

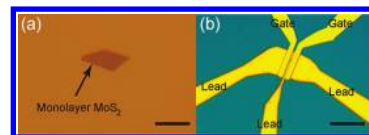
Two-Dimensional MoS₂: A Logical Choice for Integrated Circuits

Two-dimensional materials have many potential advantages as the basis for next-generation nanoelectronics. Forming circuits out of these materials may be easier than arranging nanowires with known electrical properties into predefined positions and, in addition, these materials offer the potential for extremely low-power electronic devices through greater electrostatic control in comparison to bulk materials. So far, graphene is the two-dimensional (2D) material that has been most explored for electronics. However, in its untreated form, graphene has no band gap, necessitating various processes that increase complexity and introduce drawbacks such as lowering mobility or requiring higher voltages.

Seeking a new building block for nanoelectronics, Radisavljevic *et al.* (DOI: 10.1021/

nn203715c) looked to single-layer MoS₂, a 2D semiconductor with a significant band gap and the ability to amplify signals and to perform basic logic operations in simple integrated circuits. Using MoS₂ exfoliated from bulk crystals using scotch-tape, the researchers deposited monolayers on Si substrates. They incorporated three electrical leads using electron-beam lithography, then deposited Au electrodes. After covering the device with a layer of HfO₂ to act as a gate dielectric, the researchers created local top gates, resulting in an integrated circuit composed of two single-layer MoS₂ transistors connected in series. Tests showed that this circuit could effectively operate as the most basic logic gate, a logic inverter that converts a logical 0 to 1 and *vice versa*. By connecting the two

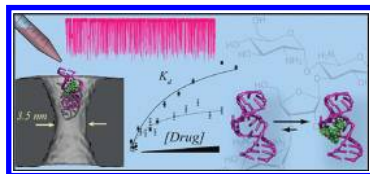
transistors in parallel and using an external resistor as a load, the MoS₂ circuit could also act as a NOR logic gate, performing every possible binary logic operation. The authors suggest that MoS₂ could pave the way for flexible, low-power nanoelectronics.



Examining RNA/Antibiotic Complexes through the Rabbit Hole

RNA molecules are ready targets for a new generation of drugs for RNA-mediated diseases and infections. As such, new methods to probe RNA/drug interactions quickly, accurately, and sensitively are in high demand. Some methods that have already been tested include using a truncated construct of prokaryotic rRNA, known as the A-site, and incorporating emissive and responsive nucleoside analogues and Förster resonance energy transfer (FRET). However, a label-free system could hold advantages over these platforms, such as greater flexibility in studying native nucleic acids and avoiding probe-specific artifacts.

Looking for a new way to probe RNA/drug interactions, Wanunu *et al.* (DOI: 10.1021/nn203764j) looked to solid-state nanopores, a system previously shown to discriminate



among various molecules through changes in current caused by electrolyte flux as solution and molecules of interest pass through a pore. Using three aminoglycoside drugs—neomycin, paromomycin, and kanamycin—as models for RNA/drug interactions, the researchers measured ion current while complexes of these drugs bound to the A-site passed through a 3 nm pore in an ultrathin silicon nitride membrane. Results showed that current amplitudes increased as paromomycin

was added to the RNA/electrolyte solution. Titration of neomycin, which has a higher binding affinity to RNA, produced an even higher increase in current amplitude, whereas introducing kanamycin produced a lower current amplitude, suggesting that nanopore measurements produce useful information on binding affinity. Molecular dynamics simulations reinforced the finding that these differences in current amplitude direction relate to drug binding. These results suggest that nanopores could prove to be a powerful tool for investigating RNA/drug interactions.

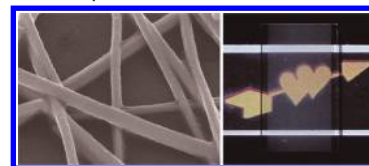
Networking with Silver Nanowires

Most transparent conductive films produced to date are made of indium tin oxide (ITO). This material's high optical transparency and low resistance have made it a natural choice for a variety of applications. However, indium's extremely limited supply makes ITO's long-term use questionable, spurring an urgent need to develop alternative transparent conductive electrodes. Several candidate base materials have been suggested and tested, including carbon nanotubes, graphene, metal grids, and thin metal films. However, each candidate has trade-offs between transparency and conductivity. Films using silver nanowires (AgNWs) have comparable performance to ITO; however, loose contacts between AgNWs have necessitated complicated treatments such as high-temperature or long-time thermal annealing, extra pressure, or vacuum filtration. Additionally, getting AgNWs to

adhere to substrate surfaces requires additional effort.

