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Beyond nanotubes

Synthesizing a breakthrough material

A unique form of carbon, graphene is the basic structural element of graphite. Essentially a single atom-thick honeycomb lattice of carbon atoms, a sheet of graphene can be rolled into 2D nanotubes or stacked into 3D graphite.

In 2004, physicists from the University of Manchester and the Institute for Microelectronics Technology in Russia isolated individual graphene planes by using Scotch tape on graphite crystals. In 2005 the same Manchester group, along with a research group from Columbia University, demonstrated that graphene electrons are massless Dirac fermions—giving graphene unique electronic and optical properties. These recent discoveries have led to an explosion of interest in graphene.

One major challenge: Graphene has previously only been produced in very small quantities, limiting how well it can be measured, understood and developed.

Michael Mullins is working to synthesize single graphene sheets in the lab. "Our goal is to make large enough quantities of graphene so that it can be shared with other researchers around the world who are studying it for future applications," he says.

Less than one nanometer thick, a graphene sheet is transparent. "Even several layers are still transparent," notes Mullins.

Graphene displays bipolar transistor effect, ballistic transport of charges, and large quantum oscillations. It can also transport electrons more quickly than other semiconductors, a quality called electron mobility.

"It's clearly a breakthrough material," says Mullins. "Graphene possesses the highest strength of any material. It has among the highest heat and electrical conductivity of any material. It can be incorporated into a great number of applications. Graphene can be added to polymers for fuel cell dividers. It can be used in battery electrodes. It is an excellent conductor with a high surface area that can exceed, 2000 m^2 per gram. A graphene sheet is the basic building block for many forms of carbon, including the nanotube. In fact, graphene is a next-generation material beyond the nanotube. But we need to make enough of the material to make it useful."

"Attempting to split bulk graphite into single sheets of graphene is not a very easy process. It can require extreme conditions," Mullins admits. His team is currently exploring two techniques. The first uses very strong acids followed by rinsing with an organic solvent. They run the mixture through an extremely fine filter to collect the sheets. The second uses supercritical carbon dioxide, which adsorbs between the graphite planes, expanding the sheets. This is followed by an injection of a surfactant material to hold the sheets apart so that they can be more easily separated in solution.

As the director of the Center for Fundamental and Applied Research in Nanostructured and Lightweight Materials (CNLM), Mullins has assembled the talents of several researchers working on a wide variety of projects—from heat-tolerant materials to replace the polymer electrolyte membrane in fuel cells to a nickel hydroxide battery electrode that can deliver more power than the batteries now in use at half the weight. Other projects include nanoencapsulation of pharmaceuticals, and nanofibers that are used as a lattice to regenerate nerve axons.

"The thing that ties all our research together is the engineering of hybrid materials at the nanoscale—polymers, ceramics and carbon."