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A Step Toward Superfast Carbon Memory
Graphene could make computer hard drives denser and speedier.
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Graphene, a flat sheet of hexagonally arranged carbon atoms, can transport electrons very quickly. This has made it a promising material for high radio-frequency logic circuits, transparent electrodes for flexible flat-panel displays, and high-surface-area electrodes for ultracapacitors.

Now researchers at the National University of Singapore have made computer memory devices using graphene. This is the first step toward memory that could be much denser and faster than the magnetic memory used in today's hard drives. The researchers have made hundreds of prototype graphene memory devices, and they work reliably, according to Barbaros Özyilmaz, the physics professor who led the work presented at a recent American Physical Society meeting in Pittsburgh. "Graphene is going to change the electronic industry," he says. "What was missing was a way to use graphene as a memory element. So far there was almost no interest because it wasn't [thought] doable."

The key to making memory elements is a material that can have two different states. That is because computer memory is stored as two bits: 1 and 0. Hard drives also need to be nonvolatile, which means the material should be able to hold on to those states without requiring power. Today's hard disks are made of magnetic cobalt alloys, and they store bits as one of two magnetic orientations of a small area on the disk.

Özyilmaz and his colleagues came up with an easy way to make graphene hold its two different levels of conductivity, or resistance. Switching between these levels requires applying and removing an electric field. The researchers deposit a thin layer of a ferroelectric material on top of the graphene. Ferroelectrics have an intrinsic electric field, and applying a voltage changes the direction of the field. The ferroelectric's field helps graphene sustain its conductivity. And, Özyilmaz explains, "we can change the polarization of the ferroelectric, which in turn changes the conductivity of graphene."

The new memory idea is "thrilling because it's very simple," says Andre Geim, professor of physics at the University of Manchester, UK, who first isolated graphene sheets from graphite. "Ferroelectrics are well known. It's also known that an electric field changes graphene's resistivity by a factor of typically 10. [Özyilmaz] combines those two very well-known facts."

Graphene memory would have significant advantages over today's magnetic memory.

Bits could be read 30 times faster because electrons move through graphene quickly. Plus, the memory could be denser. Bit areas on hard disks are currently a few tens of nanometers across. At densities of 1 terabit per square inch, they will be about 25 nanometers across, too small to hold their magnetization direction. With graphene, bits could shrink to 10 nanometers or even smaller. In fact, the memory devices would work better with smaller graphene areas. Stanford University researchers have shown that cutting graphene into ribbons a few nanometers wide enhances the difference between its two conductivity states.

The new prototype memory devices, however, are rudimentary. The Singapore researchers take graphene flakes that are 2 micrometers wide and place them on silicon. Then they deposit gold electrodes and add a top layer of the ferroelectric. Özyilmaz says that the device readout time is five times faster than current magnetic memory. The researchers can switch graphene between its two conductivities 100,000 times--practical memory devices go through millions of cycles.

This is not the first attempt at making graphene memory. In an August 2008 *IEEE Electron Device Letters* paper, researchers at the German nanotechnology company AMO described devices that could switch between two conductivity states using an electric field. "We could cycle 20 to 30 times, but not tens of thousands of times," says physicist Max Lemme, lead author of the paper. Lemme speculates that hydroxyl groups and hydrogen attached to the graphene surface detach when current is applied, changing the sheet's conductivity. Why the graphene sheets nonetheless maintain their conductivity when the power is switched off is not well understood.

Geim, who was involved in the AMO work, says that "when you don't know the mechanism, it's hard to judge whether you can in principle make this mechanism reliable to be reproducible on many devices in an identical manner." With the Singapore researchers' approach, however, "we know the physics behind it and its limitations. With well-known fundamentals behind it, it looks like a very good idea."