Scientists take steps toward creating artificial graphene

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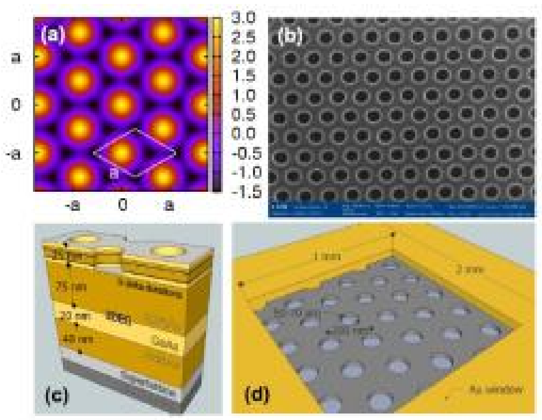

Different views of artificial graphene. Image credit: L. Nádvorník, et al. ©2012 IOP Publishing Ltd and Deutsche Physikalische Gesellschaft

(Phys.org) -- Researchers first observed graphene in 2004 by extracting the single-atom-thick sheets of carbon from bulk graphite. While graphene's electrical and optical properties have proven to have extraordinary potential for many applications, creating atomically precise structures out of graphene remains challenging. In an effort to improve graphene's usability, scientists have been searching for a way to fabricate artificial graphene, which could serve as a helpful structure where devices can be easily tested before their implementation with natural graphene. Now in a new study, scientists have identified all the main criteria required to make artificial graphene, which could provide a guide for experimentally realizing the material.

The team of scientists, from institutions in the Czech Republic, France, Canada, and the US, has published their paper on creating artificial graphene in a recent issue of the *New Journal of Physics*.

“The appealing concept of artificial graphene appeared soon after ‘real’ graphene was fabricated,” coauthor Lukas Nádvorník of Charles University and the Institute of Physics, ASCR, both in Prague, Czech Republic, told *Phys.org*. “This concept suggests taking advantage of high-quality two-dimensional semiconductors, which are nowadays routinely available, and to fabricate on their basis a new crystal with an ‘artificially’ created honeycomb lattice, typical of graphene. In other words, to use current technologies to mimic nature.”

Although researchers have been trying to fabricate artificial graphene for the past few years, no one has yet succeeded. Here, by identifying all the most important requirements, the scientists hope to change that.

“For the first time, we were able to extract all the parameters relevant for artificial graphene and suggest their proper combination, which should lead to successful realization of this system,” said coauthor Milan Orlita of Charles University, the Institute of Physics, ASCR, and the Laboratoire National des Champs Magnétiques Intenses in Grenoble, France. “This is useful for our further work, but also other groups working in this field might profit out of this. Our work does not represent a real milestone in artificial graphene; nevertheless, we believe that an important step towards its fabrication has been made.”

The researchers added that experimentally fabricating artificial graphene in the future will be challenging, but feasible.

“We do not see any principal obstacles preventing fabrication of artificial graphene – but technologically, it is rather tricky issue,” said coauthor Karel Výborný of the Institute of Physics, ASCR, and the

University of Buffalo-SUNY in Buffalo, New York. “One has to find a proper combination of a number of fine parameters such as the carrier density, strength of modulation potential, lattice constant, etc. Our work is probably the first one that approaches the problem systematically and compares quantitatively the experimental results with the criteria formulated theoretically.”

Artificial graphene has certain advantages over natural graphene, such as a crystal structure whose form can be varied. As the researchers explained, the crystal structure of natural graphene is fixed: it consists of a perfect honeycomb lattice with a carbon-to-carbon distance of 0.142 nanometers. In contrast, artificial graphene prepared from semiconductor multilayers (for example, by means of electron beam lithography) is not restricted by a precise lattice form or a precise lattice constant.

“It is also relatively easy to fabricate specific ‘devices,’ i.e., artificial graphene shaped into stripes, junctions, etc.,” Nádvorník said. “With natural graphene, it is difficult (although not impossible!) to create atomically precise structures. One could test such ‘devices’ first with artificial graphene and, if they prove useful, attempt to reproduce them with natural graphene.”

Nádvorník explained that researchers have long been trying to create various kinds of artificial crystals in order to explore their quantum mechanics, but what makes graphene unique is the behavior of its electrons, called Dirac fermions.

“Fabrication of two-dimensional superlattices with lattice constants around 100 nanometers (less than one hundredth of the thickness of a human hair), of which artificial graphene is an example, dates back to the 1990s,” he said. “What was not noticed in those times were the Dirac fermions – a special feature of artificial graphene. In our work, we clearly state four criteria that one has to fulfill in order to observe the Dirac fermions in a man-made semiconductor structure. Roughly speaking, while the race has been in place since 2009 to observe some manifestation of the Dirac fermions in artificial graphene, we show how to test the individual criteria separately. When all of the criteria are fulfilled, we can hope to observe the Dirac fermions."

He explained that the Dirac fermions not only make graphene what it is, but also provide insight into other areas of physics.

"It is just the hexagonal symmetry which is responsible for the appearance of Dirac fermions," Nádvorník said. "These are electrons which move in (artificial) graphene crystals with vanishing effective mass. They closely resemble ultra-relativistic particles and their motion can be, perhaps surprisingly, described using equations typical of relativistic physics. Dirac fermions in graphene (it doesn't matter whether it is artificial or real graphene) thus interconnects solid-state physics and relativistic quantum electrodynamics, two very different branches of modern physics."

In the future, the researchers plan to take the next steps toward experimentally realizing artificial graphene.

"It is one of the conclusions of our work that a viable way to create artificial graphene is to further reduce the lattice constant (periodicity of the applied potential) down to tens of nanometers," Nádvorník said. "To achieve this, we plan to apply the electron beam lithography with even higher resolutions as we used up to now, or take advantage of the focused-ion beam technology. We hope that we will be able to provide evidence for Dirac fermions in artificial graphene using a broad range of experimental technique available (infrared/THz or visible spectroscopy or electronic transport)."

More information: L. Nádvorník, et al. "From laterally modulated two-dimensional electron gas towards artificial graphene." *New Journal of Physics* 14 (2012) 053002. DOI: 10.1088/1367-2630/14/5/053002