NANOTUBE PRODUCTION SET FOR SUPER GROWTH

A new, rapid method for producing carbon nanotubes promises to OPEN A WIDE RANGE OF APPLICATIONS.

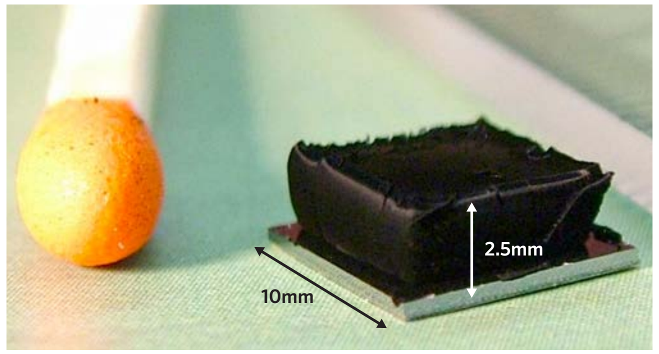
A forest of pure-carbon nanostructures, grown and harvested from a liquid-metal catalytic surface, could find applications ranging from high-performance rubber and resins, to next-generation batteries and computer chips. The miniature forest consists of super-growth, single-walled carbon nanotubes that are roughly a million times longer than they are wide.

A single-walled carbon nanotube can be conceptualized as a single-atom-thick sheet of graphene rolled up to form a long, thin tube. As well as exceptional strength, these carbon nanomaterials boast remarkable electrical properties, including a high electrical conductivity, which can be tuned for use as a semiconductor.

However, their use in practical applications has been hindered by the lack of a straightforward production method. "Few products based on single-walled carbon nanotubes have been developed, because they have been difficult to make," notes Taichi Yatsuzuka of the Carbon Nanotube Division of chemical manufacturer Zeon, based in Tokyo, Japan.

For research-scale production of single-walled carbon nanotubes, a major step forward was made when Kenji Hata and his team at Japan's national research agency, the National Institute of Advanced Industrial Science and Technology (AIST) in Tsukuba, pioneered the highly efficient 'super-growth' method for synthesizing single-walled carbon nanotubes.

Hata, who is the director of the Nano Carbon Device Research Center at AIST, showed that a substrate coated with a liquid-metal catalyst forms an ideal surface for single-walled carbon nanotube growth when placed in a furnace fed with a slightly moist gas stream. "The activity of this catalyst is several hundred times higher than for conventional growth methods," Yatsuzuka says.



▲ A forest of carbon nanotubes grown to about 2.5 millimetres high shown next to a match for scale.

▲ Flexible carbon-nanotube sheets such as this one are promising for realizing long-life batteries.

After refining and adapting the super-growth method for mass production, Zeon began commercial manufacture of super-growth carbon nanotubes in 2015. "We reach 2.5 millimetres of nanotube growth in only 10 minutes," Yatsuzuka says.

The method brings several notable benefits besides speed — super-growth carbon nanotubes possess three main technical advantages over conventionally made carbon nanotubes: long length, large specific surface area and ultrahigh purity. The vertically aligned nanotubes can be simply sliced from the substrate, so that very little catalyst residue is found in the product.

ENHANCED COMPOSITES

The high surface area and long length of super-growth carbon nanotubes — combined with the inherent high strength of carbon nanotubes — make them ideal additives for rubber and resin components, explains Zeon's Toshihiko Jimbo, a sales and marketing manager of the CNT Division. One product already on the market is a super-growth-carbon-nanotube-enhanced fluorine rubber O-ring seal for machinery operating at high temperatures and pressures.

Conventional fluorine rubbers incorporate a simple filler called carbon black, consisting of small carbon particles. O-rings made with this traditional filler degrade and crumble after only 3 hours at 420°C in a nitrogen atmosphere. The super-growth-carbon-nanotube O-ring, in contrast, looked like new after being subjected to the same testing conditions. "It's the same fluoride rubber, the only difference is super-growth carbon nanotube or carbon black, but you get totally different performance," Jimbo says. Although the detailed mechanism for this improved performance is still being investigated, it appears to be related to the entangled, reinforcing network of long super-growth-carbon-nanotube fibres that spread through the rubber.

ADVERTISEMENT FEATURE

"Adding the filler of super-growth carbon nanotubes enhances the rubber's mechanical strength, durability, pressure resistance and chemical stability," Jimbo adds. While carbon nanotubes are more expensive than carbon black, weight for weight, only a small amount of them needs to be added to the rubber to see these enhanced properties, he explains.

