The original nano workout -- Helping carbon nanotubes get into shape

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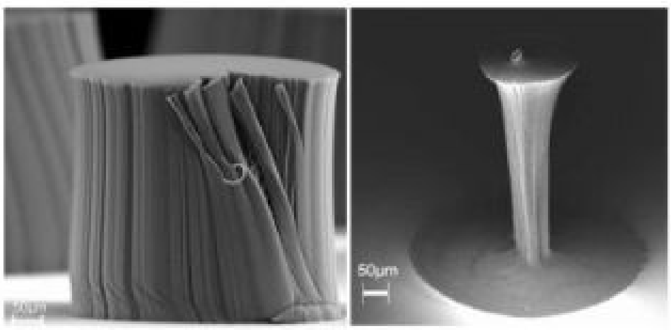
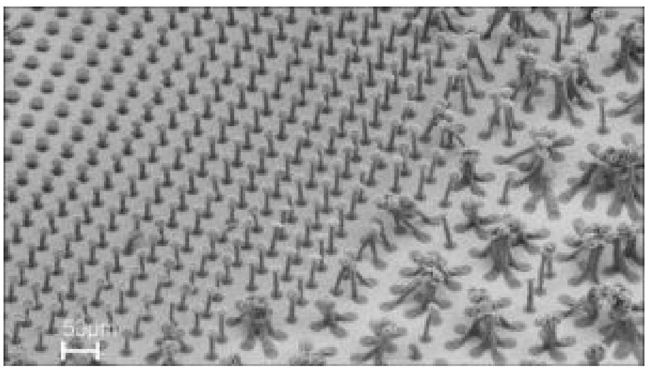


A carbon nanotube bundle before (left) and after (right) densification. Credit: Rensselaer/Liu

Researchers at Rensselaer Polytechnic Institute have developed a new method of compacting carbon nanotubes into dense bundles. These tightly packed bundles are efficient conductors and could one day replace copper as the primary interconnects used on computer chips and even hasten the transition to next-generation 3-D stacked chips.

Theoretical studies show that carbon nanotubes, if packed closely enough together, should be able to outperform copper as an electrical conductor. But because of the way carbon nanotubes are grown – in sparse nanoscale "forests" where carbon molecules compete for growth-inducing catalysts – scientists have been unable to successfully grow tightly packed bundles.

James Jiam-Qiang Lu, associate professor of physics and electrical engineering at Rensselaer, together with his research associate Zhengchun Liu, decided to investigate how to “densify” carbon nanotube bundles after they are already grown. He detailed the results of the post-growth densification project on June 6 at the Institute of Electrical and Electronics Engineers’ International Interconnect Technology Conference (IITC) in Burlingame, Calif.



Nanotube height, diameter and spacing affect the densification process. If the nanotube bundles are too short, like those on the left, there is no densification at all. If the bundles are too tall, like those on the right, bundles are not rigid enough and tend to stick with one another after densification. The middle region, where bundles are between 30-65 micrometers tall, demonstrates good densification. Credit: Rensselaer/Liu

Lu’s team discovered that by immersing vertically grown carbon nanotube bundles into a liquid organic solvent and allowing them to dry, the nanotubes pull close together into a dense bundle. Lu attributes the densification process to capillary coalescence, which is the same physical principle that allows moisture to move up a piece of tissue paper that is dipped into water.

The process boosts the density of these carbon nanotube bundles by five to 25 times. The higher the density, the better they can conduct electricity, Lu said. Several factors, including nanotube height, diameter, and spacing, affect the resulting density, Liu added. How the nanotubes are grown is also an important factor that impacts the resulting shape of the densified bundles.

Images of the experiment are more striking than any “before and after” photos of the latest fad diet. In one instance, Liu started with a carbon nanotube bundle 500 micrometers in diameter, shaped somewhat like a marshmallow, and dipped it into a bath of isopropyl alcohol. As the alcohol dried and evaporated, capillary forces drew the nanotubes closer together. Van Der Waals forces, the same molecular bonds that boost the adhesion of millions of setae on gecko toes and help the lizard defy gravity, ensure the nanotubes retain their tightly packed form.

The resulting bundle shrunk to a diameter of 100 micrometers, with a 25-fold increase in density. Instead of a marshmallow, it looked more like a carpenter’s nail.

“It’s a significant and critical step toward the realization of carbon nanotube interconnects with better performance than copper,” Lu said of his research findings. “But there’s still a lot of work to do before this technology can be integrated into industrial applications.”

Despite his initial successes, Lu said the density results obtained are not ideal and carbon nanotubes would have to be further compacted before they can outperform copper as a conductor. A close-up photo, taken using a scanning electron microscope, reveals there are still large empty spaces between densified nanotubes. The research team is exploring various methods to achieve ever-higher density and higher quality of carbon nanotube bundles, he said.

Lu is confident that these densified carbon nanotubes, with their high conductivity, ability to carry high current density, and resistance to electromigration, will be key to the development of 3-D computer chips. Chips used today can only shrink so much smaller, as their flat surface must have enough room to accommodate scores of different components. But the semiconductor industry and academia are looking at ways to layer chip components into a vertical stack, which could dramatically shrink the size of the overall chip.

Densified carbon nanotubes, with their ends trimmed and polished, can be the basic building blocks for interconnects that would link the stacked layers of a 3-D computer chip, Lu said.

“Carbon nanotubes are one of the most promising materials for interconnects in 3-D integration,” he said. Other potential applications of the densified nanotubes are high surface area electrodes for supercapacitors, fuel cell electrodes for hydrogen storage, heat dissipation materials for thermal conductors, and other situations that require high electrical, thermal, or mechanical performance.

Source: Rensselaer Polytechnic Institute

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