Fluorine grants white g

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MIKE WILLIAMS – JULY 14, 2017

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Fluorine grants white graphene new powers

Rice University researchers turn common insulator into a magnetic semiconductor

HOUSTON – (July 14, 2017) – A little fluorine turns an insulating ceramic known as white graphene into a wide-bandgap semiconductor with magnetic properties. Rice University scientists said that could make the unique material suitable for electronics in extreme environments.

A proof-of-concept paper from Rice researchers demonstrates a way to turn two-dimensional hexagonal boron nitride (h-BN) – aka white graphene – from an insulator to a semiconductor. The magnetism, they said, is an unexpected bonus.

Because the atomically thin material is an exceptional conductor of heat, the researchers suggested it may be useful for electronics in high-temperature applications, perhaps even as magnetic memory devices.

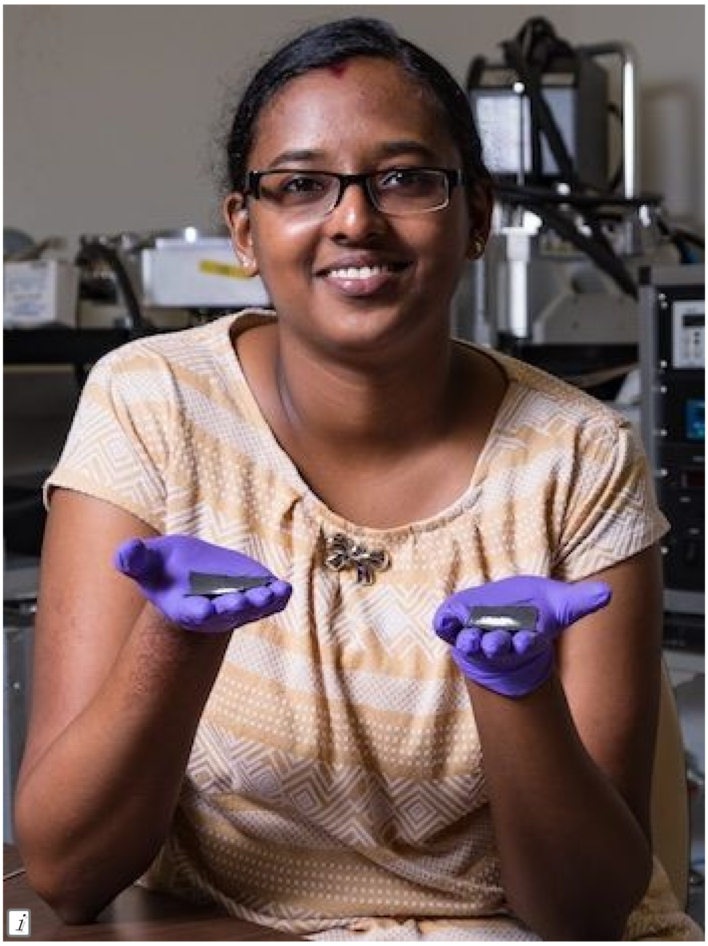
The discovery appears this week in Science Advances.

"Boron nitride is a stable insulator and commercially very useful as a protective coating, even in cosmetics, because it absorbs ultraviolet light," said Rice materials scientist Pulickel Ajayan, whose lab led the study. "There has been a lot of effort to try to modify its electronic structure, but we didn't think it could become both a semiconductor and a magnetic material.

"So this is something quite different; nobody has seen this kind of behavior in boron nitride before," he said.

The researchers found that adding fluorine to h-BN introduced defects into its atomic matrix that reduced the bandgap enough to make it a semiconductor. The bandgap determines the electrical conductivity of a material.

"We saw that the gap decreases at about 5 percent fluorination," said Rice postdoctoral researcher and

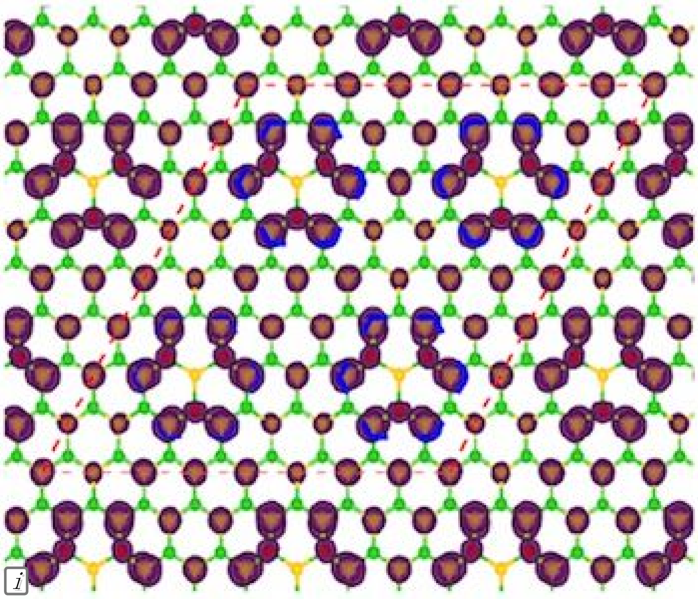


Rice graduate student Sruthi Radhakrishnan shows samples of pure hexagonal boron nitride and fluorinated hexagonal boron

co-author Chandra Sekhar Tiwary. The gap ge
smaller with additional fluorination, but only to
“Controlling the precise fluorination is somethi
need to work on. We can get ranges but we don’t have perfect control yet. Because the material is atomically thin, one atom less or more changes quite a bit.

