Nanotubes grown straight in large numbers

April 23 2008

Duke University chemists have found a way to grow long, straight cylinders only a few atoms thick in very large numbers, removing a major roadblock in the pursuit of nano-scale electronics.

These single-walled carbon nanotubes also follow parallel paths as they grow so they don't cross each other to potentially impede electronic performance, said Duke associate chemistry professor Jie Liu, who leads the research. Carbon nanotubes can act as semiconductors and could thus further scale-down circuitry to features measuring only billionths of a meter.

Liu's team directed swarms of nanotubes to extend in the same direction by using the crystal structure of a quartz surface as a template. The availability of forests of identical nanotubes would allow future nanoengineers to bundle them onto multiple ultra-tiny chips that could operate with enough power and speed for nanoprocessing.

"It's quite an exciting development," said Liu, who has received a patent on the process. "Compared with what other people have done, we have reached a higher density of nanotubes. Wherever you look through the microscope there are nanotubes. And they are much better aligned and grow very straight."

Liu and two coauthors, postdoctoral fellow Lei Ding and graduate student Dongning Yuan, described their accomplishment April 16 in the Journal of the American Chemical Society (JACS). Ding was the study's first author. Their research was funded by the United States Naval

Research Laboratory and by Duke.

Nanotubes have been a focus of research since the 1990s because of their exceptional lightness and strength and their potential to function in a new kind of electronics as either semiconductors or metals -- depending on their individual architectures.

Sized so small they can be viewed only with scanning electron or atomic force microscopes, carbon nanotubes could usher the electronics industry into an even-smaller scale of miniaturization if researchers can leap some fabrication barriers.

"This would break a logjam for reproducing enough of them in identical form to build into working devices," Liu said of his group's new innovation. "With our technique, their densities are high enough over a large area. And every device would be quite the same, even if thousands or a million of them were made," Liu said.

Researchers have for some time been able to coax nanotubes into growing and extending themselves when primed by a catalyst and provided with a continuous source of carbon delivered in a gas.

But, until now, they have been unable to make them grow straight, long and dense enough in a large enough area to be practical for carrying current on the surfaces of semiconducting wafers, Liu said.

Researchers have also been struggling to control growing nanotubes' tendencies to bend and overlap each other as they extend. Such overlaps would impede a future nanocircuit's performance at high operating speeds, he added.

In 2000, a Liu-led research team at Duke became the first to make long and aligned nanotubes grow on surfaces, though not in a sufficiently parallel and straight way, he said. He has also vied with other groups in growing nanotubes to record lengths.

Recently, other scientific groups developed a way to grow perfectly aligned nanotubes along continuous-and-unbroken "single crystal" surfaces of quartz or sapphire.

One team using that method reported making as many as 10 nanotubes grow within the space of a single micron -- one millionth of a meter -- using iron as a catalyst. They also observed areas with nanotubes as dense as 50 per micron. But such numbers at that density are still "low and not uniform enough for many useful electronic applications," Liu said.

In the new JACS report, Liu's group reports improving on that performance by modifying the method.

Using copper as their growth catalyst and gasified alcohol to supply carbon, the Duke researchers found that their nanotubes all extended in the same direction, following parallel paths determined by the crystalline orientation of "stable temperature" (ST)-cut quartz wafers used in electronic applications. "They're like a trains running on tracks that are all very straight," Liu said.

By applying computer chip fabrication-style masks to confine uniform coatings of catalyst within very narrow lines along those crystal orientations, Liu's group was able to keep an unprecedented number of nanotubes growing in parallel, without crossing paths.

"To the best of our knowledge, it is the highest density of aligned, single-wall nanotubes reported," the researchers wrote in JACS.

Once formed on ST-cut quartz, the aligned swarms of nanotubes can be transferred onto the less-expensive semiconductor wafers normally used in computer chips, Liu said. He and collaborators are now exhaustively testing their nanotubes to see how many have the right architectures to serve as semiconductors.

Source: Duke University