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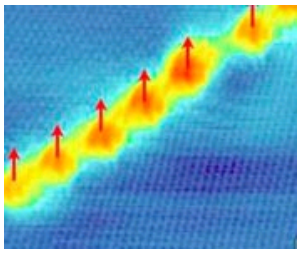
# Physicists pin down graphite's magnetism

Oct 8, 2009 1 comment

Physicists in the Netherlands have confirmed that graphite is a permanent magnet at room temperature and have pinpointed where the high-temperature ferromagnetism comes from for the first time. The result could be important for a variety of applications in nanotechnology and engineering, such as biosensors, detectors and in spintronics.



A new spin on graphite

Graphite is made up of stacks of individual carbon sheets (graphene) and is the familiar form of carbon found in pencils. Although ferromagnetism in graphite has been observed before, it has been difficult to understand where the weak magnetic signals come from. Indeed, some scientists believe that it might originate from tiny amounts of iron-rich impurities in the material, rather than from the carbon itself.

Now, Kees Flipse and colleagues at Eindhoven University of Technology and colleagues at Radboud University Nijmegen have shown that the magnetism occurs in the defect regions between the carbon layers. They did so using magnetic force microscopy (MFM) and scanning tunnelling microscopy (STM), which allowed them to measure magnetic and electronic properties with nanometre ($10^{-9}$ m) resolution.

## Surface and bulk measurements

Magnetic microscopy scans a very sharp magnetic tip over a surface and measures the magnetic forces between sample and tip. This revealed ferromagnetism at defects on the graphite surface. For bulk measurements, Flipse's team also employs a superconducting quantum interference device (SQUID) magnetometer – the most sensitive way to measure magnetic fields today.

Graphite consists of well ordered areas of carbon atoms separated by 2 nm wide boundaries of defects. The researchers found that the electrons in the defect regions behave differently to those in the ordered areas and instead resemble electrons in ferromagnetic materials, like iron and cobalt (see figure). They also discovered that the grain boundary regions in the individual carbon sheets are magnetically coupled and form 2D networks. This coupling explains why graphite is a permanent magnet.

"Pure, perfect single-crystal graphite is not a permanent magnet, but the situation changes when you create defects in the material," Flipse told *physicsworld.com*. "Single defects in the graphite lattice behave as magnetic dipoles, similar to those in ferromagnetic atoms like iron."

## Biocompatible sensors

As well as being of fundamental interest, magnetic graphite will be important in engineering and nanotechnology. For example, it could be used to make biosensors, since carbon is biocompatible. It could

also pave the way for carbon-based spintronics applications – devices that exploit the spin of an electron as well as its charge.

The Netherlands team will now study the role of defects in graphene to better understand the origins of the magnetism. "From a theoretical point of view, the next step would be to investigate the atomic and electronic structure of the grain boundaries in detail, and to develop a complete quantitative theory of the related magnetism," said Flipse.

The results are reported in *Nature Physics*.

### About the author

Belle Dumé is a contributing editor to *nanotechweb*.

## 1 comment

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1

**crnalas**
Oct 9, 2009 4:31 AM
Colne, United Kingdom

**Diamagnetism**

A thin slice of pyrolytic graphite, is an unusually strong diamagnetic material, I wonder how this new research will help us understand and explain this fascinating property of graphite.

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