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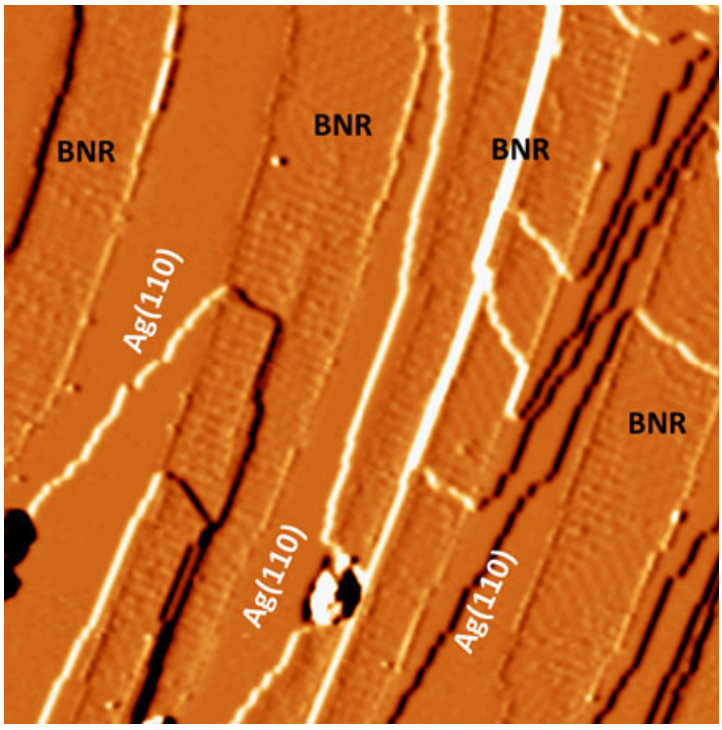
Nanoribbons of borophene synthesized on Ag(110) substrate

By Kendra Redmond September 8, 2017

Borophene, the two-dimensional allotrope of boron recently synthesized in sheet form, displays intriguing electronic properties that hint at possible applications in photovoltaics, batteries, and other devices. As reported in a recent issue of *Physical Review Materials*, a team of scientists from the Chinese Academy of Sciences have now synthesized long, thin strips of borophene. These nanoribbons demonstrate that the structure of borophene, and theoretically its electronic properties, can be easily tuned by altering the surface on which is it grown.



A derivative scanning tunneling microscope image showing boron nanoribbons (BNR) grown on Ag(110). The image size is 100 × 100 nm2. The nanoribbons run across the substrate steps without losing continuity.

Like nanoribbons of graphene, nanoribbons of borophene are predicted to have unique electronic properties not found in extended sheets. As is also true for graphene, these properties are expected to vary with ribbon width and the structure of the edges, enabling researchers to control the electronic properties of nanoribbons by shaping their geometry.

The research team was one of the first groups

Credit: Physical Review Materials

to synthesize borophene and did so on an Ag(111) surface. When the researchers examined the results, they were surprised to see a preferred structure emerge. “We noticed that the islands of borophene mostly had a triangular shape, on which the edges of the islands were always along the crystallographic directions of the Ag(111) surface,” says team member Lan Chen.

Theory predicts that freestanding borophene can take on a number of geometric arrangements. Many of these shapes minimize the total potential energy of the structure to nearly the global minimum, suggesting that no one shape should be significantly favored.

The research team hypothesized that the preferential triangular shape was the result of interaction between the borophene and the substrate on which it was grown. “We intuitively thought that the morphology of borophene would be largely different if we chose an anisotropic substrate,” Chen says.

To investigate this hypothesis, the researchers grew borophene on Ag(110), a substrate with only two-fold symmetry instead of the six-fold symmetry of Ag(111). The result was the formation of rigid, parallel nanoribbons with lengths up to hundreds of nanometers and widths within a narrow range around 10.3 nm.

These results were surprising, considering that nanoribbons of graphene are difficult to grow in this way. “The methods of fabrication of graphene by top-down approaches or surface-assisted polymerization are quite difficult and complex, resulting in graphene nanoribbons with low quality,” Chen says. “We realized borophene nanoribbons with high quality by simply growing boron atoms on an anisotropic Ag(110) surface, proving that nanostructures of borophene can be well produced by the template effect.”

High-resolution scanning tunneling microscope (STM) images of the borophene nanoribbons revealed four types of patterns, each with a different unit cell. To find out why, the researchers analyzed theoretically predicted borophene structures by overlaying them on Ag(110) at different rotation angles. This led them to four striped structures that reproduced the unit cells seen in the STM images. Using a computational model, the researchers discovered that all four structures consist of boron chains separated by single rows of hexagonal holes, but different unit cells emerge because the boron chains have different widths and they cross the Ag chains at different angles.

This research demonstrates that it may be possible to synthesize borophene nanoribbons with specific atomic structures and electronic properties by controlling the conditions for growth. “The clear opportunity here is to produce such ribbons (highly sought in graphene research) in a regular way, with the imposed confinement perhaps bringing new electronic features in addition to already known metallicity,” says Rice University’s Boris Yakobson, an expert in the theory and computational modeling of nanostructures and materials.

The challenge remains, Yakobson says, to either grow similar arrays on insulating substrates or separate these nanoribbons from the metallic silver, which would obscure possible effects such as plasmons and superconductivity.

The research team is currently investigating the electronic band structures of borophene nanoribbons with STM and angle-resolved photoemission spectroscopy. Moving forward, Chen says, the research team plans to work on exfoliating the nanoribbons from the substrate in order to study their

electronic properties and transport behaviors in free-standing form.

Read the article in *Physical Review Materials (https://journals.aps.org/prmaterials/abstract/10.1103/PhysRevMaterials.1.021001)*.

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