Graphene Makes Transistors Tunable

But even the "wonder material" has its limits

By Neil Savage

Posted 31 Aug 2009 | 4:00 GMT

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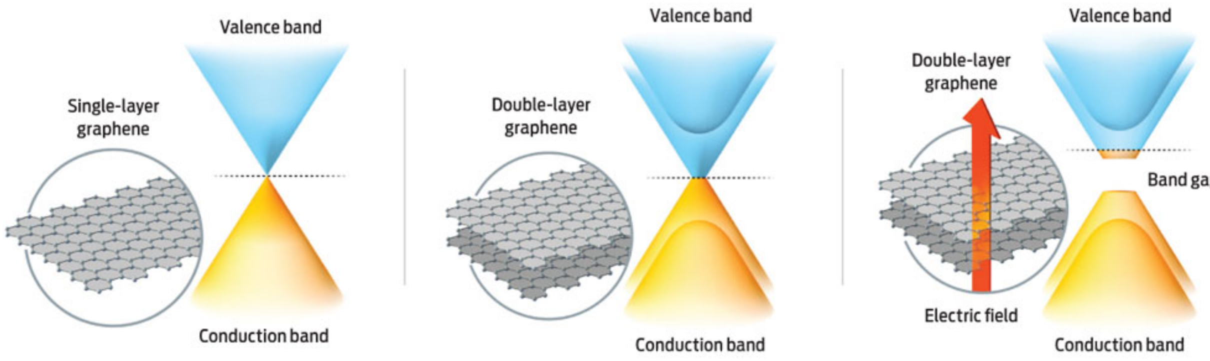

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Image: Emily Cooper

Breaking Symmetry: The existence of an energy gap between the conduction and valence electron bands of a semiconductor is what makes it possible for the material to act as a semiconductor. In both single-layer and double-layer graphene [left and middle], the valence and conduction bands are in effect conical and meet at a point, with no band gap. The introduction of an electric field perpendicular to the layers [right] creates an asymmetry, which generates a band gap. Though small, the gap is tunable, creating possibilities for new devices.

Graphene, a one-atom-thick layer of carbon atoms, is the strongest material ever tested and more conductive than the purest silver. Since its isolation in 2004, scientists have been dreaming of impossibly tiny graphene transistors. But there's a major challenge: The material has no electronic band gap, the semiconductor property that controls the operations of transistors, lasers, and other solid-state devices.

It's now been demonstrated, however, that graphene can be given a band gap—and not just any band gap, but a tunable one. The ability to modify a device's energy gap could lead to detectors that respond only to a particular wavelength of light or light emitters whose color is controlled.

Researchers at the University of California, Berkeley, and Lawrence Berkeley National Laboratory produced the band gap in a field-effect transistor, or FET, made from two layers of graphene. Though the maximum energy gap is only about a quarter of those typically found in silicon devices, the researchers believe it is big enough to allow for new kinds of semiconductor nanodevices.

Graphene lacks a band gap because of its symmetrical structure—its atoms scatter electrons in such a way that they cancel each other out. But "when we apply an electric field perpendicularly to the graphene, we break the symmetry and create a band gap," explains Feng Wang, head of the Ultra-Fast Nano Optics Group at UC Berkeley and lead author of a recent *Nature* paper describing the work [see diagram, "Breaking Symmetry"]. The symmetry can also be broken by doping one layer of graphene with metal atoms, but such doping is hard to control.

The team built their device by making a bottom gate layer out of silicon, with a thin layer of silicon oxide as an insulator. On top, they placed the two layers of graphene, with gold at each end to act as a source and a drain. Above that they put a layer of sapphire, and above the sapphire they placed a second gate made of platinum. By applying an electrical field at the gates, they were able to create a continuously tunable band gap ranging from 0 to 250 millielectron volts.

That's well short of the 1.1¿¿¿electron-volt band gap of silicon, but still valuable, says Wang, who believes he'll be able to achieve a maximum band gap of about 300 meV. "I think it can be useful, because it's already a dramatic change, but it will not function exactly like silicon," Wang says. It takes a larger band gap to get a big enough contrast between the high-voltage "on" state of the device and the low-voltage "off" state. "If you need the ultimate off state, this will not be ideal," he concedes.

Indeed, the on/off ratio of such a bilayer graphene transistor would not be high enough to meet the specifications laid out in the International Technology Roadmap for Semiconductors, says Gianluca Fiori, an assistant professor in the information engineering department at the University of Pisa, in Italy. He and his colleague Giuseppe Iannaccone ran computer simulations of bilayer graphene FETs using a supply voltage of 0.5 V between the source and the drain, as called for in the road map, and determined that the band gap could not suppress the flow of current enough to make a sharp distinction between the on state and the off state.

"Maybe you can think of using this kind of material not for high-performance transistors but for ultralow-power devices," Fiori says. "If you think that in the future you can use this kind of transistor in portable electronics, maybe you will only recharge the batteries once per month."

Wang believes that bilayer graphene may be more useful as an optical material than as a competitor to silicon transistors. For instance, it might be used for infrared light sources and sensors for measuring biological molecules, many of which have unique signatures in the infrared.

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