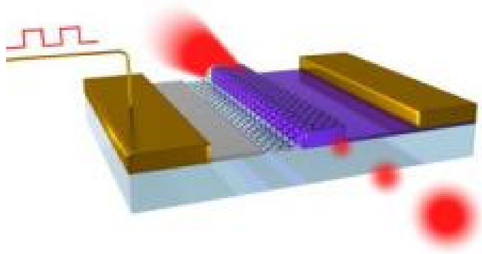
Graphene optical modulators could lead to ultrafast communications

May 8 2011, By Sarah Yang



This is a schematic illustration of the graphene-based optical modulator. A layer of graphene (black fishnet) is placed on top of a silicon waveguide (blue), which is used as an optical fiber to guide light. Electrical signals are sent in from the side of the graphene to alter the amount of photons the graphene absorbs. Credit: Graphic by Ming Liu, UC Berkeley

(PhysOrg.com) -- Scientists at the University of California, Berkeley, have demonstrated a new technology for graphene that could break the current speed limits in digital communications.

The team of researchers, led by UC Berkeley engineering professor Xiang Zhang, built a tiny optical device that uses graphene, a one-atom-thick layer of crystallized carbon, to switch light on and off. This switching ability is the fundamental characteristic of a network modulator, which controls the speed at which data packets are transmitted. The faster the data pulses are sent out, the greater the volume of information that can be sent. Graphene-based modulators could soon allow consumers to stream full-length, high-definition, 3-D movies onto a smartphone in a matter of seconds, the researchers said.

"This is the world's smallest optical modulator, and the modulator in data communications is the heart of speed control," said Zhang, who directs a National Science Foundation (NSF) Nanoscale Science and Engineering Center at UC Berkeley. "Graphene enables us to make modulators that are incredibly compact and that potentially perform at speeds up to ten times faster than current technology allows. This new technology will significantly enhance our capabilities in ultrafast optical communication and computing."

In this latest work, described in the May 8 advanced online publication of the journal *Nature*, researchers were able to tune the graphene electrically to absorb light in wavelengths used in data communication. This advance adds yet another advantage to graphene, which has gained a reputation as a wonder material since 2004 when it was first extracted from graphite, the same element in pencil lead. That achievement earned University of Manchester scientists Andre Geim and Konstantin Novoselov the Nobel Prize in Physics last year.

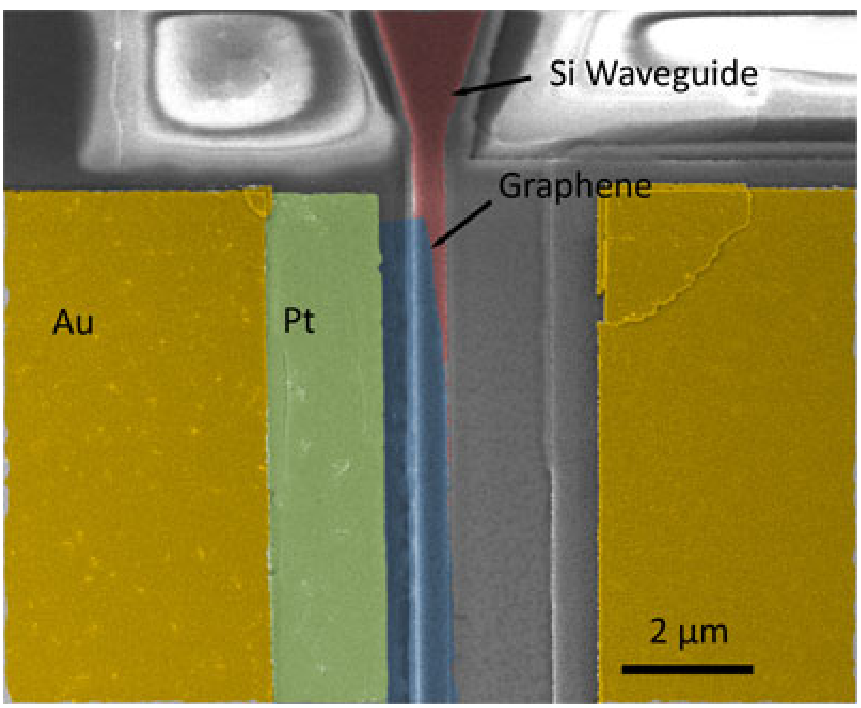
Zhang worked with fellow faculty member Feng Wang, an assistant professor of physics and head of the Ultrafast Nano-Optics Group at UC Berkeley. Both Zhang and Wang are faculty scientists at Lawrence Berkeley National Laboratory's Materials Science Division.

