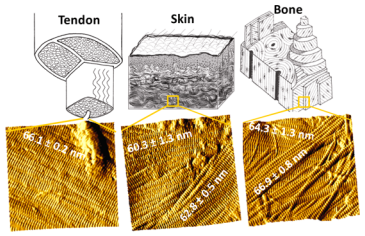
Not a Stretch: Delving into the Organization of Collagen

Collagen is the primary component of the extracellular matrix (ECM) of noncartilaginous connective tissues, such as skin, tendon, and bone. This material is important for maintaining tissue integrity, as well as influencing mechanical properties and cellular activities. Collagen arranges in a hierarchy, with collagen molecules forming fibrils, which form bundles, which then organize into tissues. At the lowest level of organization, the collagen molecules align in a parallel staggered manner, with some molecules overlapping, leaving gaps between others. Most studies have suggested that this so-called *D*-spacing has a single value of about 67 nm and has no influence on other types of organization in the collagen hierarchy. However, recent research indicates that the *D*-spacing can change as a function of disease, suggesting that it could have important biological significance.

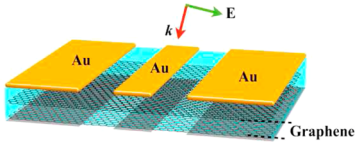
In a new study, Fang *et al.* (DOI: 10.1021/nn302483x) explore whether the nanometer-scale *D*-spacing might have an effect on the micrometer-scale fibril bundle organization. Using atomic force microscopy (AFM) imaging and two-dimensional fast Fourier transform analysis, the researchers examined collagen from healthy adult ovine bone and dermis, human dermis, and lamb tendon. While fibrils from different bundles had distinctively different *D*-spacings, spanning a range of about 10 nm, the researchers found that *D*-spacings within a single fibril bundle were nearly identical regardless of tissue type, typically differing by less than 1 nm. Further analysis suggests that *D*-spacing differences arise primarily at the bundle level, regardless of tissue type or species. The authors suggest that further research is necessary to derive the mechanisms behind bundle formation and *D*-spacing variations.



Seeing the Future in Graphene Lenses

For over a century, researchers have been seeking ways to overcome the fundamental barrier of imaging with resolution beyond the diffraction limit. Because of the fast decay of evanescent waves, the resolution of a classical imaging system is limited to about half of the illuminating wavelength. One tool developed to overcome this shortcoming is scanning near-field optical microscopy. However, this technique itself is limited because it requires pixel-by-pixel scanning of the tip near the sample, restricting its use to small samples. Researchers recently developed a device known as a superlens that uses a thin slab of a material with negative permittivity that enhances evanescent waves with a positive-permittivity host. However, this tool is also limited by having a narrow working-frequency range.

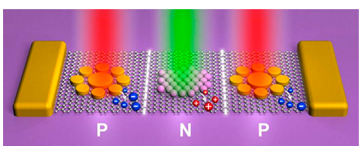
Seeking to overcome these restrictions, Li and Taubner (DOI: 10.1021/nn303845a) undertook a theoretical study that suggests that a new type of frequency-tunable lens using graphene can achieve resolution beyond the diffraction limit across a broad frequency range. Their models show that a bilayer of graphene sheets embedded in a host dieletric medium can significantly enhance transmission of evanescent waves, leading to subwavelength resolution of around $\lambda/7$. This value could be further improved to $\lambda/10$ by including even more graphene layers. Although this enhancement is considerably weaker than that of a superlens, the graphene lens could be continuously tuned over a significantly broader range, including infrared and tetrahertz frequencies. Because layered graphene structures are already commonly used in some electronics, the authors suggest that this theoretical lens could be close to fabrication.



