Tangled Nanotubes Make Speedy Transistors

By Rachel Courtland
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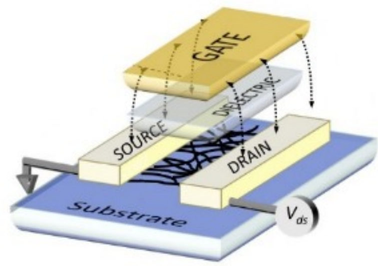
Building a good transistor is all about order – straight lines, precise dimensions, orderly crystals, and smooth films (at least on a larger-than-atomic level).



So it was a bit incongruous to walk the poster session at the Device Research Conference in Santa Barbara, CA last week and find a report of transistors that incorporate what is best described as a tangle of material – pick-up stick (http://en.wikipedia.org/wiki/Pick-up_sticks) jumbles of semiconducting carbon nanotubes.

Graduate student Nima Rouhi and others in Peter Burke's group (http://nano.ece.uci.edu/index.htm) at the University of California, Irvine have been studying these unusual transistors, which contain channels made with carbon nanotube ink. The team is hoping to optimize methods for making printable, flexible devices at temperatures low enough not to damage plastic substrates.

Despite their tangled nature, nanotube networks are actually quite good at transporting electrons from tube to tube across a channel. The behavior has already been used to make simple devices. Last year, for example, researchers at Sunchon National University in South Korea reported they had made one-bit flexible plastic RFID tags (http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=5406115) that use carbon nanotubes printed on a roll-to-roll device.

But, Rouhi says, a vital ingredient has been missing from studies of these nanotube devices: an understanding of how the concentration of nanotubes in the channel impacts transistor performance.

At first, it wasn't clear that nanotube density would have an effect. But in early wafers made by dropping and drying ink, the team found their transistors had a much wider range of properties than expected: some drew far more current while they were on and some were difficult to turn off.

After eliminating every conceivable explanation, Rouhi says, he finally put a wafer under a scanning electron microscope and had what might be described as a Eureka moment. The speediest channels had noticeably more nanotubes. "That was the most exciting moment of my whole career here," Rouhi says.

When the team began controlling the concentration of nanotubes in the ink and the surface properties of their silicon wafer, they found they could exert fairly fine control over the electronic properties of their devices. Transistors with a fairly low density of nanotubes have big on-off current ratios that make them well-suited for digital applications. The transistors with higher-density channels boast high electron mobility, ideal for radio frequency devices like RFID tags.

The team's speediest devices had electron mobilities in the range of 90 cm^2/Vs, roughly a hundred times greater than amorphous silicon used in thin film electronics and about four times the mobility of amorphous oxides (http://spectrum.ieee.org/semiconductors/materials/thin-fast-and-flexible-semiconductors/0). The full details of the team's tests were published last year in Advanced Materials (http://onlinelibrary.wiley.com/doi/10.1002/adma.201003281/full).

In general, the higher the number of nanotubes, the faster electrons sped through transistor channels. There were simply more paths for them to take.

But the team found that if they packed more than 100 nanotubes per square micron in a channel, the difference between a transistor's on current and off current dropped precipitously. Rouhi says the best explanation is that there are a few stray metallic nanotubes in the semiconducting inks. The higher the density of nanotubes in the channel, the higher the probability these metallic tubes will line up to connect the source to the drain, effectively shorting out the transistor. The team expects purer inks and fewer contaminants in the channels could yield transistors with even better performance.

Image: Burke lab