Scientists discover new method for creating high-yield single-walled carbon nanotubes

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Cousins of the 1996 Nobel Prize-winning buckyball, carbon nanotubes have taken the nanotechnology industry by storm. Exhibiting extraordinary strength, flexibility and unique electrical, mechanical and optical properties, these hollow microscopic fibers are being integrated into numerous electronic and biological products—high-performance computer chips, combat jackets, bomb detectors and drug delivery devices for the treatment of diseases.

Pushing the field one step further, scientists at Stanford University have devised a novel method for growing vertical single-walled carbon nanotubes (SWNTs) on a large scale, a feat that has eluded researchers until now. By modifying the industry's standard approach to producing carbon-based materials—plasma-enhanced chemical vapor deposition (PECVD)—they achieved ultra-high-yield growth of SWNTs, thus increasing their application into commercial products. They report their research in the Oct. 26 issue of Proceedings of the National Academy of Sciences.

Carbon nanotubes are cylindrical molecules 2 nanometers in diameter—more than 10,000 times smaller than the width of a human hair. Since their discovery in 1991, multi-walled carbon nanotubes have been easily synthesized using several methods. Yet, large-scale production of smaller single-walled nanotubes into ordered films has remained intangible.

Given widespread commercial use of the PECVD method for economical, robust production of various materials by the semiconductor industry, scientists hoped to harness this same method for generating high-quality single-walled nanotubes. PECVD works by exposing substrates densely seeded with catalytic particles to a hydrocarbon gas such as methane, which should theoretically produce a plush carpet of carbon nanotubes. Previous attempts, however, have generated only sparse and inefficient synthesis of SWNTs.

Hongjie Dai, associate professor of chemistry, and his colleagues discovered the key component to attaining single-walled fibers—adding oxygen to the reaction.

"There is a dilemma here," Dai said. "What we found is that the carbon atoms are good and needed for nanotube growth, but the hydrogen atoms are bad. The carbon atoms try to form the nanotube's planar structure, while at the same time the hydrogen radicals are eating the carbon tube away. This was never realized before in nanotube synthesis."

Adding oxygen remedies the problem. By scavenging up the hydrogen radicals—creating a carbon-rich and hydrogen-deficient environment—growth is jumpstarted, spawning a vertical forest of nanotubes.

Using this method, Dai and his colleagues were able to create 4-inch wafers blanketed with SWNTs. In addition, they devised a method for lifting the nanotubes off their original growth substrate and transferring them onto a variety of more desirable mediums such as plastics and metals—materials incompatible with the high temperatures required for nanotube growth. These planted plastics and metals further expand the nanotubes' commercial utility.

Testing already has begun to determine the effectiveness of single-walled carbon nanotube wafers as a thermal interface material, conducting and dissipating heat away from computer chips. The researchers are pursuing additional applications as well.

Postdoctoral fellow Guangyu Zhang is lead author of the study. Other co-authors are chemistry graduate students David Mann, Li Zhang, Ali Javey, Yiming Li and Erhan Yenilmez, research associate Qian Wang and staff scientist James McVittie. James Gibbons, former dean of the School of Engineering, and Yoshio Nishi, director of the Stanford Nanofabrication Facility, both professors of electrical engineering, also contributed to the work.

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Source: Stanford University (by Anne Strehlow)