Making Graphene Even Hotter

Graphene's unusual electrical, mechanical, and optical characteristics have ignited intense interest in using this material for a variety of applications, including transparent electrodes, solar cells, photodetectors, and phototransistors. Graphene can also be easily doped, effectively changing its electrical properties in a tunable manner. Recently, researchers have taken advantage of hot carrier injection to generate high internal quantum efficiencies in graphene photodetectors, as well as other applications including graphene-based heterojunctions and bolometers. One way to generate light-induced hot carriers is to place metal-based subwavelength antennas composed of closely spaced, coupled nanoparticles directly onto the graphene surface. These plasmonic oligomers can generate Fano resonances that lead to enhanced absorption and hot electron production.

Taking advantage of this effect, Fang *et al.* (DOI: 10.1021/nn304028b) developed nanoantennas that produce photoinduced n-doping of graphene through plasmon-generated hot electrons. The researchers used electron beam lithography and Au evaporation to pattern source and drain electrodes and plasmonic nonamer antennas onto graphene on silicon wafer substrates. The Au nonamers, each composed of a large center disk surrounded by eight smaller disks, generated hot electrons from plasma excitation under laser irradiation. These hot electrons were injected into the graphene sheets, resulting in n-type doping, observed in electrical transport measurements. Results showed that the degree of doping was tunable by varying the plasmonic antenna size, the laser wavelength used to excite the antennas, and the laser power density. The authors suggest that these nanoantennas provide a useful way to dope graphene that could be exploited in a variety of graphene-based optoelectronic devices.



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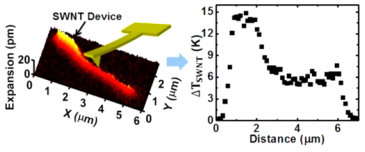
Taking the Temperature of Carbon Nanotubes

Single-walled carbon nanotubes (SWNTs) are increasingly becoming pivotal components in electronics and optoelectronics. All known growth techniques generate SWNTs with differing diameters, chiralities, and densities of defects that can create uneven Joule heating, potentially affecting device performance. Optical techniques such as Raman and infrared spectroscopy can generate temperature maps of SWNT devices, but their spatial and temperature resolution is substantially limited. Techniques based on atomic force microscopy (AFM) can significantly improve resolution. For example, scanning thermal microscopy, which uses a specialized tip with an integrated temperature sensor, has been used to characterize temperature distributions in SWNT-based devices. However, previous studies have shown that it can be difficult to describe heat flow between the tip and substrate accurately, diminishing this technique's quantitative capabilities.

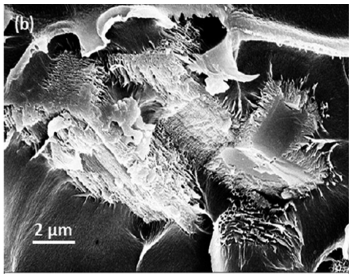
In a new study, Xie *et al.* (DOI: 10.1021/nn304083a) looked to an alternative technique known as scanning Joule expansion microscopy (SJEM). This method involves using conventional AFM cantilevers to measure nanometer-scale thermal expansion caused by Joule heating, revealing underlying temperature distributions. The researchers tested this technique on arrays of aligned SWNTs on silicon substrates. Their results revealed that SJEM at various applied voltages could distinguish electrical behaviors among different SWNTs in the same array, including whether individual nanotubes were metallic or semiconducting. Scanning Joule expansion microscopy was also able to discern physical characteristics that can influence heating, such as nanotube diameter and chirality, and the presence of defect sites. Their technique enabled spatial resolution of about 100 nm and temperature resolution down to 0.7 K. The authors suggest that SJEM could eventually be used to optimize the design, operation, and reliability of devices based on SWNTs.



Layering on the Benefits in Zeolitic Materials

Researchers have long relied on the nanoporous aluminosilicate materials known as zeolites for separations and catalysis. Recent advances in controlling molecular diffusion limitations have included synthesis of new zeolite materials, including nanosized zeolites and layered and exfoliated zeolites. Being able to combine these novel zeolites with conventional forms can create materials with interesting microporous and mesoporous conformations that could be used for applications beyond those available to just the bulk zeolites, such as uses involving heavy hydrocarbons and biomolecules.

