Scientists carve functional nanoribbons using super-heated, nano-sized particles of iron

July 31 2008

Due to its remarkable electronic properties, few layer graphene, or FLG, has emerged as a promising new material for use in post-silicon devices that incorporate the quantum effects that emerge at the nanoscale. Now, physicists at the University of Pennsylvania have demonstrated a new method by which FLG can be etched along flawless, crystallographic axes by using thermally activated nanoparticles, a technique that results in atomically precise, macroscopic length ribbons of graphene. The advance could enable atomically precise, and far simpler, construction of integrated circuits from single graphene sheets with a wide range of technological applications.

A.T. Charlie Johnson, professor in the Department of Physics and Astronomy at Penn, and his team have demonstrated this new etching process which relies on catalytic metal particles to etch the graphene along precise atomic directions.

Johnson's team is now attempting to refine their control of the process and test Penn's capability to fabricate devices whose properties will reflect the intrinsic quality of atomically precise graphene.

"Graphene is a great material for electronics, but it would be even better if it were possible to create devices with crystallographic edges, that is, edges where the atoms lie along single lines in the graphene plane," Johnson said. "Standard etching techniques being used in the semiconductor industry do not allow this sort of fabrication. Instead, they produce rough edges with lots of atomic scale defects that limit the performance of the fabricated devices."

Specifically, the Penn team investigated the construction of atomically precise graphene nanoribbons in which charge-carrying electrons are confined in a nearly two-dimensional, lateral plane and the electronic properties of the ribbon are controlled by the width and specific crystallographic orientation of the material. These structures hold enormous promise as nanoscale devices, with the advantage that graphene's two-dimensionality lends itself to existing device architectures based on planar geometries.

Attempts with current nanofabrication standards such as lithography and plasma etching, however, have left rough edges to the nanoribbons that affect their performance. Until now, these structures have been impossible to achieve because the rough, non-crystalline edges of the graphene, resulting from current state-of-the-art nanolithography techniques, are considered the limiting factor to attaining useful performance from nanoscale graphene devices. Even atomic-scale flaws would derail electrical conductivity of any graphene transistors. Johnson's technique, employing hot iron nanoparticles to carve out patterns in graphene sheets, appears to be the first detailed example of such precise fabrication.

To create these ribbons, researchers deposited graphene onto a silicon substrate, coated them in iron nitrate and heated them to 900° C. At that temperature, the iron forms particles with diameters of about 15 nm, spreads across the surface of the substrate and etches away trenches in the graphene sheets.

By identifying areas where two iron nanoparticles carved parallel tracks like skis in fresh snow, researchers managed to isolate nanoribbons as narrow as 15 nm and as much as a few micrometers long. The nanoparticles travel predominantly along a single direction, although why this was so is a question for another study. However, scientists also observed the existence of other paths of nanoparticles, at angles of 30º and 60º, suggesting possibly that the motion of the iron nanoparticles — and hence the etching — is related to the atomic structure of graphene, a honeycomb shape employing those measurements. This natural phenomena could be used in the future to fabricate devices and circuits with those required angles.

Source: University of Pennsylvania