"The impact of this technology will be far-reaching," said Wang. "In addition to high-speed operations, graphene-based modulators could lead to unconventional applications due to graphene's flexibility and ease in integration with different kinds of materials. Graphene can also be used to modulate new frequency ranges, such as mid-infrared light, that are widely used in molecular sensing."

Graphene is the thinnest, strongest crystalline material yet known. It can be stretched like rubber, and it has the added benefit of being an excellent conductor of heat and electricity. This last quality of graphene makes it a particularly attractive material for electronics.

"Graphene is compatible with silicon technology and is very cheap to make," said Ming Liu, post-doctoral researcher in Zhang's lab and co-lead author of the study. "Researchers in Korea last year have already produced 30-inch sheets of it. Moreover, very little graphene is required for use as a modulator. The graphite in a pencil can provide enough graphene to fabricate 1 billion optical modulators."

It is the behavior of photons and electrons in graphene that first caught the attention of the UC Berkeley researchers.



Shown is a scanning electron microscope (SEM) image magnifying the key structures of the graphene-based optical modulator. (Colors were added to enhance the contrast). Gold (Au) and platinum (Pt) electrodes are used to apply electrical charges to the sheet of graphene, shown in blue, placed on top of the silicon (Si) waveguide, shown in red. The voltage can control the graphene's transparency, effectively turning the setup into an optical modulator that can turn light on and off. (Ming Liu image)

The researchers found that the energy of the electrons, referred to as its Fermi level, can be easily altered depending upon the voltage applied to the material. The graphene's Fermi level in turn determines if the light is absorbed or not.

When a sufficient negative voltage is applied, electrons are drawn out of the graphene and are no longer available to absorb photons. The light is "switched on" because the graphene becomes totally transparent as the photons pass through.

Graphene is also transparent at certain positive voltages because, in that situation, the electrons become packed so tightly that they cannot absorb the photons.

The researchers found a sweet spot in the middle where there is just enough voltage applied so the electrons can prevent the photons from passing, effectively switching the light "off."

"If graphene were a hallway, and electrons were people, you could say that, when the hall is empty, there's no one around to stop the photons," said Xiaobo Yin, co-lead author of the Nature paper and a research scientist in Zhang's lab. "In the other extreme, when the hall is too crowded, people can't move and are ineffective in blocking the photons. It's in between these two scenarios that the electrons are allowed to interact with and absorb the photons, and the graphene becomes opaque."

In their experiment, the researchers layered graphene on top of a silicon waveguide to fabricate optical modulators. The researchers were able to achieve a modulation speed of 1 gigahertz, but they noted that the speed could theoretically reach as high as 500 gigahertz for a single modulator.

While components based upon optics have many advantages over those that use electricity, including the ability to carry denser packets of data more quickly, attempts to create optical interconnects that fit neatly onto a computer chip have been hampered by the relatively large amount of space required in photonics.

Light waves are less agile in tight spaces than their electrical counterparts, the researchers noted, so photon-based applications have been primarily confined to large-scale devices, such as fiber optic lines.

"Electrons can easily make an L-shaped turn because the wavelengths in which they operate are small," said Zhang. "Light wavelengths are generally bigger, so they need more space to maneuver. It's like turning a long, stretch limo instead of a motorcycle around a corner. That's why optics require bulky mirrors to control their movements. Scaling down the optical device also makes it faster because the single atomic layer of graphene can significantly reduce the capacitance – the ability to hold an electric charge – which often hinders device speed."

Graphene-based modulators could overcome the space barrier of optical devices, the researchers said. They successfully shrunk a graphene-based optical modulator down to a relatively tiny 25 square microns, a size roughly 400 times smaller than a human hair. The footprint of a typical commercial modulator can be as large as a few square millimeters.

Even at such a small size, graphene packs a punch in bandwidth capability. Graphene can absorb a broad spectrum of light, ranging over thousands of nanometers from ultraviolet to infrared wavelengths. This allows graphene to carry more data than current state-of-the-art modulators, which operate at a bandwidth of up to 10 nanometers, the researchers said.

"Graphene-based modulators not only offer an increase in modulation speed, they can enable greater amounts of data packed into each pulse," said Zhang. "Instead of broadband, we will have 'extremeband.' What we see here and going forward with graphene-based modulators are tremendous improvements, not only in consumer electronics, but in any field that is now limited by data transmission speeds, including bioinformatics and weather forecasting. We hope to see industrial applications of this new device in the next few years."

Provided by University of California - Berkeley

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