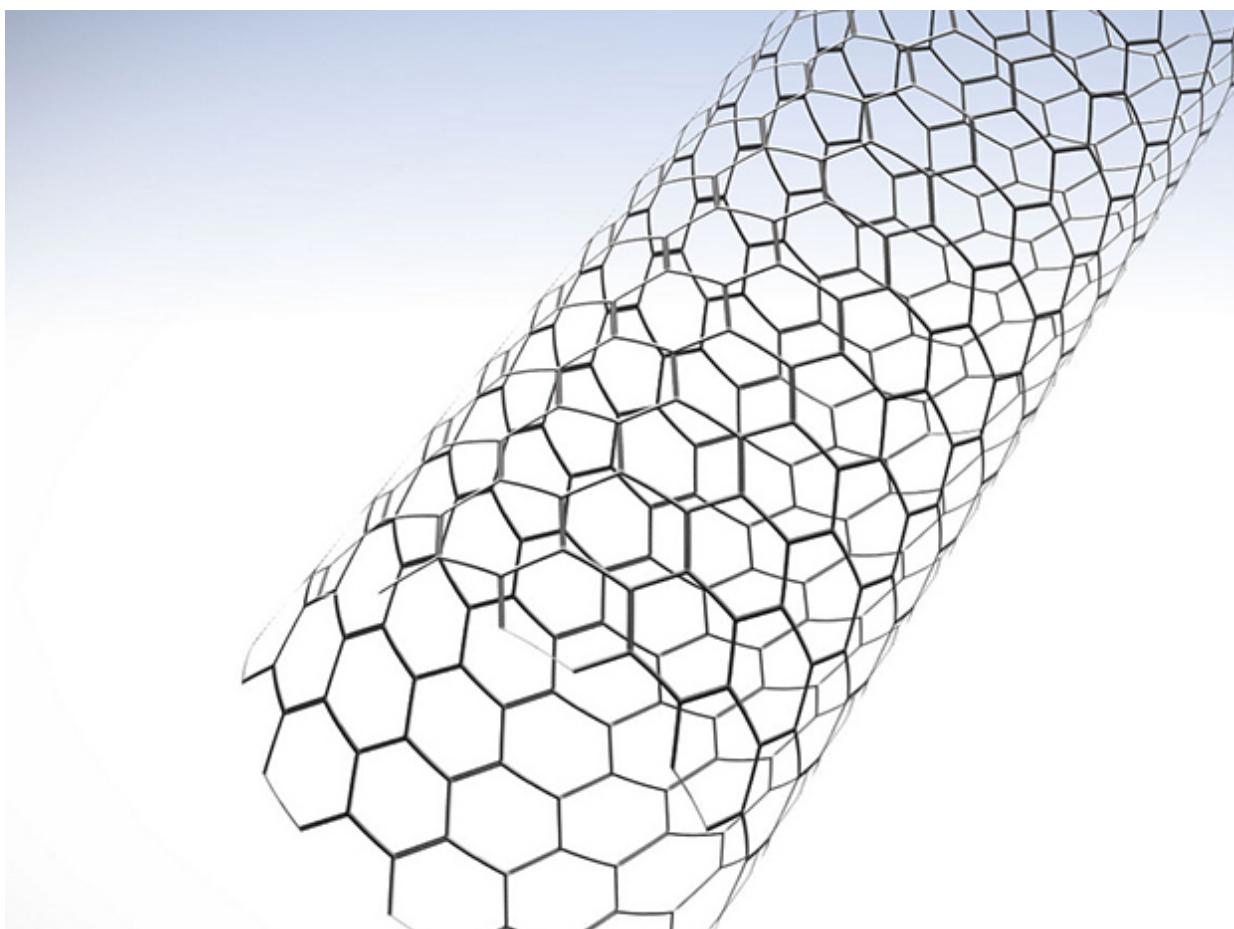


IBM Solves Nanotube Transistor's Big Shrinking Problem

By Jeremy Hsu

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Carbon nanotubes could allow transistors on computer chips to shrink beyond the physical limits of today's silicon switches. But to get there, nanotube transistors would need to get past a major hurdle, the resistance between the nanotube and the metal contacts that inject current into them. Now IBM researchers have broken through that barrier (<https://www-03.ibm.com/press/us/en/pressrelease/47767.wss>), paving the way to devices that could be the heart the next decade's chips.

Resistance between the metal contacts and the semiconductor channel in a transistor tends to increase when the size of the contacts is reduced, and that limits the device's performance. This has been a particular problem for carbon nanotube transistors, because, although IBM has made devices with a channel a mere 10 nanometers across, the contacts had to be comparatively huge.

IBM solved that problem using a kind of microscopic welding process that bonded metal contacts made of molybdenum to carbon nanotubes so that the nanotube ends at the contact. Unlike other contact forming processes, this one chemically binds the metal and the nanotube. The breakthrough enabled the company's engineers to

demonstrate a nanotube transistor with a contact length of just 9 nm and minimal contact resistance (25–35 kilohm).

