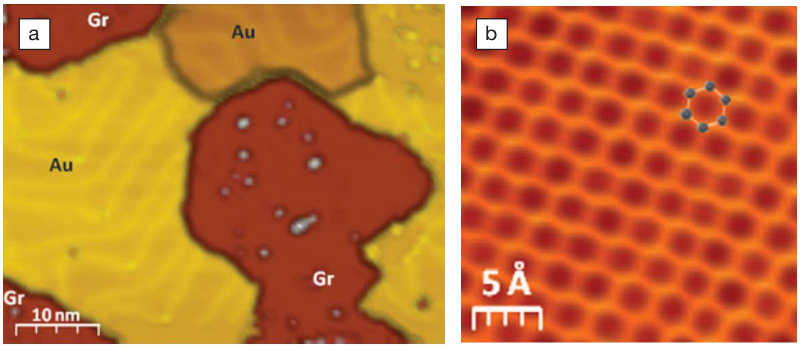
Nano Focus

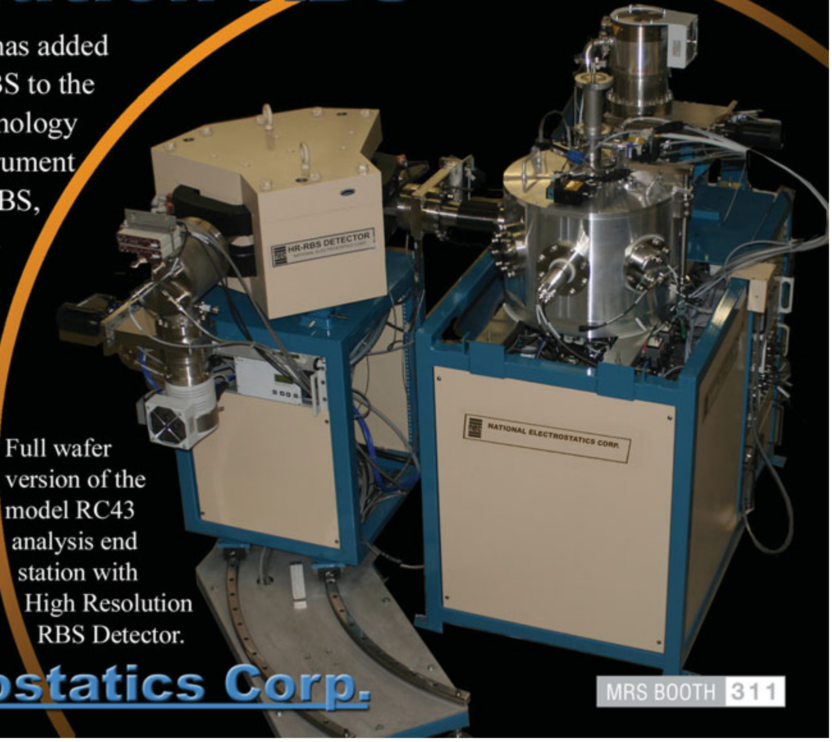
Novel method developed to grow graphene on low reactivity metals

The commercial exploitation of the remarkable properties of graphene relies on the development of efficient methods to fabricate the large quantities required for industrial applications. One of the most promising approaches is the epitaxial growth of graphene layers on metals, where chemical vapor deposition can produce large areas of graphene with uniform thickness. However, this technique relies on the metals' catalytic activity and is expected to be less effective on low reactivity metals. Recently, however, A.J. Martínez-Galera and co-researchers at the Universidad Autónoma de Madrid, Spain, have devised a novel method for preparing graphene on the surface of relatively inert metals, and used this technique to grow high-quality, monolayer graphene films on Cu(111) and Au(111).

The researchers report in the September 14 issue of *Nano Letters* (DOI: 10.1021/nl201281m; p. 3576) that thermal decomposition of hydrocarbon fragments produced by irradiating a metal surface at high temperature with low-energy ethylene ions can result in the formation of graphene on the metal surface. The researchers placed clean metal single crystals as substrates in an ultrahigh vacuum (UHV) chamber at 800°C together with ethylene at high pressure. Irradiation with an ion gun results in low-energy ethylene ions that are accelerated



(a) Three graphene flakes grown epitaxially on a Au(111) surface are shown in this scanning tunneling micrograph with area 53 nm × 41 nm. Reconstruction of the herringbone pattern characteristic of the Au(111) pattern is evident. (b) A scanning tunneling micrograph of a portion of defect-free graphene grown on a Au(111) surface displays a honeycomb pattern. Reprinted with permission from *Nano Lett*. **11** (9) (2011), DOI: 10.1021/nl201281m; p. 3576. © 2011 American Chemical Society.



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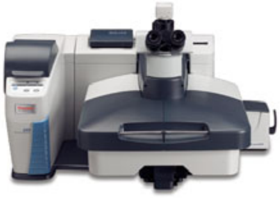
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against the metal surface, after which the sample is annealed at 900–950°C. The researchers observed negligible ethylene adsorption or decomposition when the same process was followed but without the ion gun treatment.

