## Bio Focus

### Nanobubble plus chemotherapy equals single-cell cancer targeting

Using light-harvesting nanoparticles to convert laser energy into "plasmonic nanobubbles," Dmitri Lapotko of Rice University, Malcolm K. Brenner of Baylor College of Medicine, and their colleagues are creating methods to inject drugs and genetic payloads directly into cancer cells without affecting nearby healthy cells. In tests on drug-resistant cancer cells, the researchers found that delivering chemotherapy drugs with nanobubbles was up to 30 times more deadly to cancer cells than traditional drug treatment and required less than one-tenth the clinical dose. The researchers recently reported their findings in the July issue of *Biomaterials* (DOI:10.1016/j.biomaterials.2012.03.077; p. 5441).

Delivering drugs and therapies selectively so they affect cancer cells but not healthy cells nearby is a major challenge in drug delivery. Sorting cancer cells from healthy cells has been successful, but it is both time-consuming and expensive. Researchers have also used nanoparticles to target cancer cells, but nanoparticles can be taken up by healthy cells, so attaching drugs to the nanoparticles can also kill healthy cells.

Nanobubbles are not nanoparticles; rather, they are short-lived events. The nanobubbles are pockets of air and water vapor that are created when laser light strikes a cluster of nanoparticles and is converted instantly into heat. The bubbles form just below the surface of cancer cells. As the bubbles expand and burst, they briefly open small holes in the surface of the cells and allow cancer drugs to rush inside. The same technique can be used to deliver gene therapies and other therapeutic payloads directly into cells. "We are delivering cancer drugs or other genetic cargo at the single-cell level," said Lapotko.

To form the nanobubbles, the researchers must first place the gold nanoclusters inside the cancer cells. The researchers do this by tagging individual gold nanoparticles with an antibody that binds to the surface of the cancer cell. Cells ingest the gold nanoparticles and sequester them together in tiny pockets just below their surfaces. The gold nanoparticles are then irradiated with single short laser pulses of 70 ps, at 532 nm. The optical energy is converted to thermal energy through plasmon resonance, resulting in heat being released by the nanoparticles, evaporating their liquid environment, and producing nanobubbles.

While a few gold nanoparticles are taken up by healthy cells, the cancer cells take up far more, and the selectivity of the procedure owes to the fact that the minimum threshold of laser energy needed to form a nanobubble in a cancer cell is too low to form a nanobubble in a healthy cell.

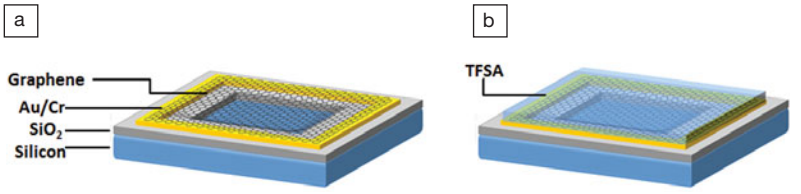
"The nanobubble injection mechanism is an entirely new approach for drug and gene delivery," Brenner said. "It holds great promise for selectively targeting cancer cells that are mixed with healthy cells in the same culture."

## Energy Focus

### Chemical doping helps break efficiency record for graphene solar cells

Solar cells based on the Schottky junction between graphene and silicon could provide a useful alternative to silicon diode-based cells, as they are less costly to make and the graphene can act as both a transparent electrode and an active layer. This cell design has recently been given new promise by X. Miao and co-workers at the University of Florida, whose article in the June 13 issue of *Nano Letters* (DOI: 10.1021/nl204414u; p. 2745) describes how a new record in power-conversion efficiency has been set by chemically doping the graphene layer.

The team first prepared a silicon substrate by depositing a frame of gold-chromium and etching the rest of the surface to remove the insulating oxide layer. Graphene grown on copper foil by chemical vapor deposition was then transferred to the substrate using a poly(methyl methacrylate) (PMMA) support, and was placed so that the edges made electrical contact with the metallic frame, while the rest of the sheet formed a Schottky junction with the exposed silicon (see Figure). After removing the PMMA in an acetone vapor bath, chemical *p*-doping of the graphene was achieved by spin coating the electron acceptor *bis*(trifluoromethanesulfonyl)-amide (TFSA) over the device.




(a) The structure of a pristine graphene solar cell and (b) one with *bis*(trifluoromethanesulfonyl)-amide (TFSA) doping. Reproduced with permission from *Nano Lett.* **12** (2012), DOI: 10.1021/nl204414u; p. 2745. © 2012 American Chemical Society.

