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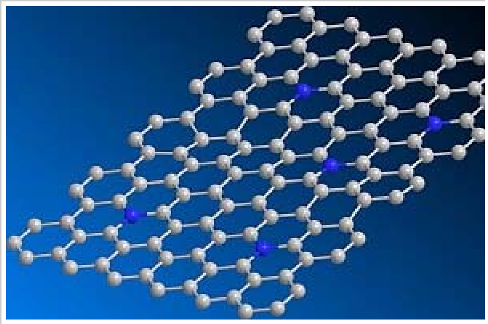
Graphene: Negative does not mean bad

Doping graphene with nitrogen to generate negative carriers can be achieved through irradiation and annealing in ammonia.



Schematic structure of nitrogen-doped graphene showing carbon (gray) and nitrogen (blue)

There is no doubt that the electronic properties of a graphene sheet are exceptional. It is known in particular for its outstanding electron mobilities even at room temperature. However, manipulating these properties — essential for integration into electronic devices — remains difficult.

One of the main problems is that graphene has no energy gap. Several ways to induce one are being pursued, including atomic and molecular doping. Another issue is that although introducing extra electron vacancies, or holes, in graphene by molecular and atomic adsorption is relatively common, doping the lattice with foreign elements to generate free electrons (‘n-doping’) is rather difficult. Jian Ru Gong and co-workers from the National Center for Nanoscience and Technology and Chongqing University in China have now demonstrated an efficient n-doping approach involving nitrogen atoms[1].

The procedure consists of two steps: irradiation with nitrogen ions to introduce defects — mainly carbon vacancies — in the two-dimensional graphene lattice, and subsequent annealing in ammonia to fill those vacancies with nitrogen atoms. Monitoring the evolution of the structure of the material by Raman spectroscopy revealed that the defects introduced by irradiation were restored during the annealing step.

Further characterization using a technique known as Auger electron spectroscopy showed that the ammonia annealing step introduced nitrogen atoms into the carbon vacancies in the graphene lattice. Annealing under dinitrogen instead of ammonia also restored the structure, but did not lead to doping.

Gong and his colleagues evaluated the performance of their nitrogen-doped graphene in electronics applications by using it to fabricate field-effect transistors. The electrical properties of the transistors were typical of those of n-doped graphene, exhibiting a minimum source–drain conductance at negative gate voltages. This is the opposite for undoped graphene, which shows a minimum at positive gate voltages due to the effect of oxygen in the lattice adsorbed from the atmosphere.

As Gong explains, the doping concentration can be controlled by tuning the conditions of irradiation and annealing, and it may also be possible to replace the nitrogen atoms with other dopants. This approach is therefore an effective and universal method for graphene doping, and is compatible with current complementary metal oxide semiconductor (CMOS) processing.

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Reference

1. Guo, B.,[1,2] Liu, Q.,[1] Chen, E.,[1] Zhu, H.,[1] Fang, L.[2] & Gong, J.R.[1] Controllable N-doping of graphene. *Nano Lett*. **10**, 4975 (2010) | article

Author affiliation

1. Laboratory for Nanodevices, National Center for Nanoscience and Technology, China, 11 Zhongguancun Beiyitiao, Beijing 100190, China

2. Department of Applied Physics, Chongqing University, Chongqing 400044, China

This research highlight has been approved by the author of the original article and all empirical data contained within has been provided by said author.

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