Seeking a less complicated way to form this useful material into transparent conductive films, Zhu *et al.* (DOI: 10.1021/nn203576v) developed a simple and effective solution-based method. The researchers coated AgNWs onto glass substrates, then treated the films with a TiO₂ solution. After low-temperature hydration in air, the TiO₂ converted into nanoparticle clusters. Afterward, the film was coated with a solution of poly(3,4-ethylenedioxythiophene)/poly(styrenesulfonate) (PEDOT:PSS). Scanning electron microscopy and transmission electron microscopy showed that TiO₂'s solvent evaporation and its resulting capillary force caused random aggregation of TiO₂ nanoparticles, pulling the AgNW into a reinforced network. The PEDOT:PSS solution further bound this network together

and adhered it onto the substrate. Testing this material in an organic photovoltaic device, results showed performance comparable to ITO. The researchers suggest that their novel solution-based method readily transformed AgNW into a useful transparent conductive film.



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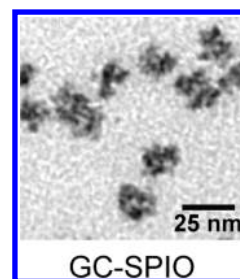
Acid Proves Attractive for Tumor-Seeking Nanoparticles

Several groups have developed nanoparticle applications to diagnose and to treat cancerous tumors selectively. Strategies to target these nanoparticles to tumors have largely relied on allowing them to collect passively in tumors or through receptor–ligand approaches. However, cancer cells typically have up-regulated glycolysis and reduced oxidative phosphorylation, producing a microenvironment with increased levels of lactic acid and low extracellular pH. Producing pH-responsive nanoparticles that take advantage of this acidic microenvironment could be a new strategy for targeting tumors.

To this end, Crayton and Tsourkas (DOI: 10.1021/nn202863x) developed supramagnetic iron oxide nanoparticles coated with glycol chitosan, a pH-responsive polymer of glycosamine. These glycol chitosan-supramagnetic iron oxide (GC-SPIO) nanoparticles

have the advantage of a core that is an effective magnetic resonance contrast agent, providing T_2^* -weighted contrast enhancement, while sporting an outer coat containing amino groups that become increasingly protonated in acidic environments. The positive surface charge then allows cells to retain these nanoparticles more readily. Putting these ideas into action, the researchers compared native GC-SPIO with GC-SPIO that was chemically modified with glycol to block the pH-responsive amino groups and pH-unresponsive dextran-stabilized SPIO nanoparticles. Magnetic resonance tests showed that cancer cells incubated with native GC-SPIO exhibited pronounced pH dependence to their T_2 relaxation times, whereas the other nanoparticles did not. These native GC-SPIO nanoparticles also showed long blood circulation with superior accumulation in a murine

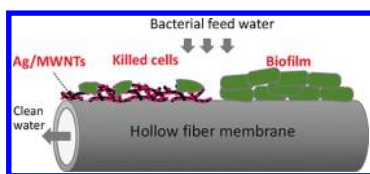
tumor model and improved magnetic resonance contrast compared to the other nanoparticles. The authors suggest that glycol chitosan and other pH-responsive polymers could be a useful addition to tumor-targeting nanoparticles.



A Combination Approach for Clean Water

As the demand for clean water to satisfy public and industrial needs has grown, researchers have become increasingly interested in finding new and more efficient ways to generate pathogen-free water from natural sources and wastewater. One way to purify water is by passing it through a membrane, especially one made of hollow fibers. However, current filtration membranes typically lack bactericidal properties, allowing biofouling that clogs the membranes' pores and limits efficiency. Consequently, keeping membranes functional often requires frequent back-flushing, chemical treatments, and even membrane replacements.

