are generally 1.4 nm high, indicating that the nanotube telescopes in a series of double-shell lengths (the inter-shell spacing is about 0.35 nm). Occasionally the researchers see single-shell ruptures (step heights of 0.7 nm).

Not only does this technique offer a way to make relatively wide hollow carbon 'nanopipes', by removing the inner layers of MWNTs, but it also ultimately frees the very narrow innermost tubes — 10 percent of them have diameters less than 0.7 nm. Kim and colleagues measured the electronic properties of these very narrow single-walled nanotubes and found that, out of 20 samples, all were metallic: none showed semiconducting behaviour.

This is surprising. A nanotube's electronic behaviour depends on the precise structure of the helical bands of hexagonal carbon rings that wind along its wall, and in general two thirds of all single-walled carbon nanotubes are predicted to be semiconducting. So there seems to be some feature of the smallest-diameter nanotubes that enforces metallic conductivity — perhaps, say the researchers, the limited number of fullerene-like end caps for such small tubes imposes a certain helicity on the wall structure.

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