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Graphene Transistors
A new form of carbon being pioneered by Walter de Heer could lead to speedy, compact computer processors.
By Kevin Bullis

WHO
Walter de Heer, Georgia Tech

DEFINITION
Transistors based on graphene, a carbon material one atom thick, could have extraordinary electronic properties.

IMPACT
Initial applications will be in -ultrahigh-speed communications chips, with computer processors to follow.

CONTEXT
A number of academic researchers and several electronics companies are studying graphene-based electronics.

The remarkable increases in computer speed over the last few decades could be approaching an end, in part because silicon is reaching its physical limits. But this past December, in a small Washington, DC, conference room packed to overflowing with an audience drawn largely from the semiconductor industry, Georgia Tech physics professor Walter de Heer described his latest work on a surprising alternative to silicon that could be far faster. The material: graphene, a seemingly unimpressive substance found in ordinary pencil lead.

Theoretical models had previously predicted that graphene, a form of carbon consisting of layers one atom thick, could be made into transistors more than a hundred times as fast as today's silicon transistors. In his talk, de Heer reported making arrays of hundreds of graphene transistors on a single chip. Though the transistors still fall far short of the material's ultimate promise, the arrays, which were fabricated in collaboration with MIT's Lincoln Laboratory, offer strong evidence that graphene could be practical for future generations of electronics.

Today's silicon-based computer processors can perform only a certain number of operations per second without overheating. But electrons move through graphene with almost no resistance, generating little heat. What's more, graphene is itself a good thermal conductor, allowing heat to dissipate quickly. Because of these and other factors, graphene-based electronics could operate at much higher speeds. "There's an ultimate limit to the speed of silicon—you can only go so far, and you cannot increase its speed any more," de Heer says. Right now silicon is stuck in the gigahertz range. But with graphene, de Heer says, "I believe we can do a terahertz—a factor of a thousand over a gigahertz. And if we can go beyond, it will be very interesting."

Besides making computers faster, graphene electronics could be useful for communications and imaging technologies that require ultrafast transistors. Indeed, graphene is likely to find its first use in high-frequency applications such as terahertz-wave imaging, which can be used to detect hidden weapons. And speed isn't graphene's only advantage. Silicon can't be carved into pieces smaller than about 10 nanometers without losing its attractive electronic properties. But the basic physics of graphene remain the same—and in some ways its electronic properties actually improve—in pieces smaller than a single nanometer.

Interest in graphene was sparked by research into carbon nanotubes as potential successors to silicon. Carbon nanotubes, which are essentially sheets of graphene rolled up into cylinders, also have excellent electronic properties that could lead to ultrahigh-performance electronics. But nanotubes have to be carefully sorted and positioned in order to produce complex circuits, and good ways to do this haven't been developed. Graphene is far easier to work with.

In fact, the devices that de Heer announced in December were carved into graphene using techniques very much like those used to manufacture silicon chips today. "That's why industry people are looking at what we're doing," he says. "We can pattern graphene using basically the same methods we pattern silicon with. It doesn't look like a science project. It looks like technology to them."

Graphene hasn't always looked like a promising electronic material. For one thing, it doesn't naturally exhibit the type of switching behavior required for computing. Semiconductors such as silicon can conduct electrons in one state, but they can also be switched to a state of very low conductivity, where they're essentially turned off. By contrast, graphene's conductivity can be changed slightly, but it can't be turned off. That's okay in certain applications, such as high-frequency transistors for imaging and communications. But such transistors would be too inefficient for use in computer processors.

In 2001, however, de Heer used a computer model to show that if graphene could be fashioned into very narrow ribbons, it would begin to behave like a semiconductor. (Other researchers, he learned later, had already made similar observations.) In practice, de Heer has not yet been able to fabricate graphene ribbons narrow enough to behave as predicted. But two other methods have been shown to have similar promise: chemically modifying graphene and putting a layer of graphene on top of certain other substrates. In his presentation in Washington, de Heer described how modifying graphene ribbons with oxygen can induce semiconducting behavior. Combining these different techniques, he believes, could produce the switching behavior needed for transistors in computer processors.

Meanwhile, the promise of graphene electronics has caught the semiconductor industry's attention. Hewlett-Packard, IBM, and Intel (which has funded de Heer's work) have all started to investigate the use of graphene in future products.

Potential graphene applications include lightweight, thin, and flexible electric/photonics circuits, solar cells, and various medical, chemical and industrial processes enhanced or enabled by the use of new graphene materials. In 2008, graphene produced by exfoliation was one of the most expensive materials on Earth, with a sample the area of a cross section of a human hair costing more than $1,000 as of April 2008 (about $100,000,000/cm2). Since then, exfoliation procedures have been scaled up, and... Simply put, graphene field-effect transistors take the typical FET device and insert a graphene channel tens of microns in size between the source and drain. Learn more about graphene transistors here. Graphenea is a leading graphene manufacturer, producing high quality graphene products sold worldwide.Â Written By: Miklos Bolza. Graphene has been revolutionizing electronics since October 2004 when Andre Geim and Kostya Novoselov first determined how to remove a single layer of carbon lattice from graphite. What are Graphene Transistors? Alan. 24 March 2020.Â Graphene transistor was brought to people's attention by the 2010 Nobel Prize in Physics. In 2004, Professor Andre Heim and Konstantin Novoselov of the University of Manchester in the United Kingdom stripped graphene from graphite flakes in a very simple way, for which they also won the 2010 Nobel Prize award in Physics. In particular, graphene-based transistors have developed rapidly and are now considered an option for post-silicon electronics. However, many details about the potential performance of graphene transistors in real applications remain unclear. Here I review the properties of graphene that are relevant to electron devices, discuss the trade-offs among these properties and examine their effects on the performance of graphene transistors in both logic and radiofrequency applications. Graphene Transistors to Replace Silicon. 17FebFebruary 17, 2012. Graphene Transistors to Replace Silicon. By Ligo George Electronics Graphene, transistors 0 Comments.Â The newly developed Graphene transistors might replace silicon in computer chips. The main benefit of using Graphene for making transistors is that, we can scale down size of transistors to 10-15 atom across. Thus transistors can be made of nano-scale, thus it can have more transistors in chips, and makes them more powerful.