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NEMA The Association of Electrical and Medical Imaging Equipment Manufacturers ■ www.nema.org ■ September 2011 ■ Vol. 17 No. 9

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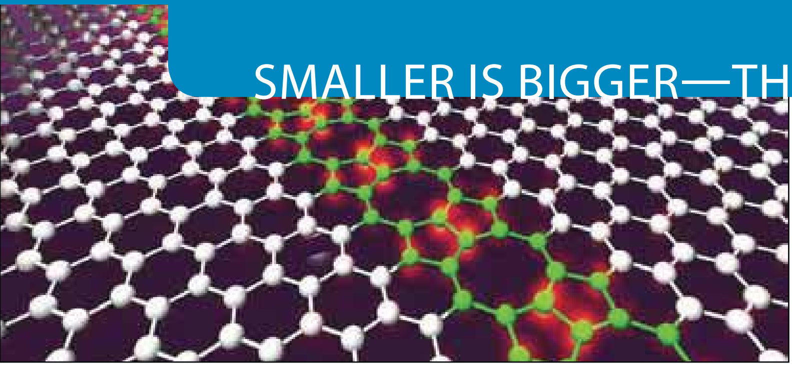

Intentional molecular defects create a metal wire in a sheet of graphene. *Image by You Lin, courtesy of the National Science Foundation*

Graphene: A New Horizon for Modern Technology

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Graphene, a carbon material that has only recently begun to be widely investigated, is a single layer of carbon atoms arranged in a hexagonal honeycomb extending in a single plane. It is the building block for all other graphitic materials, including carbon nanotubes. Although graphene is commonly produced by simple daily activities (e.g., writing with a pencil), modern research is now revealing its superior electrical, mechanical, and optical properties. The list of potential applications continues to grow.

Intensive research on graphene began in 2004, when teams from the University of Manchester in the UK and the Institute for Microelectronics in Russia isolated single graphene layers from blocks of graphite, using what has become known as the "scotch tape method." Subsequent measurements of the optical properties of graphene showed that it absorbs 2.3 percent of white light, a seemingly small number, which makes graphene layers nearly transparent.

Closer examination, however, revealed that this small number is actually surprisingly large, considering that graphene sheets are a fraction of a nanometer (1 billionth of a meter) thick, and white light radiates with wavelengths thousands of times larger. This unusual opacity is a result of the electronic structure of graphene, which is equally unusual.

The charge carriers in graphene behave as massless fermions. Thus, it is able to conduct electricity very efficiently, and has been calculated to have a conduction superior even to carbon nanotubes. Unexpectedly, however, it does not act as a semiconductor, but rather as a semi-metal. Although graphene is composed entirely of carbon, which is a nonmetal, graphene does not have the band gap that nonmetal semiconductors usually show, making it a unique substance.

Likewise, graphene is mechanically one of the strongest materials known, yet at the same time it is very flexible. It is the combination of these properties that makes graphene a silver bullet for modern technology, and the wide range of applications for graphene is only becoming wider.

From Circuits to the Sun and Beyond

Graphene has the potential to improve a long list of daily electronics, including the integrated circuits and transistors that are the foundation of the modern computing revolution, and are found in every computer. In step with research in renewable energy, graphene can and has been used in efficient, flexible solar cells.

Crossing the gap between physics and biology, graphene is the perfect material for incorporation in bio-electronics, such as microbial sensors or in-body diagnostic tools for medicine, as its organic composition makes graphene-based electronics less likely to be rejected by the immune system. Likewise, in any application for transparent electrodes, such as touchscreens or flexible displays, graphene is the material of choice.

As a result of its unique electronic structure, graphene also makes the measurement of several physical standards possible, with high levels of accuracy. In particular, graphene opens the opportunity to dramatically improve current measurement capabilities of the fine-structure constant, which is a fundamental physical quantity, as well as the quantum Hall effect, which enables a very accurate measurement of electrical resistance.

Current research on graphene is focused on the further characterization of this peculiar material, and also on industrial methods for its production. Though a number of methods exist for the production of graphene in the laboratory, none of these are yet suitable for the economic development of the material because of the lack of appropriate standards. Standards that are necessary include measurement of the number of graphene layers, electrical and structural impurities, electrical conductance, as well as optical transparency.

Development of these standards is being contemplated within International Electrotechnical Commission Technical Committee 113 (IEC TC113), which addresses nano-electrotechnologies. The U.S. Technical Advisory Group to IEC TC 113 is considering taking the lead in this work. While there are major hurdles to overcome before graphene becomes widespread, graphene is being investigated internationally as a result of its prodigious potential for modern society.

Dr. Obrzut is a materials research engineer in the polymers division at NIST, where he specializes in processing characterization. His research interests include carbon allotrope electronic materials, polymer networks with nanoscale objects, metrology, high-k dielectrics, dielectric relaxation, and non-linear optical polymers.