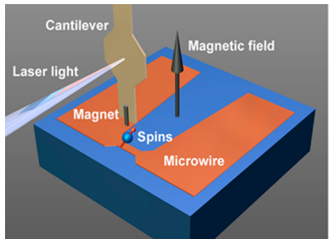
In a new approach toward creating such a hybrid material, Kim *et al.* (DOI: 10.1021/nn3036254) developed a bulk three-dimensional zeolite epitaxially covered with a layered two-dimensional (2D) one. Using a method developed to create 2D layers of the mordenite framework inverted zeolite (MFI), the researchers added conventional bulk MFI particles, resulting in the hybrid bulk MFI-layered MFI (BMLM) material. Using a variety of characterization methods, the researchers show that the 2D layers and the bulk MFI epitaxially match in at least two crystallographic directions and potentially in a third. Further examination shows that the resulting material successfully combines the properties of bulk MFI and 2D layered MFI, with an interconnected microporous/mesoporous network, mechanical support, large surface roughness, and large external surface area. Testing the new hybrid material's potential, the researchers incorporated it into a polyimide, fabricating a membrane for gas separation. Results showed that the hybrid material adhered better to the polyimide than bulk MFI, providing good CO_2/CH_4 selectivity. The authors suggest that the hybrid material could provide enhanced performance above conventional zeolites in a variety of other molecular separation applications.



An Attractive New Tip for Magnetic Resonance Force Microscopy

Magnetic resonance force microscopy (MRFM), which combines magnetic resonance imaging and atomic force microscopy, has enabled imaging down to 4–10 nm resolution. Such high resolution suggests that MRFM could play an important role in discerning the structure of single biomacromolecules, biomacromolecule complexes, and other organic nanostructures. However, this level of resolution is currently achievable only by attaching the sample to the leading edge of a cantilever. Because few biological samples are sufficiently robust to withstand such treatment, this limits current MRFM techniques to hardy materials. Switching to a geometry that places the magnet on the cantilever instead of the sample could broaden the range of biological samples that can be imaged. Previous studies have showcased the potential of fabricating high-gradient magnets directly on high-compliance cantilevers. However, these efforts have suffered from limitations including magnetic field gradients limited by ion damage and low yield.

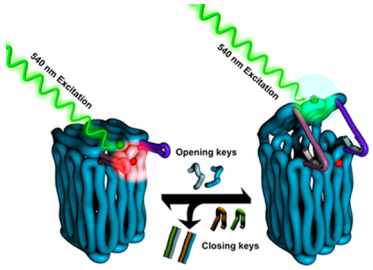
Taking a new approach, Longenecker *et al.* (DOI: 10.1021/nn3030628) developed attonewton-sensitivity cantilevers with high gradient cobalt nanomagnet tips. Testing their new MRFM cantilever on signals from protons in a polystyrene film, the researchers show that this novel cantilever has a magnetic field gradient that exceeds previous efforts at incorporating magnets on cantilevers by at least a factor of 8. Consequently, the resolution produced by this new effort is comparable to that of previous work that relied on attaching the sample to the MRFM tip. The authors suggest that their tip design could eventually allow MRFM to be used on fragile biological samples and go beyond the limits of cryoelectron microscopy for imaging far broader classes of macromolecules.



DNA Origami, All Boxed Up

DNA origami, a technique that involves folding single-stranded DNA into patterns held together with shorter oligonucleotides "staples", was initially developed to construct two-dimensional nanoscale structures. Since its origin several years ago, researchers have expanded this technique to create elaborate three-dimensional (3D) structures, including tile-based tetrahedra, prisms, and buckyballs, as well as more complicated assemblies such as octahedra and small solid 3D structures. However, these existing structures had some limitations: none combined closed surfaces with a hollow cavity that could carry cargo, and opening mechanisms for these structures were irreversible.