The researchers obtained monolayers of high-quality graphene on Cu(111) substrates and atomically characterized them in UHV using scanning tunneling microscopy (STM). As expected for graphene monolayers weakly coupled to substrates, several moiré patterns with different periodicities were observed due to small rotations of the graphene lattice with respect to the substrate. As shown in the figure, relatively large defect-free regions of graphene monolayer were grown on the Au(111) surface. These findings were supported by low-energy electron diffraction measurements and Auger spectroscopy and confirmed the macroscopic formation of graphene on the Au(111) surface.

The properties of the graphene/ metal contact were also investigated and were shown to be weaker than in any previously reported graphene/metal system. The Fermi wave vector, estimated from low-bias STM images, where standing waves coming from the Au(111) surface are observed through the graphene layer, is in perfect agreement with the value for pristine Au(111). The minimum around the Fermi level observed in differential conductance plots, as obtained with STM, is associated with the Dirac point of the graphene's electronic structure—an indication of the lack of doping for this system. The researchers said, "Our new method paves the way to extend the range of possible substrates for the epitaxial growth of graphene to other low reactivity metals."

Steven Trohalaki

Energy Focus

Electronic bucket brigade could boost solar-cell voltages

If solar cells could generate higher voltages when sunlight falls on them, they would produce electrical power more efficiently than is currently possible. Now a team of researchers at Lawrence Berkeley National Laboratory (Berkeley Lab) and the University of California–Berkeley (UCB) has studied bismuth ferrite, or BFO, to determine how the photovoltaic process occurs in materials known as ferroelectrics, known for developing very high voltages under illumination. The researchers reported their findings in the September 16 issue of *Physical Review Letters* (DOI: 10.1103/PhysRevLett.107.126805).

"We worked with very thin films of bismuth ferrite, or BFO, grown in the laboratory of our colleague Ramamoorthy Ramesh," said Joel Ager of Berkeley Lab's Materials Sciences Division (MSD), who led the research effort. "These thin films have regions—called domains—where the electrical polarization points in different directions. Ramesh's group is able to make film with exquisite control over this domain structure."

Because BFO has a range of unusual properties, the group led by Ramesh, who is a member of MSD and a professor of materials sciences, engineering, and physics at UCB, has long studied its characteristics by building custom devices made from the material.

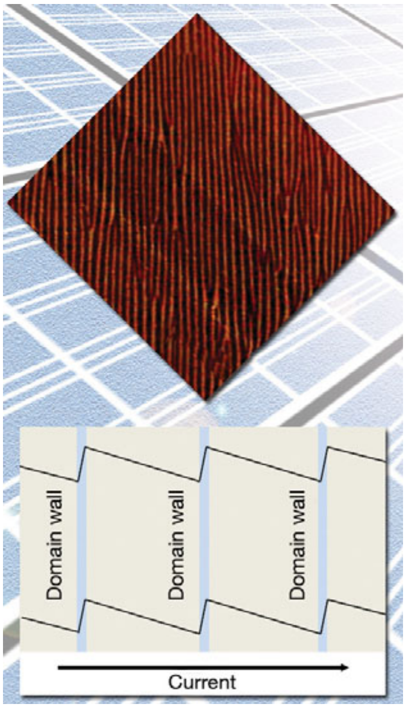
The BFO films studied by Ager and his colleagues have a unique periodic domain pattern extending over distances of hundreds of micrometers. The domains form in stripes, each measuring 50–300 nm across, separated by domain walls 2 nm thick. In each of these stripes the electrical polarization is opposite from that of its neighbors.

Because of the wide extent and highly periodic domain structure of the BFO thin films, the research team avoided the problems faced by groups who had tried to understand photovoltaic effects in other ferroelectrics, whose differences in polarity were thought to surround impurity atoms or to occur in different grains of a polycrystalline material.

By contrast, said Ager, "We knew very precisely the location and the magnitude of the built-in electric fields in BFO." Thus Ager and J. Seidel of MSD were able to gain "full microscopic understanding" of what went on within each separate domain, and across many domains.

"When we illuminated the BFO thin films, we got very large voltages, many times the bandgap voltage of the material itself," said Ager. "The incoming photons excite the electrons and create corresponding holes, and a current begins to flow perpendicular to the domain walls—even though there's no junction, as there would be in a solar cell with negatively and positively doped semiconductors."

In an open circuit the current flows at right angles to the domain walls, and to



At top, domains with opposite electrical polarization, averaging about 140 nm wide and separated by walls 2 nm thick, form a well-aligned array in a thin film of bismuth ferrite. When illuminated, electrons collect on one side of the walls and holes on the other, driving the current at right angles to the walls. Voltage increases as excess electrons accumulate stepwise from domain to domain.