"The key innovation is not only that we made a 9-nanometer device, but also that the contact resistance no longer depends on the size of the contact," says Shu-Jen Han, manager of the Nanoscale Device & Technology team at IBM. The researchers reported their results in the 2 Oct 2015 issue of the [journal Science](http://www.sciencemag.org/lookup/doi/10.1126/science.aac8006) (<http://www.sciencemag.org/lookup/doi/10.1126/science.aac8006>).

Transistors have traditionally relied on a design that bonds the metal contacts lengthwise along the main body of the transistor's semiconductor material—making a long contact along the channel. By comparison, the "end-bond" configuration enabled IBM to shrink the contact length of the experimental nanotube transistors from 300 nanometers to just 10 nanometers without any increases in the contact resistance.

Silicon transistors have spurred decades of progress along the lines of [Moore's Law](http://spectrum.ieee.org/static/special-report-50-years-of-moores-law) (<http://spectrum.ieee.org/static/special-report-50-years-of-moores-law>)—an expectation of doubling the transistors in a computer chip every two years—but they've begun to approach their physical limits.

Carbon nanotubes hold the promise of a material that can pick up where silicon leaves off. In less than two decades, IBM has pioneered nanotube transistors that perform efficiently at half the size of today's silicon transistors. The company's latest success in overcoming the contact resistance problem means that it can continue making smaller nanotube transistors without running into performance issues.

The recent breakthrough should accelerate the timeline for developing nanotube transistors, Han says. IBM expects the end-bond configuration for nanotube transistors to efficiently scale all the way down to the 1.8-nanometer node. That's roughly the equivalent of four transistor technology generations into the future. As Han explains:

It gives us faith, because we see the data and we really believe we can scale carbon nanotube transistors down that small. Previously we saw channels as easy to understand but contacts as tricky to understand. Contacts were the big question mark. But now, because of this demonstration, it really ends our doubts.

Of course, it's one thing to make an experimental carbon nanotube transistor and another thing to churn out billions of such transistors at a quality suitable for future computer chips. Teams at IBM, Stanford University, and elsewhere have independently worked on creating [dense arrays of nanotube transistors](http://spectrum.ieee.org/semiconductors/materials/carbon-nanotube-transistors-go-headtohead-with-silicon) (<http://spectrum.ieee.org/semiconductors/materials/carbon-nanotube-transistors-go-headtohead-with-silicon>) that could rival silicon transistors.

Han and his IBM colleagues plan to focus on improving the manufacturability and reliability of the nanotube transistors

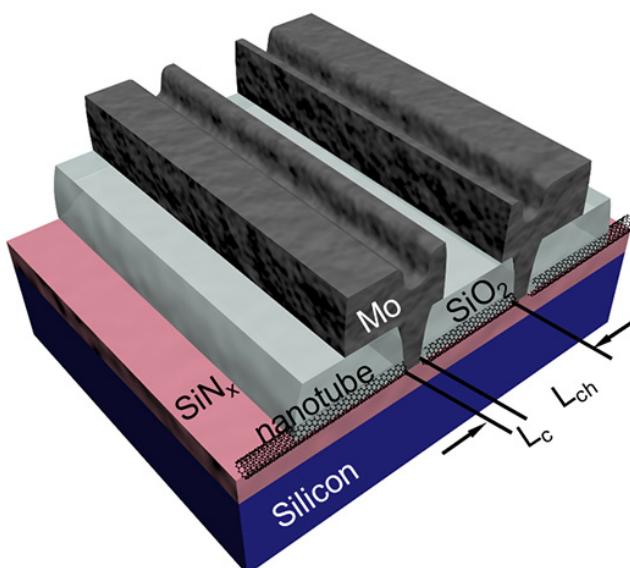


Illustration: IBM Research

Schematic showing the fabricated nanotube transistor with an end-bonded contact and a contact length below 10 nanometers

demonstrated in their latest research. But first, they hope to experiment with different metals besides molybdenum to see if they can improve upon the already low contact resistance.

Beyond transistors, Han pointed out that a future filled with carbon nanotubes could offer much more to the world than just the next generation of faster electronic devices. Nanotubes could prove useful material for new flexible electronics such as a [stretchable, conductive fiber](http://spectrum.ieee.org/nanoclast/semiconductors/materials/stretchable-conducting-fiber-provides-super-hero-capabilities) (<http://spectrum.ieee.org/nanoclast/semiconductors/materials/stretchable-conducting-fiber-provides-super-hero-capabilities>). The tiny carbon tubes could also lead to small sensors and electronics wirelessly linked together with other devices in the so-called [Internet of Things](http://spectrum.ieee.org/searchContent?q=internet+of+things&type=&sortby=relevance) (<http://spectrum.ieee.org/searchContent?q=internet+of+things&type=&sortby=relevance>).

Editor's Note: The original story mistakenly said that IBM has shrunk the channel length of the experimental nanotube transistors from 300 nanometers to just 10 nanometers without any increases in the contact resistance. This has been corrected from "channel length" to "contact length."