Scientists Build First Nanotube Computer

Device Is a Milestone on Path Toward Faster, More Powerful Electronics

By Robert Lee Hotz

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In an advance toward a future of smaller, faster and more powerful electronics, researchers at Stanford University on Wednesday unveiled the first working computer built entirely from carbon nanotube transistors.

These seamless cylinders of ultrapure carbon are among many exotic materials researchers are investigating—including the quantum particles inside every atom and the DNA inside every cell—as electronics developers near the limits of conventional silicon transistors.

While primitive, the invention proves that transistors made with these unusual carbon fibers, among the strongest materials yet discovered, can be assembled into a general purpose computer. It can run a basic operating system, perform calculations and switch between different processes running at the same time, the scientists said.

"It really is a computer in every sense of the word," said Stanford University electrical engineer Max Shulaker, who led construction of the device. "This shows that you can build working, useful circuits out of carbon nanotubes and they can be manufactured reliably."

Their research was published Wednesday in Nature.

"They have tamed nanotubes," said carbon electronics expert Franz Kreupl at the Technical Institute of Munich in Germany, who wasn't involved in the project.

Mihail Roco, senior adviser for nanotechnology at the National Science Foundation, which helped fund the work, called the nanotube computer "an important scientific step." If perfected, he said, "this would allow a computer to work faster, and with smaller components and with about one-tenth the energy."

Researchers are tantalized by the digital potential of carbon nanotubes, which are exceptional at conducting electricity and heat, and at absorbing or emitting light. Long a laboratory curiosity, they are made from sheets of carbon just one atom thick and rolled into tubes about 10,000 times thinner than a human hair.

"Of all the candidates that have been considered as a successor to silicon, carbon nanotubes remain the most promising," said Supratik Guha, director of physical sciences at [International Business Machines](http://quotes.wsj.com/IBM) Corp.'s [IBM +0.62%**IBM**](http://quotes.wsj.com/IBM) **in** Your Value Your Change Short position Thomas J. Watson Research Center in Yorktown Heights, N.Y.

The first nanotube transistor—a version of the digital on-and-off switch at the heart of almost every commercial electronics device—was invented in 1998. Until recently, though, researchers found it all but impossible to manufacture batches of the infinitesimally small tubes with the perfect alignment, regularity and purity required for a computer's complex integrated circuits.

Nanotubes are grown, like crystals. They fall into place randomly, like a shower of pick-up sticks, which can cause cross-connections. About 30% develop unpredictable metallic impurities. Any imperfection can cause a short-circuit.

"People said you would never be able to manufacture this stuff," said Stanford electrical engineer Subhasish Mitra, who was part of the project. The researchers developed a special circuit design and a powerful debugging technique to overcome the impurities.

Driven by the commercial possibilities, researchers have been racing to harness the material's promising electrical properties.

Last year, IBM researchers showed off carbon nanotube transistors that run three times as fast as conventional silicon transistors, while using a third of the power. And last October, scientists at the IBM's Watson Research Center reported a way to create batches of 10,000 or more carbon nanotube transistors arrayed on a single computer wafer. They have yet to connect them into a working circuit.

Last week, at Cambridge University in the U.K., scientists said they had devised a simple way to grow the densest array of carbon nanotubes to date—about five times as compact as previous methods, while researchers at the University of Southern California recently found a way to custom-tailor their atomic structure.

At Stanford, the experimental nanotube computer contains 178 transistors formed from "several tens of thousands of carbon nanotubes," Dr. Shulaker said. A conventional silicon chip today can pack two billion transistors in an area the size of thumbnail. The Stanford system contains as many transistors as in the earliest transistor-based computers made in the 1950s. The researchers used a logic design on a par with computers made in the 1960s.

The Stanford scientists assembled 985 of the nanotube computers—each with 178 carbon nanotube transistors—on a single chip wafer, using standard chip-fabrication techniques and design tools.

"What we have demonstrated is a very simple computer," said Stanford engineering professor Philip Wong, who worked on the device. "There is a vast distance between what we accomplished and an eventual product."