690 nm was scanned over the sample. The researchers observed that the photocurrent displays polarity reversal during a backgate voltage sweep, an effect which was attributed to alternation between two dominant mechanisms—photovoltaic and photoinduced bolometric effects.

In the photovoltaic effect, photoexcited electrons and holes are accelerated in opposite directions by an electric field, and the carriers produce a photocurrent either by reaching the contacts while still hot or by establishing a local photovoltage that drives the photocurrent through the device. In the bolometric effect, the incident electromagnetic radiation raises the local temperature of the graphene, which alters the resistance of the device, producing a change in direct current under bias. Modulation of the photocurrent polarity and magnitude by electrostatic doping allowed the researchers to probe the nonequilibrium characteristics of graphene's hot carriers as well as phonons, which are involved in the dominant energy-loss pathway.

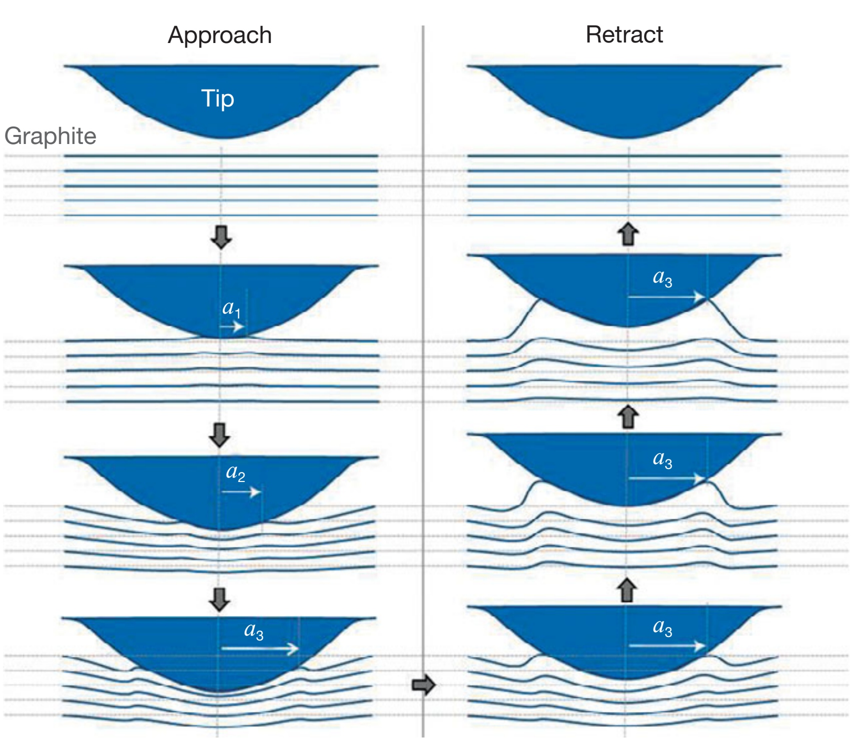
"Our work opens up the possibility of engineering the hot carrier photoresponse, which plays an essential role in applications such as bolometers, calorimeters and photodetectors," said the researchers.

**Steven Trohalaki**

Nano Focus

## Chemically modified graphite yields adhesion-dependent negative friction coefficient

If less force is applied on a pencil, the reduced friction means that it slides more easily over a surface. A somewhat different situation arises, however, if the tip is sharpened to nanoscale dimensions. As a collaborative project between researchers at the National Institute of Standards and Technology (NIST) at the University of Maryland and the University of Colorado Boulder, the Maryland Nanocenter, University of Maryland, and Tsinghua University have now investigated the nanoscale frictional behavior of graphite and have found a negative coefficient of friction for chemically modified graphite. Graphite and other carbon-based materials have gained interest owing to their unique and superior electrical, thermal, and mechanical properties that make them attractive for nanomechanical systems ranging from bionanosensors to optical switches.




Schematic representation of approach-retract hysteresis in the deformation of several surface and subsurface layers of graphite. Reproduced with permission from *Nature Mater*. **11** (2012), DOI: 10.1038/NMAT3452; p. 1032. © 2012 Macmillan Publishers Ltd.

As reported in the October 14, 2012 online publication of *Nature Materials* (DOI: 10.1038/NMAT3452), Zhao Deng of NIST and the Nanocenter and co-researchers performed nanoscale friction force microscopy (FFM) experiments using a nanoscale probe tip sliding on a chemically modified graphite surface by systematically varying tip-surface adhesion and measuring the corresponding friction using an atomic force microscope. The researchers found that when the adhesive force between the graphene and the probe tip was greater than the graphene layer's attraction to the graphite below, it was harder to drag the tip across the surface, resulting in a negative friction coefficient.

The figure illustrates the hysteresis in contact deformation that may be happening, based on the lateral stiffness and friction data. As the pressure on the tip increases, the contact radius increases from $a_1$ to $a_3$. As the interaction energy between the tip and the graphene is larger than the interlayer interaction, the top layer of the graphite remains attached to the tip on retraction.

This work was also supported by computer simulations which showed that this behavior is due to an increase in lateral stiffness with decreasing load, demonstrating that the negative coefficient is a result of partial exfoliation of the topmost graphene layer. The lamellar structure of graphite therefore yields nanoscale tribological properties that fall outside the predictive capacity of existing continuum mechanical models.

**Jean Njoroge**


https://doi.org/10.1557/mrs.2013.29 Published online by Cambridge University Press