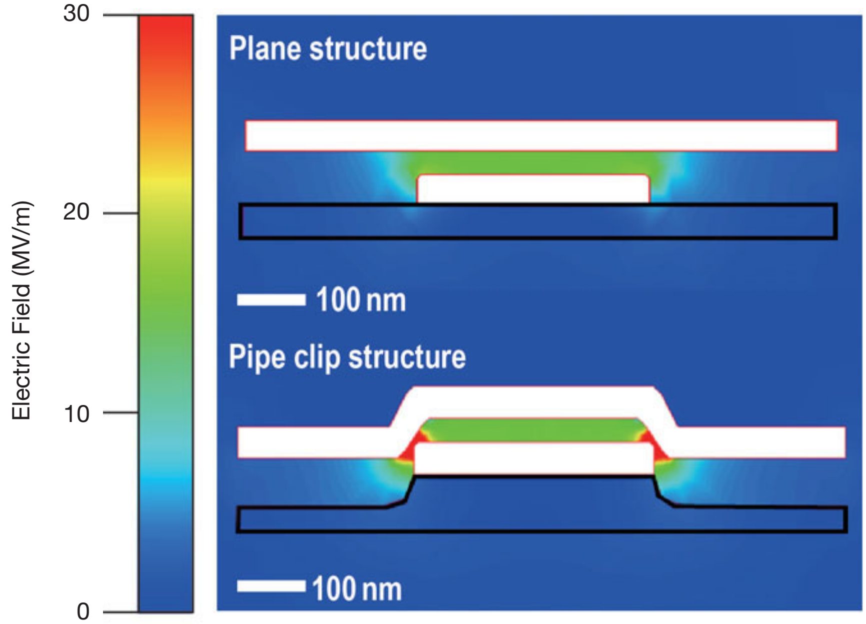
Nano Focus

"Pipe clip" interface structure for nanoelectromechanical switching device operates below 1 V

Nanoscale electromechanical (NEM) switches can be used as relays, transistors, logic devices, and sensors, and compared with conventional semiconductor switches offer reduced power consumption and improved ON/OFF ratios. NEM switches operate by controlling the contact between terminals, where a physical gap is typically overcome by applying large voltages (4–20 V) across the terminals. This prevents low-power applications and strong adhesion forces can occur that dominate over the restoring force. Overcoming these problems, a group of researchers at the Korea Advanced Institute of Science and Technology (KAIST) and the Korea National NanoFab Center (NNFC) recently fabricated NEM devices with ultrathin physical gaps by creating a curved or "pipe clip" suspended electrode structure. These operate below 1 V and exhibit negligible leakage current and on/off ratios of 1×10^6.

As described in a letter published online on November 25, 2012 in *Nature Nanotechnology* (DOI: 10.1038/NNANO.2012.208), Jeong Oen Lee of KAIST and co-researchers used a high-density plasma (HDP) method to deposit a sacrificial SiO_2 layer that was sandwiched between tungsten//tungsten/titanium electrodes. This resulted in an ultrathin gap of <10 nm between the electrodes.



Electric-field distribution of the traditional plane structure (upper) and the proposed pipe clip structure (lower) for a nanoscale electromechanical switching device. Reproduced with permission from *Nature Nanotech*. **8** (2013), DOI: 10.1038/nnano.2012.208; p. 36. © 2013 Macmillan Publishers Ltd.

The researchers used three-dimensional finite-element simulations to evaluate the electromechanical characteristics of the pipe clip structure, and to compare them with a plane structure. As shown in the figure, large forces exist near the small gap regions due to the quadratic nature of the electrostatic force. Electrical characterization showed repeatable switching near 400 mV with a very small subthreshold slope of 10 mV/dec.

This unique device structure addresses key requirements of low-voltage operated NEMs through a small physical gap (~4 nm), minimized physical contact to reduce adhesion forces, and straightforward fabrication using the sacrificial trenched-layer method.

Christopher J. Patridge

Photocurrent generation mechanism in biased graphene found to be PV or bolometric

Graphene has interesting optoelectronic properties due to its zero bandgap, electron–hole symmetry, and high carrier mobility. For example, graphene can convert absorbed light into photocurrent. The origin of this photoresponse in graphene junctions has been attributed to either thermoelectric or photovoltaic (PV) effects. However, identifying which photocurrent mechanism is dominant is challenging because the polarities of PV and thermoelectric currents measured in metal–graphene or graphene *p–n* junctions are the same.

Recently, M. Freitag, T. Low, F. Xia, and P. Avouris at IBM's T. J. Watson Research Center have investigated the mechanism of photocurrent response in biased, homogeneous graphene. By measuring the photoconductivity of the homogeneous graphene channel in a graphene field-effect transistor (FET) fabricated on Si/SiO_2, wherein photocurrent polarities due to PV and thermoelectric effects are opposite, the researchers determined that the dominant photocurrent generation mechanism at low electrostatic doping is photovoltaic, and that the thermoelectric effect is an order of magnitude smaller.

The researchers report in an article published online on December 16, 2012 in *Nature Photonics* (DOI: 10.1038/NPHOTON.2012.314) that they biased their graphene FET at one contact with a moderate drain voltage of about –1 V. Doping was controlled electrostatically with a global silicon backgate, and the alternating photocurrent amplitude and phase were measured while a chopped, focused laser beam at a wavelength of

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.

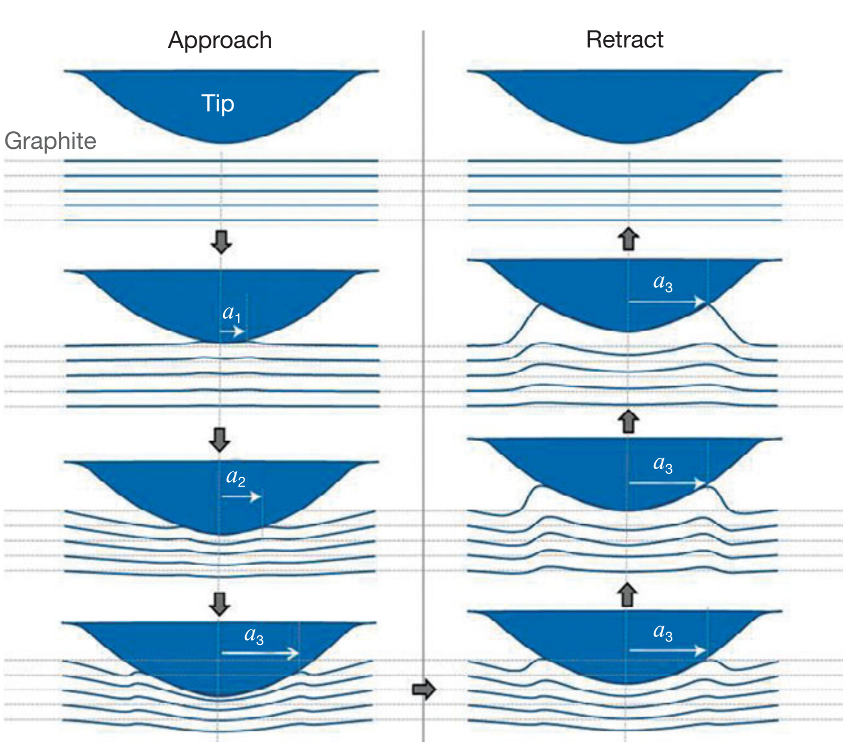
"Our work opens up the possibility of engineering the hot carrier photoresponse, which plays an essential role in applications such as bolometers, calorimeters and photodetectors," said the researchers.

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