Photo by Jeff Fitlow

“In the next set of experiments, we want to learn to tune it precisely, atom by atom,” he said.



A density functional theory calculation showed the magnetic properties of a fluorinated sample of hexagonal boron nitride. This version is ferromagnetic, determined by how the fluorine atoms (red) attach to the boron and nitrogen matrix. Courtesy of the Ajayan Group

They determined that tension applied by invading fluorine atoms altered the “spin” of electrons in the nitrogen atoms and affected their magnetic moments, the ghostly quality that determines how an atom will respond to a magnetic field like an invisible, nanoscale compass.

“We see angle-oriented spins, which are very unconventional for 2-D materials,” said Rice graduate student and lead author Sruthi Radhakrishnan. Rather than aligning to form ferromagnets or canceling each other out, the spins are randomly angled, giving the flat material random pockets of net magnetism. These ferromagnet or anti-ferromagnet pockets can exist in the same swatch of h-BN, which makes them “frustrated magnets” with competing domains.

The researchers said their simple, scalable method can potentially ot als “Making new materials through nanoengineering is exactly what our group is about,” Ajayan said.

Co-authors of the paper are graduate students Carlos de los Reyes and Zehua Jin, chemistry lecturer Lawrence Alemany, postdoctoral researcher Vidya Kochat and Angel Martí, an associate professor of chemistry, of bioengineering and of materials science and nanoengineering, all of Rice; Valery Khabashesku of Rice and the Baker Hughes Center for Technology Innovation, Houston; Parambath Sudeep of Rice and the University of Toronto; Deya Das, Atanu Samanta and Rice alumnus Abhishek Singh of the Indian Institute of Science, Bangalore; Liangzi Deng and Ching-Wu Chu of the University of Houston; Thomas Weldeghiorghis of Louisiana State University and Ajit Roy of the Air Force Research Laboratories at Wright-Patterson Air Force Base.

Ajayan is chair of Rice’s Department of Materials Science and NanoEngineering, the Benjamin M. and Mary Greenwood Anderson Professor in Engineering and a professor of chemistry.

The research was supported by the Department of Defense, the Air Force Office of Scientific Research and its Multidisciplinary University Research Institute, the National Science Foundation and Indian Department of Science and Technology Nano Mission. The Indian Institute of Science provided supercomputer resources.

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Read the open-access paper at http://advances.sciencemag.org/content/3/7/e1700842

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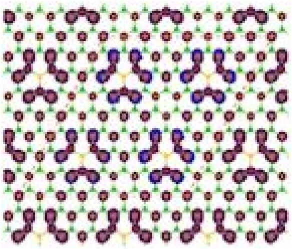
Rice University graduate student Sruthi Radhakrishnan shows samples of pure hexagonal boron nitride and fluorinated hexagonal boron nitride. Fluorination turns the material known as white graphene, a common insulator, into a magnetic semiconductor that may be suitable for electronics and sensors in extreme environments. (Credit: Jeff Fitlow/Rice University)



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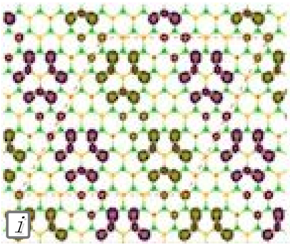
A density functional theory calculation showed the magnetic properties of a fluorinated sample of hexagonal boron nitride. This version is ferromagnetic, determined by how the fluorine atoms (red) attach to the boron and nitrogen matrix. (Credit: Ajayan Group/Rice University)



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A density functional theory calculation showed the magnetic properties of a fluorinated sample of hexagonal boron nitride. This version is anti-ferromagnetic, determined by how the fluorine atoms (red) attach to the boron and nitrogen matrix. (Credit: Ajayan Group/Rice University)

Located on a 300-acre forested campus in Houston, Rice University is consistently ranked among the nation's top 20 universities by U.S. News & World Report. Rice has highly respected schools of Architecture, Business, Continuing Studies, Engineering, Humanities, Music, Natural Sciences and Social Sciences and is home to the Baker Institute for Public Policy. With 3,879 undergraduates and 2,861 graduate students, Rice's undergraduate student-to-faculty ratio is 6-to-1. Its residential college system builds close-knit communities and lifelong friendships, just one reason why Rice is ranked No. 1 for happiest students and for lots of race/class interaction by the Princeton Review. Rice is also rated as a best value among private universities by Kiplinger's Personal Finance. To read "What they're saying about Rice," go to http://tinyurl.com/RiceUniversityoverview.

TAGS: Engineering, Materials Science and NanoEngineering

About Mike Williams

Mike Williams is a senior media relations specialist in Rice University's Office of Public Affairs.

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