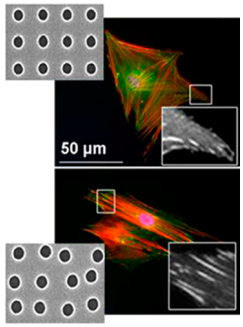
Addressing these shortcomings, Zadegan *et al.* (DOI: 10.1021/nn303767b) used DNA origami to construct hollow boxes with lids that open and shut reversibly with DNA "keys". The researchers synthesized the boxes in a single-step annealing process with a yield of about 90%. Various characterization methods revealed boxes that had external and internal dimensions of 18 × 18 × 24 and 14 × 14 × 20 nm^3, respectively. The team installed two locks, each composed of a unique 8 nucleotide toehold, inserted between the lid and side of each box. Upon addition of the correct keys (two sets of single-stranded DNA corresponding to two breast-cancer-specific micro-RNAs), the locks were displaced and the box lids opened. By introducing an additional set of closing keys, the opening keys were displaced and the box lids shut. Förster resonance energy transfer spectroscopy confirmed that the box lids could reversibly open and shut for several cycles. The authors suggest that these boxes could make suitable drug-delivery vehicles, with the next challenge being the delivery of these nanosized boxes into cells.



Multipotency on the Surface

Reliably steering mesenchymal stem cells (MSCs) into tissue types, including osteoblasts, chondrocytes, or adipocytes, or preventing these cells from cycling into differentiation has remained a challenge. The most common techniques for trying to control differentiation or to keep cells in a stem-like state use poorly understood cocktails of soluble factors. Another option for directing stem cell fate lies in taking advantage of the stem cell/substrate interface, with previous research showing that various nanotopography can influence cells either to retain multipotency or to direct differentiation.

To understand how this interface contributes to cell fate, Tsimbouri *et al.* (DOI: 10.1021/nn304046m) investigated the effects of two different nanotopographies on MSCs, one specifically engineered to steer the cells toward osteoblast differentiation, on the cells' metabolomic profiles. The researchers grew the cells on surfaces with either 120 nm diameter, 100 nm deep pits with 300 nm center−center spacing (called square, SQ) that held cells in a stem-like state, or similar surfaces with a ~50 nm offset from the center position (near square 50, NSQ50). Various experiments showed that the MSCs led to smaller adhesions on the SQ surface and larger ones on the NSQ50 surface, with higher levels of intracellular tension on the latter. By blocking adhesion with antibodies and examining the cells' metabolic profiles, the researchers found that the cells started on a path to differentiation; reversing this process re-established a stem cell phenotype. The authors note that the metabolome, combined with nanotopography, offers a useful way to examine differentiation and self-renewal processes in stem cells.



Writing It Down, Molecule by Molecule

Electronics continue to shrink due to continuing developments in the semiconducting industry. Currently, integrated circuits can accommodate a million times more transistors than they could 40 years ago, thanks to optical lithography that can produce circuits with 32 nm features. To make even smaller devices, researchers will need to develop lithography techniques that push current limits even further. Previous research has shown that scanning tunneling microscopy can accomplish the ultimate lithography limit by manipulating single atoms. However, this method is too unwieldy to apply on an industrial scale. Another lithographic technique that could be promising for improving resolution for commercial applications is focused electron-beam-induced deposition (FEBID), which uses a focused beam of electrons to dissociate these precursor molecules from a substrate and leave nonvolatile fragments as a deposit.

To determine if FEBID can increase resolution down to the molecular level, van Dorp *et al.* (DOI: 10.1021/nn303793w) tested this method using the organometallic precursor $W(CO)_6$ on few-layer graphene substrates. The researchers monitored the FEBID process using the annular dark-field signal in a scanning tunneling electron microscope. Their findings show that the recorded signal increases stepwise during the initial stages of deposit growth. The steps' height is consistent with the signal expected for a single molecule, suggesting that individual molecules were being deposited on the substrates. The authors suggest that decorating graphene with metal *via* FEBID could be used for a variety of applications, including catalysis and electronics.