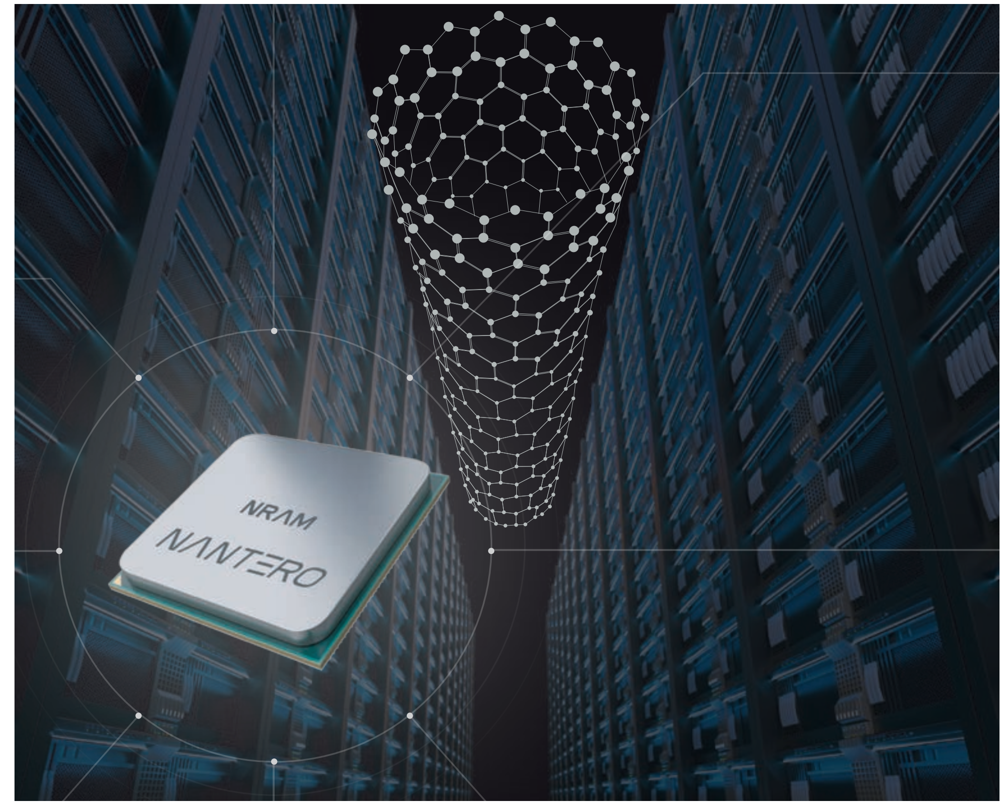
Super-growth-carbon nanotube additives offer additional advantages in applications requiring electrical conductivity. One potential biomedical application, currently in development, is a wearable silicone-rubber device that applies electrical stimulation to reduce essential tremor in the hands of Parkinson's disease patients. When a silicone rubber containing carbon black is stretched or compressed, its electrical resistance changes significantly as the embedded carbon particles are pulled apart.

"But with super-growth carbon nanotubes, the entangled carbon-nanotube network provides a steady electrical resistance during deformation, so we obtain a highly stable conductivity," Jimbo says.

LONG-LIFE BATTERIES

Just as long, thin carbon-based cellulose fibres of wood pulp can be made into sheets of paper, super-growth-carbon nanotubes can be made into robust, self-supporting, thin and flexible carbon-nanotube sheets. "The long length of the super-growth carbon nanotubes allows us to easily make carbon-nanotube sheets without using a binder," Yatsuzuka says. "The sheets are made by suction filtration from a carbon-nanotube dispersion."

By altering the production conditions, the porosity of the resulting sheet can be controlled between 10% and 95%. These materials are now being assessed as potential electrode materials for next-generation rechargeable batteries, Yatsuzuka says.



▲ Low-power, non-volatile nano-random access memory (NRAM) based on carbon nanotubes could drastically reduce the power consumption of data centres.

"WE REACH 2.5 MILLIMETRES OF NANOTUBE GROWTH IN ONLY 10 MINUTES"

"The large specific surface area of sheets of super-growth carbon nanotubes enables them to store a lot of electronic charge, and the high purity results in longer life and improved safety due to no reaction with electrolyte," he says. The sheets may also find use as an electrode material to suppress the growth of lithium dendrite spikes that can damage the battery.

SUSTAINABLE MEMORY

In early 2022, Zeon researchers started leading a 10-year National Project, sponsored by Japan's New Energy and Industrial Technology Development Organization (NEDO), to develop a low-energy memory chip that uses super-growth carbon nanotubes.

"As everybody knows, energy consumption in data centres is a huge problem," Jimbo says. The team is leading the development of a novel form of computer memory called nano-RAM (NRAM). To store data, nanotubes in the chip can exhibit a unique performance — switching on or off the current flow — to represent the '1s' and '0s' of binary computer data. A small voltage can flip the pairs between these two states.

Like conventional DRAM memory technology, NRAM promises high-speed data storage. However, whereas DRAM is an energy-hungry 'volatile' memory technology that continually consumes power to retain data, NRAM is non-volatile memory with no continual power requirement. Thus, NRAM could be used to reduce the carbon footprint of high-performance servers in data centres.

The team's target is to get a real NRAM product to the market as soon as possible. Zeon's high-quality, reliably manufactured, ultrapure carbon nanotubes will be critical to the success of the project. This may be the first time that a chemical company has led a project to develop a new memory chip, say the scientists. ■

ZEON

www.zeon.co.jp/en