BIOELECTRONICS

The bionic material

Graphene could make an ideal basis for a medical repair kit.

BY CHARLES SCHMIDT

More and more people are having their ruined body parts replaced with prostheses interconnected to the nervous system. Advances in graphene technology might bring these artificial devices to their senses — in bionic eyes and ears.

Graphene is impervious to the harsh ionic solutions found in the human body. Moreover, graphene's ability to conduct electrical signals means it can interface with neurons and other cells that communicate by nerve impulse, or action potential. These features have made graphene a material of some promise in next-generation bionic technology.

In November 2011, Jose Garrido, a nanotechnologist at the Walter Schottky Institute in Munich, Germany, took a big bionic step when he showed that arrays of transistors made of graphene can detect action potentials in heart cells.

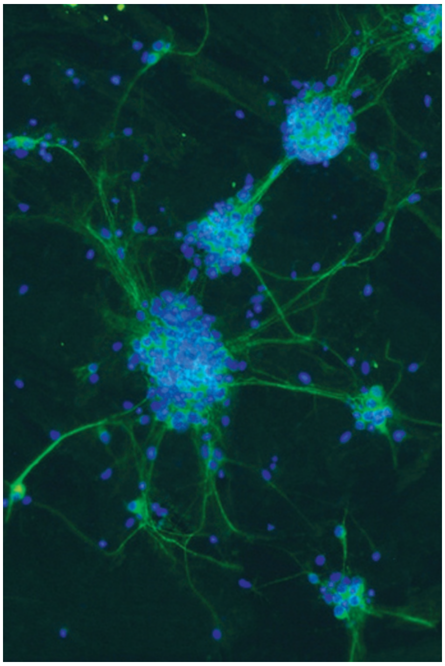
Garrido's work was a welcome breakthrough, says Philippe Bergonzo of CEA-LIST in Saclay, France; Bergonzo is coordinator of NeuroCare, a European project looking into using carbon-based implants in ears, eyes and the brain. Apart from its stability and favourable electronic properties, graphene is also flexible, so it can be wrapped around delicate tissues. No other material shares all these features, Bergonzo says, adding that graphene opens up research opportunities in neural prosthetics.

To make graphene transistors, Garrido uses a method called chemical vapour deposition (see 'Beyond sticky tape', page S32) and grows a layer of cardiomyocytes directly on top of the array.

HOW IT WORKS

Like other electrogenic cells, cardiomyocytes use action potentials to pass electrical signals along from cell to cell. Each of those voltage spikes changes the local electrostatic environment by inducing a flow of ions in the channel in the electrolyte separating the cells and the transistors. Garrido's transistors respond to this ion current by altering their electrical resistance, explains James Hone, who specializes in nanoscale devices at Columbia University in New York. The fluctuation in resistance constitutes a detectable signal between cardiomyocytes.

Unlike silicon transistors, those made of graphene can't be switched off — its physical properties don't allow for that, Hone says — and this means they're not suited to digital applications where devices must be able to generate ones and zeroes (see 'Back to analogue', page S34). What graphene transistors are good at, according to Garrido, is biological sensing — the sort of task that eyes and ears perform. In such analogue applications, the ability to switch off is not critical, and graphene's distinct qualities come to the fore. Should silicon transistors be used in the human body, they would need to be coated with metal oxide to boost their stability in solution, Garrido says. Those layers trap ions that produce noisy interference and thus degrade signal quality. Graphene transistors, on the other hand, don't require an oxide coat so they generate less intrinsic noise, which enables them to detect the faint signals (generally below a few hundred microvolts) of cell communication.



Cortical neurons being grown on graphene for use as biological implants (nuclei are stained blue).

JAMES M. TOUR/RICE UNIVERSITY

Graphene is not the only carbon-based material with bionic potential. Diamond nanocrystals show promise in retinal implants to treat blindness, says Bergonzo. But diamond is solid, inflexible and a poor conductor. For Bergonzo and his collaborators at NeuroCare — which is expected set to launch in March 2012 with an expected budget of US$6.3 million — the optimal neural device will both sense and stimulate cell activity. "That's where we expect a breakthrough from graphene," Bergonzo says. "We'd like to know how neural networks are behaving in real time so we can stimulate them more effectively. Otherwise, you risk giving too much stimulation, or not enough."

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Serge Picaud, principal investigator with the Vision Institute in Paris, involved in the NeuroCare project, adds that because graphene is so thin, it could improve the interface between retinal implants and eye tissues. And those closer connections, he says, could improve sight.

REMAINING CHALLENGES

Hone emphasizes that research into graphene-based bioelectronics is in its infancy. Scientists still face fundamental challenges in manufacturing, he says. Chemical vapour deposition, in particular, doesn't generate perfect graphene, and this limits the material's electronic performance (see 'Beyond sticky tape', page S32).

Moreover, materials scientist John Rogers at the University of Illinois in Urbana–Champaign cautions that silicon is still a contender. Silicon can be fabricated into structures as thin as 10 nm; while that doesn't match the 1-nm dimensions possible with graphene, it might just work. What's more, Rogers points to a deep scientific and engineering base for silicon in the semiconductor industry. Rogers says that researchers are finding new ways to encapsulate implanted silicon devices so they don't harm tissue. Still, Rogers sees tremendous opportunities for graphene in bioelectronic sensing because of the carbon material's much lower electrical noise. He envisages a hybrid approach that takes advantage of the strengths of both silicon and graphene. "I don't think you'd want to make your entire electronic system out of graphene," he says. "You could use ultra-thin silicon for switching and processing hardware and then use graphene to establish your interface with tissue."

For his part, Garrido says he's now working to stack graphene transistor arrays on flexible substrates, such as the biocompatible polymers parylene and polyimide, each mechanically and heat stable. Graphene is clearly an "enabling material", he says. "And it has properties that could lead to a whole new generation of neural devices." ■

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1. Hess, L. H. *et al. Adv. Mat.* **23,** 5045–5049 (2011).