Seeking a new way to avoid these expensive, time-consuming solutions that also generate additional waste, Gunawan *et al.*



(DOI: 10.1021/nn2038725) looked to Ag, an element that is known to kill numerous infectious bacteria. Rather than entrapping Ag nanoparticles within membranes, a tactic that did not inhibit biofilm formation in previous research, investigators in the new study combined Ag nanoparticles with multi-walled carbon nanotubes (Ag/MWNTs) on the surface of hollow fiber membranes. Using *Escherichia coli* (*E. coli*) as their model—a bacterium causing growing concern worldwide—the authors sent water that had been

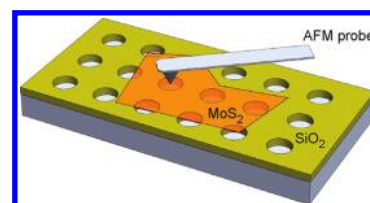
purposefully contaminated with a set concentration of this microbe through their novel modified membrane. Tests showed that membranes that were not decorated with Ag/MWNTs fouled easily over time, reducing the flux of water through the membrane by 55% in 20 h. Conversely, those with the Ag/MWNT modification showed significantly better biofouling resistance, with flux dropping just 6% within the same time period. The authors note that their combination approach eases water's flow to the membrane while also allowing contact with bacteriocidal Ag ions, a potentially useful new strategy for water filtration.

Probing MoS₂, Literally

While graphene continues to be the most studied two-dimensional crystal due to its unusual and potentially useful electrical and physical properties, single-layer MoS₂ is drawing increasing attention for its potential applications in nanotechnology. This material's band gap of 1.8 eV has spurred a growing interest in using this material for nanoelectronics, in which it might be incorporated into transistors with low power dissipation but very high current on/off ratios. Some researchers have also suggested that this material could be used to make flexible electronics. However, it has remained unclear whether MoS₂ had the necessary mechanical properties to play a role in bendable devices.

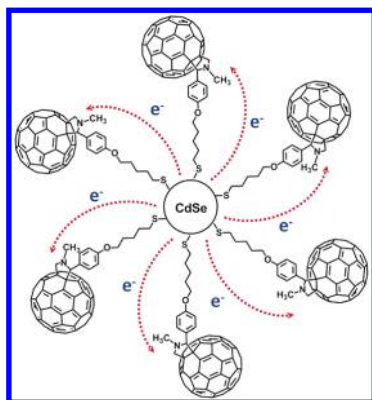
To understand this material's mechanical properties, Bertolazzi *et al.* (DOI: 10.1021/nn203879f) measured the in-plane elastic modulus and breaking strength of monolayer and bilayer MoS₂. The researchers draped these ultrathin MoS₂ membranes over a SiO₂ substrate patterned with 550 nm circular holes. Then, using the tip of an atomic force microscope, they indented the membranes above these holes to the point of mechanical failure of the MoS₂, acquiring loading and unloading curves. On a total of 9 monolayer and 6 bilayer membranes, the team found that these curves largely overlapped, indicating the elastic nature of this material. The calculated Young's modulus of monolayer MoS₂ showed exceptional strength comparable to

that of steel, exceeded only by carbon nanotubes and graphene. Since MoS₂'s breaking strain exceeded that of the thin polymer films typically used for flexible electronics, the authors note that this semiconductor could be a welcome addition in such devices.



Shining Light on Quantum Dot–Fullerene Nanocomposites

■ Semiconductor nanocrystals have become a popular focus for designing next-generation solar cells. To harvest energy effectively, semiconductor quantum dots (QDs), such as Cd- or Pb-chalcogenide QDs, are often incorporated into nanocomposites with primarily inorganic materials that have type-II band gap align-



ment. However, organic/inorganic hybrid nanocomposites have also shown promise for solar cells, especially those that incorporate fullerenes (C_{60}). However, despite C_{60} 's decided advantage as an excellent electron acceptor, researchers have not fully explored its role in QD-based light harvesting systems, including the particulars behind the electron-transfer processes of these nanocomposites.

To eliminate this knowledge gap, Bang and Kamat (DOI: 10.1021/nn204350w) conducted a systematic study to probe the electron-transfer mechanism between excited CdSe QDs and C_{60} and to evaluate the photoelectrochemical properties of nanocomposites made of these materials. Because absorption depends on the particle size for the CdSe QDs, the researchers assembled different nanocomposites by chemically linking CdSe QDs of three different sizes with thiol-functionalized C_{60} . Using ultrafast pump–probe laser

spectroscopy to examine the photoinduced charge-transfer process in these materials, the researchers found that the nanocomposites had accelerated bleaching recovery compared to CdSe QDs alone, with faster electron transfer in those nanocomposites with smaller QDs. Tests after depositing the nanocomposites onto optically transparent electrodes showed that those with larger QDs had significantly higher photocurrent than their smaller counterparts under monochromatic light, suggesting that slower hole transfer and faster recombination of charge carriers is more important for performance in this system than the forward electron injection process. The authors suggest that these findings could ultimately help improve efficiency in solar cells made of these nanocomposite materials.

