Metal oxide nanotubes: lower-cost alternative to carbon?

R. Colin Johnson
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PORTLAND, Ore. — Nanotubes historically have been synonymous with organic carbon nanotubes, but no more.

Researchers at the Georgia Institute of Technology (Atlanta) have defined a new class of inorganic nanotube materials that are analogous to volcanically formed minerals found in Japan and New Zealand. By combining aluminum oxide with silicon and germanium, professor Sankar Nair's group at Georgia Tech claims to have defined a new class of single-walled nanotube that is less expensive to fabricate than carbon nanotubes, offering properties that are easier to control.

"Our inorganic metal oxide nanotubes are closer to what the chip industry is already fabricating," said Nair. "We use a type of inorganic chemistry that is similar to what is already used for semiconductors, but the conditions we use are much milder, offering many more opportunities to customize their construction."

Today, semiconductors and carbon nanotubes alike require relatively extreme temperatures and pressures to fabricate, prompting many chip makers to experiment with doped organic polymers as a less costly, simpler alternative. But the electronic properties of organic polymers are inferior to those of inorganic silicon and germanium. Now Nair's group claims to have found the best of both worlds: high-performance materials that are as inexpensive and as easy to fabricate as polymers.

"Our metal oxide nanotubes can be formed at normal atmospheric pressure and at temperatures below 100°C," said Nair. "So far, we have proven the concept by making two types of metal oxide nanotubes—[one] at each end of a whole class of new materials with which we should be able to make all the same types of [electronic] devices that people envision making with carbon nanotubes."

Other groups are working on planar metal oxide devices by which heterojunctions are created by confining two types of insulators between two different types of metals. Nair believes that his metal-oxide nanotubes could someday be similarly sandwiched between metals to craft a new class of nanoscale metal-insulator electronic devices.

"I wouldn't yet claim that our metal-oxide nanotube materials can be directly applied to metal insulator tunneling devices," said Nair. "But the extremely small size of the nanotubes, combined with their tubular shape, could lead to very interesting and different electron-tunneling properties by confining them between two metal layers."

To form nanotubes, a mechanism must be built into the atomic structure of the material that defeats the natural tendency of molecules to form flat, linear planes. Carbon nanotubes are essentially extruded fullerenes (also called buckyballs, after geodesic dome inventor Buckminster Fuller). Inorganic metal-oxide nanotubes, on the other hand, achieve their tubular shape by combining atoms with different bond lengths, thereby achieving a more controlled atomically precise curvature.

"We form inorganic nanotubes by starting with aluminum, which wants to form sheets; but by attaching atoms that have different bond lengths—here, silicon or germanium—we get a curvature that forms them into tubes," said Nair.

Because the nanotubes are synthesized in dilute solutions of water, aluminum, silicon and germanium, the varieties of inorganic nanotubes that can be formed in this manner are theoretically endless, depending on the precise mixture of elements, their temperature, pH and similar easily controlled process parameters.

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Tunable process

"The crux here is that when you try to make carbon nanotubes with diameters of less than about 10 nanometers, they become very difficult to control," said Nair. "But these metal oxide materials are very easy to control because of the mild chemistry we use—reactions sometimes take days to complete—which means we can take samples and analyze them with different types of characterization to fine-tune our process, which is very hard to do with carbon nanotubes."

So far the two nanotube materials fabricated in Nair's lab are varieties of aluminosilicogermanate (AlSiGeO) with diameters of from 1.5 to 4.8 nanometers and lengths of less than 100 nanometers. Electronic characterization of the current experimental material reveals bandgaps between 3.5 4.5 electron volts, making them similar to gallium nitride and zinc sulfide. Nair plans to lower the bandgap in the next generation of materials by inserting transition atoms into the organic nanotube to bring them nearer to traditional semiconductors.

The researchers also plan to do detailed characterization of the metal oxide nanotubes, examining their electronic properties as well as chemical properties such as adsorption and diffusion. The team further wants to create a general theory regarding the formation of the materials, along with detailed models, so that new versions can be designed with specific desirable properties.

Nair's research was funded by Georgia Tech and the American Chemical Society Petroleum Research Fund. The team included Georgia Tech doctoral candidates Suchitra Konduri and Sanjoy Mukherjee.

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