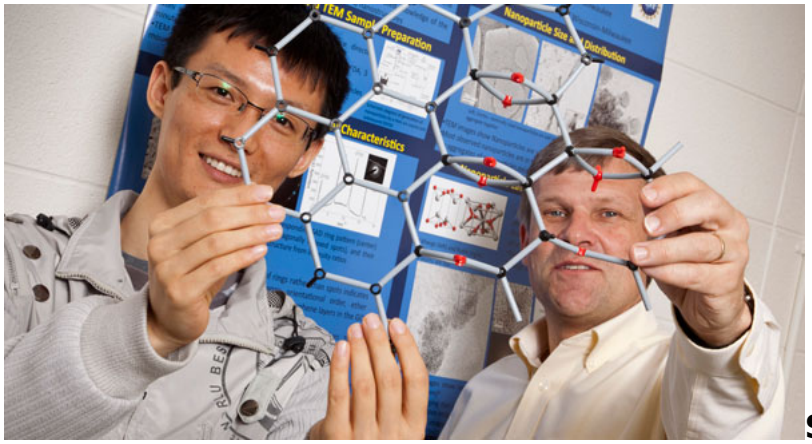
UWM Discovery Advances Graphene-based Electronics

Physics Professor Michael Weinert and engineering graduate student Haihui Pu display the atomic structure on GMO. (Photos by Alan Magayne-Roshak)



Scientists and engineers at the University of Wisconsin-Milwaukee (UWM) have discovered an entirely new carbon-based material that is synthesized from the "wonder kid" of the carbon family, graphene. The discovery, which the researchers are calling "graphene monoxide (GMO)," pushes carbon materials closer to ushering in next-generation electronics.

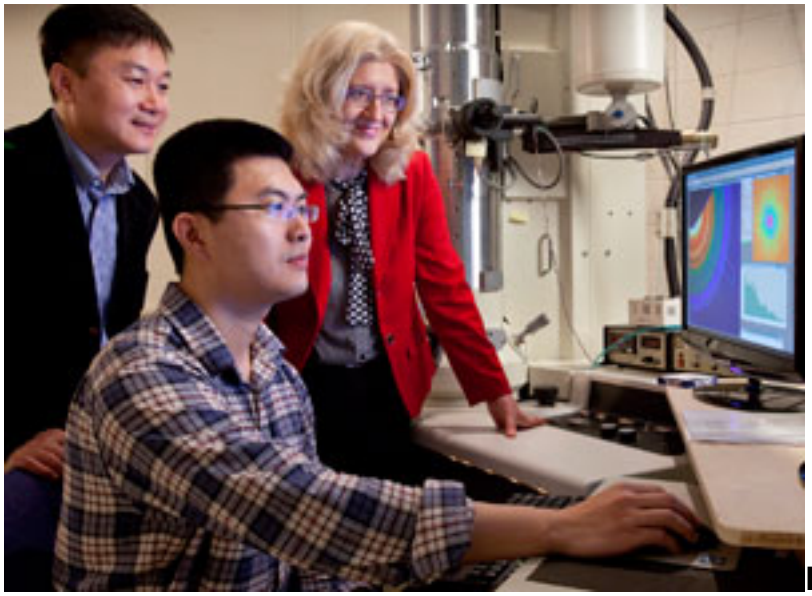
Graphene, a one-atom-thick layer of carbon that resembles a flat sheet of chicken wire at nanoscale, has the potential to revolutionize electronics because it conducts electricity much better than the gold and copper wires used in current devices. Transistors made of silicon are approaching the minimum size at which they can be effective, meaning the speed of devices will soon bottom out. Carbon materials at nanoscale could be the remedy.

Currently, applications for graphene are limited because it's too expensive to mass produce. Another problem is that, until now, graphene-related materials existed only as conductors or insulators.

"A major drive in the graphene research community is to make the material semiconducting so it can be used in electronic applications," says Junhong Chen, professor of mechanical engineering and a member of the research team. "Our major contribution in this study was achieved through a chemical modification of graphene."

GMO exhibits characteristics that will make it easier to scale up than graphene. And, like silicon in the current generation of electronics, GMO is semiconducting, necessary for controlling the electrical current in such a strong conductor as

graphene. Now all three characteristics of electrical conductivity – conducting, insulating and semiconducting – are found in the carbon family, offering needed compatibility for use in future electronics.