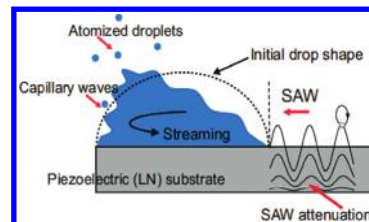
Many Layers of Potential for Nanocarriers

■ Precisely targeting and timing drug delivery remains a challenge for the pharmaceutical industry, with nanocarriers made of multiple polyelectrolyte layers as one means to this end. Thus far, the most prevalent method for producing multilayer polyelectrolyte nanocarriers is the layer-by-layer (LbL) approach, which alternately deposits oppositely charged polyelectrolytes onto a colloidal particle template that is later sacrificially removed. However, LbL has a variety of drawbacks, such as the difficulty of getting many desired compounds into these carriers efficiently and reproducibly.

Seeking a new way to create multilayer nanocarriers, Qi *et al.* (DOI: 10.1021/nn202833n) created a method that takes advantage of surface acoustic wave (SAW) atomization. Applying an

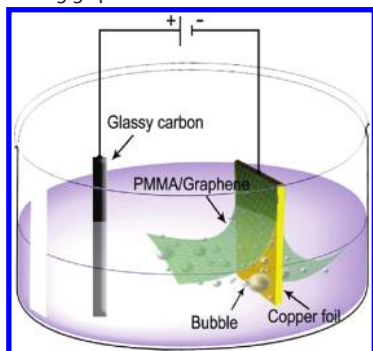
oscillating electrical signal to electrodes topped with a polymer solution, the researchers used SAW to atomize the fluid. As the solvent evaporated, it left behind solidified polymer nanocarriers, which were then collected in a solution containing a complementary polymer of opposite charge. Repeating this process induced additional layers to form over the original polymer core, which could be loaded with proteins or DNA by including these in the initial solution. The researchers successfully synthesized multilayer nanocarriers made of chitosan, carboxymethyl cellulose, and linear polyethyleneimine, confirmed by Fourier transform infrared spectroscopy, zeta potentials, atomic force microscopy, and fluorescence imaging. *In vitro* experiments showed that multiple layers

significantly slowed encapsulated plasma DNA release time. Additionally, plasma DNA in these nanocarriers readily transfected cells, showing that its integrity was preserved. The authors suggest that this method could provide a new and facile way to target and time drug delivery.



Recycling Extends to Graphene Growth Catalysts

■ To grow large-area, high-quality graphene films, researchers typically rely on chemical vapor deposition (CVD). However, successfully delaminating graphene from the metal substrates used



for CVD usually involves a chemical etching step, which significantly increases production cost and requires long treatment cycles of several hours. In principle, peeling graphene from Cu catalyst foils should be possible due to the relatively weak binding energy between the two materials. However, delaminating graphene in this way from its growth substrate had not yet been demonstrated.

In a new study, Wang *et al.* (DOI: 10.1021/nn203700w) show not only that peeling graphene from Cu foils is possible, but that the same foils can be reused repeatedly for subsequent graphene growth cycles. The researchers spin-coated a polymer layer onto graphene grown on Cu foils as a protective coating, then used this combination as a cathode in an electrolytic cell.

Running direct current voltage through the cell caused hydrogen bubbles to emerge at the graphene/Cu interface as water in the electrolyte solution was reduced. These bubbles provided a force that within 60 min gently detached graphene from the Cu foil, which could then be used for subsequent growth cycles. Although a small amount of Cu is etched away by the process, the researchers suggest that foils of typical thickness can be used to grow graphene layers hundreds of times. Tests showed that graphene film quality improved with each growth cycle, which the researchers credit to gradual smoothing of step edges on the foils. The authors note that this novel method avoids the drawbacks of chemical etching, saving both time and money.