Plumbing Carbon Nanotubes

Scientists have determined how to connect carbon nanotubes together like water pipes, a feat that may lead to a whole new group of bottom-up-engineered nanostructures and devices.

The researchers, from Japan's National Institute of Advanced Industrial Science and Technology, were able to “plumb” together nanotubes with similar or equal diameters using a technique they developed. They expect that their method could be used in the future to seamlessly join carbon nanotubes regardless of their diameters.

“Our method could allow longer carbon nanotubes to be created, and even nanotubes with multiple branches,” the study's corresponding scientist, Chuanhong Jin, said to *PhysOrg.com*. “Such structures could have many applications, such as field-effect transistors or current lead-wires.”

The work is described in a paper in *Nature Nanotechnology*.

Working through the eyes of a transmission electron microscope, which allowed them to watch the process as it occurred, Jin and his colleagues first split a single carbon nanotube by bridging it across two electrodes and applying a high current. This caused the middle section of the nanotube to become gradually narrower until it eventually split, resulting in two nanotubes with equal diameters and closed, or capped, ends.

The capped ends were moved near each other and the voltage across the electrodes was slowly raised from zero. At certain threshold values of voltage and current, the two nanotubes suddenly joined again. This process was so quick that Jin and his colleagues are as yet unsure of how it occurs.

The researchers found that they could repeat this split/join process on the same nanotube several times; so far, up to seven times.

The group also attempted to join carbon nanotubes with different diameters, but were not successful. In each case, at a certain threshold of voltage and current, an obvious deformation occurred on the cap of the larger nanotube. The nanotubes would then detach, pulling away from each other, and the cap structures of both nanotubes seemed to change, causing a shrinkage in length. Attempts to reposition and attach the nanotubes produced the same results.

“It seems intrinsically difficult to join two carbon nanotubes with entirely different diameters,” says Jin.

The difficulties seem to arise from the nanotubes' “chiralities”—whether the carbon atoms are bonded in chains that run straight down the tube or chains that twist around it. Two nanotubes made from the same mother tube have the same chirality, but nanotubes with different diameters rarely do. This mismatch caused problems at the atomic level when the scientists attempted to force the tubes to merge.

But the scientists came up with a fix: inserting tungsten atoms between the two nanotubes to catalyze the joining process. Tungsten has long been known to help carbon atoms “graphitize,” or arrange themselves into ordered structures, as are found in one crystal form of carbon, graphite. By moving the particle back and forth during the annealing process, the nanotubes joined seamlessly.

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