Mixing theory and experiments

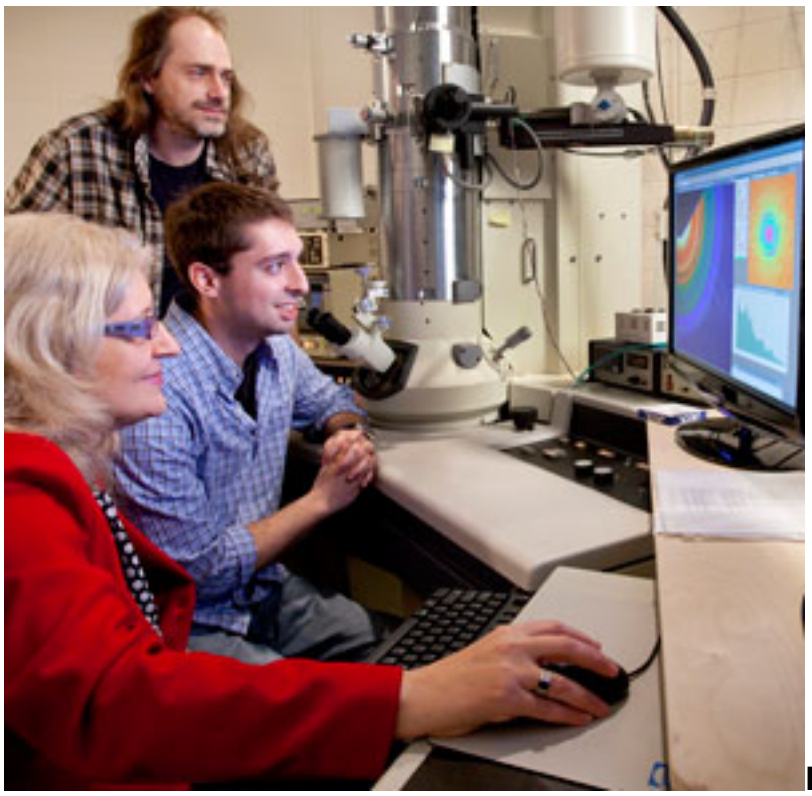
The team created GMO while conducting research into the behavior of a hybrid nanomaterial engineered by Chen that consists of carbon nanotubes (essentially, graphene rolled into a cylinder) decorated with tin oxide nanoparticles. Chen uses his hybrid material to make high-performance, energy-efficient and inexpensive sensors.

To image the hybrid material as it was sensing, he and physics professor Marija Gajdardziska used a high-resolution transmission electron microscope (HRTEM). But to explain what was happening, the pair needed to know which molecules were attaching to the nanotube surface, which were attaching to the tin oxide surface, and how they changed upon attachment.

So the pair turned to physics professor Carol Hirschmugl, who recently pioneered a method of infrared imaging (IR) that not only offers high-definition images of samples, but also renders a chemical “signature” that identifies which atoms are interacting as sensing occurs.

Chen and Gajdardziska knew they would need to look at more attachment sites than are available on the surface of a carbon nanotube. So they “unrolled” the nanotube into a sheet of graphene to achieve a larger area.

That prompted them to search for ways to make graphene from its cousin, graphene oxide (GO), an insulator that can be scaled up inexpensively. GO consists of layers of graphene stacked on top of one another in an unaligned orientation. It is the subject of much research as scientists look for cheaper ways to replicate graphene’s superior properties.



Puzzling outcome

Physics research associate Marvin Schofield (left), physics doctoral student Eric Mattson, and Graduate School associate dean and physics professor Marija Gajdardziska examine the images of GMO using Selected Area Electron Diffraction (SAED) in a transmission electron microscope.

In one experiment, they heated the GO in a vacuum to reduce oxygen. Instead of being destroyed, however, the carbon and oxygen atoms in the layers of GO became aligned, transforming themselves into the “ordered,” semiconducting GMO – a carbon oxide that does not exist in nature.

It was not the result they expected.

“We thought the oxygen would go away and leave multilayered graphene, so the observation of something other than that was a surprise,” says Eric Mattson, a doctoral student of Hirschmugl’s.

At different high temperatures, the team actually produced four new materials that they collectively refer to as GMO. They captured video of the process using Selected Area Electron Diffraction (SAED) in a transmission electron microscope.

Because GMO is formed in single sheets, Gajdardziska says the material could have applications in products that involve surface catalysis. She, Hirschmugl and Chen also are exploring its use in the anode parts of lithium-ion batteries, which could make them more efficient.

Laborious process

But the next step is more science. The team will need to find out what triggered the

reorganization of the material, and also what conditions would ruin the GMO's formation.

"In the reduction process, you expect to lose oxygen," says Michael Weinert, professor of physics and director of UWM's Laboratory for Surface Studies. "But we actually gained more oxygen content. So we're at a point where we're still learning more about it."

Weinert points out that they have only made GMO at a small scale in a lab and are not certain what they will encounter in scaling it up.

The team had to be careful in calculating how electrons flowed across GMO, he adds. Interactions that occur had to be interpreted through a painstaking process of tracking indicators of structure and then eliminating those that didn't fit.

"It was a long process," says Weinert, "not one of those 'Eureka!' moments."

UWM [1]

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