Thursday, January 15, 2009

Bigger, Stretchier Graphene

High-quality, clear graphene films are a leap toward bendable OLED displays.

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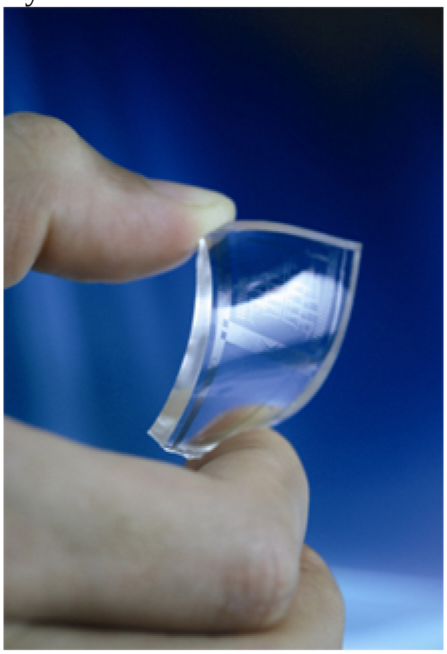

Big and bendy: A transparent graphene film, two centimeters on each side, stretches and flexes when transferred to a rubber stamp. The stamp can be used to deposit the film on any substrate.
Credit: Ji Hye Hong

Korean researchers have found a way to make large graphene films that are both strong and stretchy and have the best electrical properties yet. These atom-thick sheets of carbon are a promising material for making flexible, see-through electrodes and transistors for flat-panel displays. Graphene could also lead to foldable organic light-emitting diode (OLED) displays and organic solar cells. However, it has not been easy finding a way make large, high-quality sheets of graphene.

Researchers from the Sungkyunkwan University and the Samsung Advanced Institute of Technology, in Suwon, Korea, have made centimeters-wide graphene films that are 80 percent transparent and can be bent and stretched without breaking or losing their electrical properties. Others have made large graphene films using simpler techniques, but the new films are 30 times more conductive. In addition, it is easy to transfer the new films onto different substrates. "We have demonstrated that graphene is one of the best materials for stretchable transparent electronics," says Byung Hee Hong, who led the work, which is published in *Nature*.

Graphene is an excellent conductor, and it transports electrons tens of times faster than silicon does. It could replace the brittle indium tin oxide (ITO) electrodes that are currently used in displays, organic solar cells, and touch screens. Graphene transistors could also replace silicon thin-film transistors, which are not transparent and are hard to fabricate on plastic.

The easiest way to make tiny flakes of high-quality graphene is to peel off graphene layers from graphite (which is, essentially, just a stack of graphene sheets). Last year, a group led by Rutgers University materials-science and engineering professor Manish Chhowalla devised a method for making centimeters-scale pieces for practical applications. The researchers dissolved graphite oxide in water, creating a suspension of individual graphene-oxide sheets, which they deposited on top of a flexible substrate.

The Korean researchers use a method called chemical vapor deposition. First, they deposit a 300-nanometer-thick layer of nickel on top of a silicon substrate. Next, they heat this substrate to 1,000 Cº in the presence of methane, and then cool it quickly down to room temperature. This leaves behind graphene films containing six to ten graphene layers on top of the nickel. By patterning the nickel layer, the researchers can create patterned graphene films.

Others, such as MIT electrical-engineering professor Jing Kong, are working on similar approaches to making large graphene pieces. But the Korean researchers have taken the work a step further, transferring the films to flexible substrates while maintaining high quality. The transfer is done in one of two ways. One is to etch away the nickel in a solution so that the graphene film floats on its surface, ready to be deposited on any substrate. A simpler trick is to use a rubber stamp to transfer the film.

Columbia University physics professor Philip Kim, who is a coauthor of the new paper, says that chemical vapor deposition is one of the cheapest ways to make quality graphene on a large scale and should be compatible with existing semiconductor fabrication technologies. Right now, the researchers can make four-inch pieces, but Hong says that they could easily scale up the process.

The new graphene films are less defective than ones made in the past, Hong says, which is why they are about 30 times more conductive and have about 20 times higher mobility than do previous graphene sheets. "The conductivity is sufficient for some entry-level applications in small LCD displays and touch-panel displays," says Yang Yang, a materials-science and engineering professor at the University of California, Los Angeles. However, he adds, the conductivity would still need to be 10 times better in order to replace ITO in organic solar cells and OLEDs.

Many other materials are being considered for transparent, bendable electronics. Carbon nanotubes could be a tough competitor. For example, researchers are making headway with creating flexible nanotube transistors, and Unidym, based in Menlo Park, CA, will soon start selling nanotube-coated plastic films, which could be used instead of ITO coatings on displays.

Others have made flexible, see-through transistors using indium-oxide coatings, or zinc-oxide and indium-oxide nanowires. Meanwhile, University of Michigan researchers have made transparent electrodes using a grid of very thin metal wires.

Graphene's advantage could be its exceptional strength and high mobility (predicted to be twice that of nanotubes). Tao He, a graphene researcher at Rice University, says that the conductivity and mobility values of the new films are impressive. "I didn't see any [other work] similar or comparable to this one," he says, adding that the new work could make large-scale, low-cost manufacture of flexible graphene electronics possible.