Science in Synch

Seeing inside nanotubes

Carbon nanotubes – tiny rolled sheets of carbon atoms – are one of the main building materials used in nanotechnology. In their plain, pure carbon form, carbon nanotubes (or CNTs) are prized for several unique properties such as their mechanical strength, which can be used to build structures that are very strong and yet very light, such as a tether for a space elevator. But replace some of the carbon atoms in the tubes' walls with atoms of another element, such as nitrogen (a process called doping) and CNTs can be used for a host of other applications, ranging from batteries and fuel cells, to ultrafast electronics and sensors.

Using the Soft X-ray Spectromicroscopy (SM) beamline, CLS researchers Jigang Zhou and Jian Wang, along with collaborators from the University of Western Ontario, have for the first time been able to see where and how nitrogen atoms congregate in nitrogen-doped CNTs. The finding, published in the *Journal of Physical Chemistry Letters*, yielded some surprising results that not only offer new insights into this nanomaterial, but also demonstrates the exciting science that can come when CLS staff from different areas works together.

"When you dope a carbon nanotube you turn it into a highway for electrons," explains Zhou, a member of the CLS industrial science group. "CNTs doped with nitrogen can replace electrodes that are made of expensive materials in fuel cells, like platinum. To make fuel cell-powered cars practical, we need to get the costs down. To do that we need to understand the CNT's structure and how it forms."

The carbon nanotubes used in the experiment were grown in a special furnace in the presence of nitrogen-containing materials that released nitrogen as the tubes formed. Using a technique called scanning transmission X-ray microscopy (STXM), Zhou and Wang were able to identify not only where the nitrogen ended up in the nanotube, but in what chemical form and even how the atoms were oriented.

"With STXM you can exactly see where the spectroscopy is coming from," says Wang, who is a staff scientist on the SM beamline. "We can image the distribution of nitrogen throughout the nanotube – both in the wall and inside the tube, as well as the tube's internal structure."

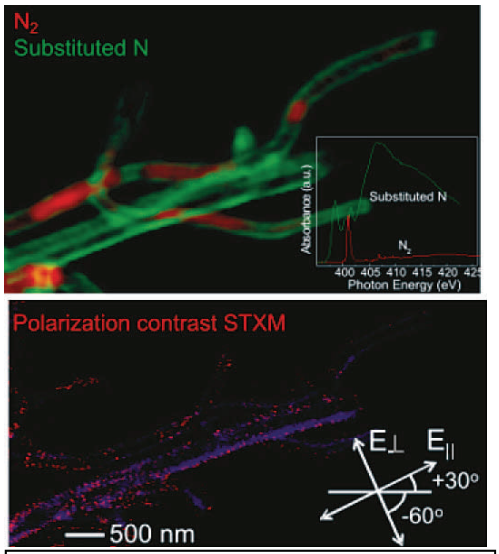
The nature of the nitrogen inside the nanotubes surprised the researchers. Trapped in compartments 100 nanometres across that resemble segments of bamboo (for comparison, this sheet of paper is about 100,000 nanometres thick). This trapped nitrogen exists at pressures 60 times higher than atmospheric pressure at sea level.

"We have never seen a system like this before," remarks Wang. "We didn't expect to see nitrogen inside the tube at all, and certainly not at these pressures."

The discovery of the nitrogen nanocompartments might lead to new ways to store gases, like hydrogen in a hydrogen-fuelled car.

"The high pressure really surprised us," adds Zhou. "The membranes separating these bamboo-like compartments are made up of only one or two layers of atoms. It really gives a sense of how strong these things are."

"This sort of material can be used in a sensor to detect gases such as carbon monoxide," notes Zhou. "Our next step will be to mount the nanotube in a way that we can measure its response electronically while watching how it responds to a gas on the beamline."



Two false colour images of carbon nanotubes taken at the CLS. In the top picture, nitrogen atoms that have taken the place of carbon atoms within the nanotubes' wall are shown as green, while nitrogen inside bamboo-like cells within the nanotube are red. In the bottom picture, polarized X-rays show the orientation of nitrogen atoms in the nanotube wall (purple) and interior (red).

Fast facts:

- Carbon nanotubes—tubes made out of rolled sheets of carbon atoms—are one of the main building materials used in nanotechnology. On their own, carbon nanotubes are extremely strong. But add some other kind of atom to the nanotube, such as nitrogen, and they can be used in a host of electronic applications.
- For the first time ever, CLS researchers have been able to see the location and orientation of nitrogen both in the walls and inside the compartments of carbon nanotubes.
- The discovery sheds new light on both the amazing strength of carbon nanotubes and their usefulness in building cheaper fuel cells and new kinds of sensors.

Reference: J. Zhou, J. Wiang, et al. 2010. Imaging Nitrogen in Individual Carbon Nanotubes. ***Journal of Physical Chemistry Letters, 1***, 1709-1713.
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