With 'ribbons' of graphene, width matters

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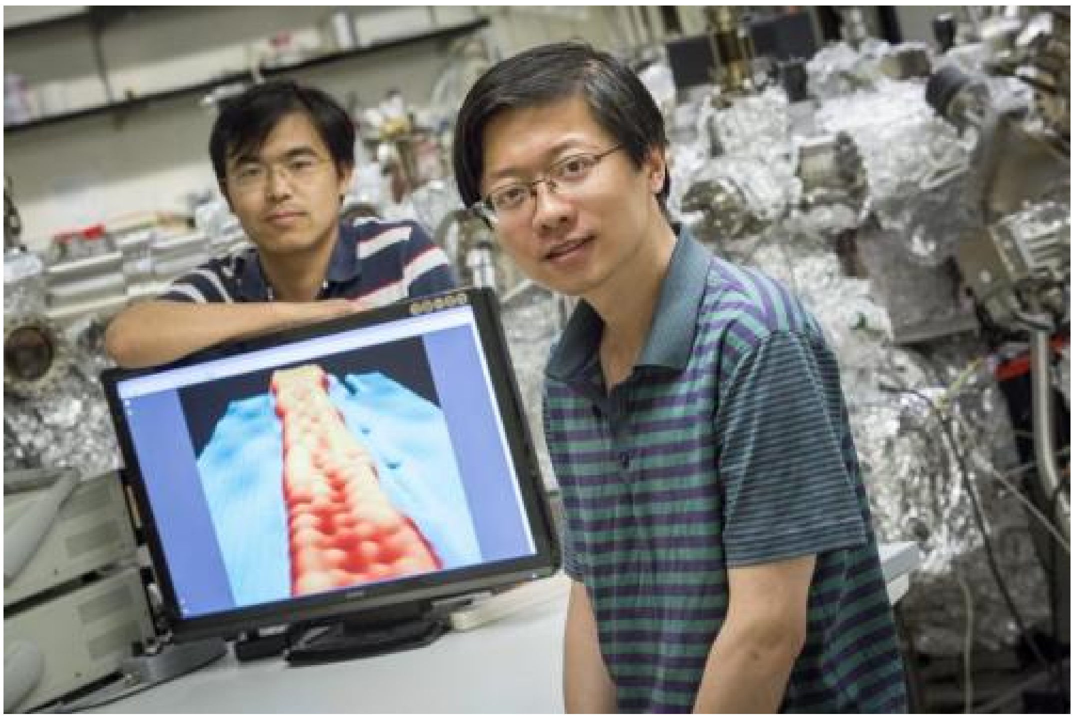

Yaoyi Li (foreground) and Mingxing Chen, UWM physics postdoctoral researchers, display an image of a ribbon of graphene 1 nanometer wide. In the image, achieved with a scanning-tunneling microscope, atoms are visible as "bumps." Credit: Troye Fox, UWM Photo Services

Using graphene ribbons of unimaginably small widths – just several atoms across – a group of researchers at the University of Wisconsin-Milwaukee (UWM) has found a novel way to "tune" the wonder material, causing the extremely efficient conductor of electricity to act as a semiconductor.

In principle, their method for producing these narrow ribbons – at a width roughly equal to the diameter of a strand of human DNA – and manipulating the ribbons' electrical conductivity could be used to produce nano-devices.

Graphene, a one-atom-thick sheet of carbon atoms, is touted for its high potential to yield devices at nanoscale and deliver computing at quantum speed. But before it can be applied to nanotechnology, researchers must first find an easy method of controlling the flow of electrons in order to devise even a simple on-off switch.

"Nano-ribbons are model systems for studying nanoscale effects in graphene, but obtaining a ribbon width below 10 nanometers and characterizing its electronic state is quite challenging," says Yaoyi Li, a UWM physics postdoctoral researcher and first author of a paper published July 2 in the journal *Nature Communications*.

By imaging the ribbons with scanning-tunneling microscopy, researchers have confirmed how narrow the ribbon width must be to alter graphene's electrical properties, making it more tunable.

"We found the transition happens at three nanometers and the changes are abrupt," says Michael Weinert, a UWM theoretical physicist who worked on the Department of Energy-supported project with experimental physicist Lian Li. "Before this study, there was no experimental evidence of what width the onset of these behaviors is."

The team also found that the narrower the ribbon becomes, the more "tunable" the material's behaviors. The two edges of such a narrow ribbon are able to strongly interact, essentially transforming the ribbon into a semiconductor with tunable qualities similar to that of silicon.

The first hurdle

Current methods of cutting can produce ribbon widths of five nanometers across, still too wide to achieve the tunable state, says Yaoyi Li. In addition to producing narrower ribbons, any new strategy for cutting they devised would also have to result in a straight alignment of the atoms at the ribbon edges in order to maintain the electrical properties, he adds.

So the UWM team used iron nanoparticles on top of the graphene in a hydrogen environment. Iron is a catalyst that causes hydrogen and carbon atoms to react, creating a gas that etches a trench into the graphene. The cutting is accomplished by precisely controlling the hydrogen pressure, says Lian Li.

The iron nanoparticle moves randomly across the graphene, producing ribbons of various widths – including some as thin as one nanometer, he says. The method also produces edges with properly aligned atoms.

One limitation exists for the team's cutting method, and that has to do with where the edges are cut. The atoms in graphene are arranged on a honeycomb lattice that, depending on the direction of the cut produces either an "armchair-shaped" edge or a "zigzag" one. The semiconducting behaviors the researchers observed with their etching method will only occur with a cut in the zigzag configuration.

Manipulating for function

When cut, the carbon atoms at the edges of the resulting ribbons have only two of the normal three neighbors, creating a kind of bond that attracts hydrogen atoms and corrals electrons to the edges of the ribbon. If the ribbon is narrow enough, the electrons on opposite sides can still interact, creating a semiconductive electrical behavior, says Weinert.

The researchers are now experimenting with saturating the edges with oxygen, rather than hydrogen, to investigate whether this changes the electrical behavior of the graphene to that of a metal.

Adding function to graphene nano-ribbons through this process could make possible the sought-after goal of atomic-scale components made of the same material, but with different electrical behaviors, says Weinert.

Provided by University of Wisconsin - Milwaukee