Under illumination, the TFSA-doped devices yielded a power-conversion efficiency of 8.6% as compared with 1.9% for the undoped devices. This represents the highest reported figure for a graphene-based solar cell, where the increase in efficiency is attributed to the fact that doping leads to a reduction in graphene sheet resistance, improving charge transport and increasing the graphene work function. Photons that are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absorbed by the silicon generate electron–hole pairs that can then be separated by the electric field associated with the Schottky junction at the material interface. Increasing the work function of the graphene increases the voltage drop at the interface, which leads to more efficient separation of electron–hole pairs into useful current. The hydrophobic dopant also acts to protect the device, endowing it with superior environmental stability as compared with pristine graphene solar cells, which degrade over time.

The factor of 4.5 increase in efficiency achieved though TFSA doping represents a significant improvement in performance, which could lead to these cells acting as viable alternatives to expensive silicon diode cells and less stable organic cells. Alternatively, the doped graphene layer could itself be applied to a range of other substrates including flexible polymer semiconductors.

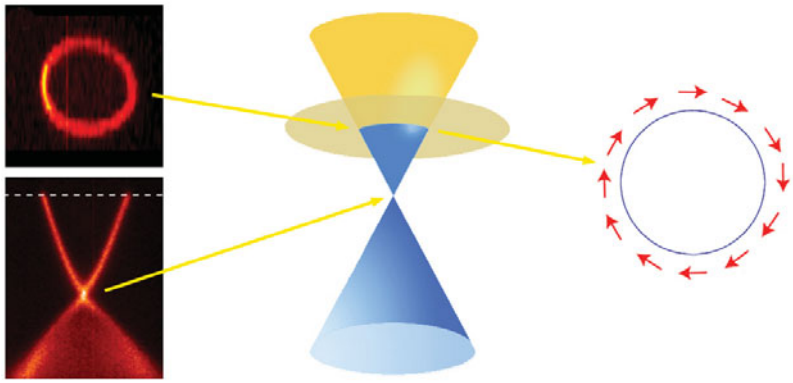
**Tobias Lockwood**

## Nano Focus

### Topological insulator $Bi_2Se_3$ opens path to room-temperature spintronics

In the search for new materials with improved electrical conductivity, a team of researchers led by Tonica Valla of Brookhaven National Laboratory has found a potential candidate in the topological insulator $Bi_2Se_3$. Electrons on the metal surface of a topological insulator can flow with little resistance. Using angle-resolved photoemission spectroscopy (ARPES) at Brookhaven's National Synchrotron Light Source and at the Advanced Light Source at Lawrence Berkeley National Laboratory (LBNL), the researchers discovered that the surface electrons of $Bi_2Se_3$ can flow at room temperature, making it an attractive candidate for practical applications like spintronics devices, plus farther-out ones like quantum computers.

As reported in the May 4 issue of *Physical Review Letters* (10.1103/PhysRevLett.108.187001), Valla, Alexei Fedorov of LBNL, Young Lee of the Massachusetts Institute of Technology, and their colleagues generated a direct graphic visualization of the sample's electronic structure. The band structure of the surface states of a topological insulator like $Bi_2Se_3$ appear as two cones that meet at a point, called the Dirac point. There is no gap between the valence and conduction bands, only a smooth transition with increasing energy. This is similar to the band structure of graphene in which ARPES diagrams look like slices through the cones, an X centered on the Dirac point.



ARPES maps the electronic properties, including the band structure and Fermi surface, of the topological insulator bismuth selenide (left). Like graphene, the lower energy valence band of a topological insulator meets the higher energy conduction band at a point, the Dirac point, with no gap between the bands (center). Unlike graphene, however, the Fermi surface of a topological insulator does not usually pass through the Dirac point. For surface electrons, distinct spin states (red arrows) are associated with each different orientation in momentum space (right).

Although graphene and topological insulators have similar band structures, their other electronic characteristics are very different. The combinations of different speeds and orientations equivalent to a material's highest particle energies (at zero degrees) make up its momentum space, mapped by the Fermi surface. While the Fermi surface of graphene lies between the conical bands at the Dirac point, this is not true of topological insulators. The Fermi surface of $Bi_2Se_3$ cuts high across the conical conduction band, mapping a perfect circle. It is as if the circular Fermi surface were drawn right on the surface of the topological insulator, showing how spin-locked surface electrons must change their spin orientation as they follow this continually curving path.

"One way that electrons lose mobility is by scattering on phonons," said Fedorov. Phonons are the quantized vibrational energy of crystalline materials, treated mathematically as particles. "Our recent work on a particularly promising topological insulator [TI] shows that its surface electrons hardly couple with phonons at all. So there's no impediment to developing this TI for spintronics and other applications."

Values including electron–phonon coupling can be calculated from the diagrams that ARPES builds up. ARPES measures of $Bi_2Se_3$ show that electron–phonon coupling remains among the weakest known to have been reported for any material, even as the temperature approaches room temperature.

Fedorov said, "Although there's still a long way to go, the experimental confirmation that electron–phonon coupling is very small underlines $Bi_2Se_3$'s practical potential." With continued progress, the spin-locked electronic states of room-temperature topological insulators could open a gateway for spintronic devices



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