

Researchers are developing insights into the factors governing the formation of tubular nanomaterials from inorganic metal oxide materials. Created in a water-based process, these inorganic nanotubes have properties that complement those of carbon nanotubes.

Photo: Gary Meek

Assistant Professor Sankar Nair and graduate student Suchitra Konduri show a model of the metal oxide nanotubes they are developing.



Nanotube Formation:

Researchers Learn to Control Dimensions of Inorganic Metal Oxide Nanotubes

By John Toon

Moving beyond carbon nanotubes, researchers are developing insights into a remarkable class of tubular nanomaterials that can be produced in water with a high degree of control over their diameter and length. Based on metal oxides in combination with silicon and germanium, such single-walled inorganic nanotubes could be useful in a range of nanotechnology applications that require precise control over nanotube dimensions.

At the Georgia Institute of Technology, researchers are studying the formation of these metal oxide structures to understand the key factors that drive the emergence of nanotubes with specific diameters and lengths from a “soup” of precursor chemicals dissolved in water. Their goal is to develop general guidelines for controlling nanotube diameter with sub-nanometer precision and nanotube length with precision of a few nanometers.

So far, the researchers have obtained encouraging results with a model system that produces aluminosilicogermanate (AlSiGeO) nanotubes.

“We have shown that there is a clearly quantifiable molecular-level structural and thermodynamic basis for tuning the diameter of these nanotubes,” says Sankar Nair, an assistant professor in Georgia Tech’s School of Chemical and Biomolecular Engineering. “We’re interested in developing the science of these materials to the point that we can manipulate their curvature, length and internal structure in a sophisticated way through inexpensive, water-based chemistry under mild conditions.”

Using chemical reactions carried out in water at

less than 100 degrees Celsius, Nair’s research team – which includes graduate students Suchitra Konduri and Sanjoy Mukherjee – varied the germanium and silicon content during the nanotube synthesis and then quantitatively characterized the resulting nanotubes with a variety of analytical techniques to show a clear link between the nanotubes’ composition and their diameter. Simultaneously, the group’s molecular dynamics calculations showed a strong correlation between the composition, diameter and internal energy of the material.

“There appear to be energy minima that favor or stabilize certain nanotube diameters because they have the lowest energy, and those stable diameters change with the composition of the material,” adds Nair. “This shows that the nanotube dimensions are not just a fortuitous coincidence of the many synthesis parameters, but that there is an underlying thermodynamic basis arising from the subtle balance of inter-atomic forces within the material.”

Specifically, the molecular dynamics simulations – which are corroborated by experiments – show that the variation of germanium and silicon content causes sheets of aluminum hydroxide to form nanotubes with diameters ranging from 1.5 to 4.8 nanometers and lengths of less than 100 nanometers.

Once the researchers fully understand the factors affecting the formation of nanotubes from aluminosilicogermanate materials, they hope to apply similar principles to other metal oxides. The ultimate goal will be an ability to predictably vary the dimensions of nanotubes – and potentially other useful nanostructures – em-

playing different chemical process conditions across a broader range of metal oxide materials.

Though the chemical reactions that produce the metal oxide nanotubes are complicated, they occur over a period of days at low temperatures and can be carried out with simple laboratory apparatus. That facilitates control over processing conditions and allows the researchers to track many different aspects of the reaction with a variety of characterization tools.

Controlling the dimensions of nanostructures is critical because properties such as electronic band-gap depend strongly upon the dimensions. Dimension control has proven to be difficult in carbon nanotube fabrication processes, leading to an entire area of research focused on purifying nanotubes of specific dimensions from an initial mixture of different sizes.

The metal oxide nanotubes have properties very different from those of carbon nanotubes, which have been studied extensively since they were discovered in the 1990s. "For example, the materials that we are working with are much more hydrophilic than carbon and can load nearly 50 percent of their weight with water," Nair explains. "There is a whole range of behavior in oxide nanotubes that we cannot explore with carbon-based materials."

This work, sponsored by the American Chemical Society Petroleum Research Fund, has been published in *ACS Nano* and in the *Journal of the American Chemical Society*. **rh**

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Photo: Gary Meek



Assistant Professor Sankar Nair holds a model of the inorganic nanotubes while graduate student Suchitra Konduri demonstrates the water-based process used to create them.