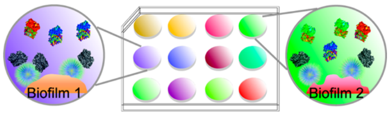
Better Discrimination for Biofilm Bacteria

Biofilms, the thick, sticky matrices secreted by many species of bacteria, are a significant threat to health. The biofilm matrix itself restricts antibiotics from reaching their microbial targets, making infections in wounds, implants, and indwelling devices notoriously hard to treat. Although rapid detection and identification of biofilms could give care providers a leg up in fighting these infections, biofilms' physiological heterogeneity makes identifying bacterial species difficult. The conventional biodetection method is culturing, which can take several days and has low sensitivity. Molecular methods, including polymerase chain reaction (PCR) and fluorescence *in situ* hybridization, still face challenges to rapid identification.

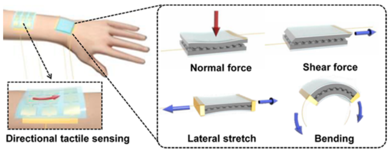
Seeking a new way to differentiate quickly between biofilm-generating bacteria, Li *et al.* (DOI: 10.1021/nn505753s) employed an array-based "chemical nose" approach that makes use of the differences in the structure and composition of the extracellular polymeric matrix that vary among species and even among strains. The researchers fabricated two Au nanoparticles with different cationic functional groups, one hydrophobic and one hydrophilic. The researchers then established a multichannel output for this sensor by reversibly adsorbing and then partially displacing three fluorescent proteins that glowed red, blue, or green. In the presence of biofilms, these fluorescent protein conjugates are disrupted by competitive interactions with the negatively charged matrix and the cationic particles, restoring fluorescence in a unique pattern for different species and strains. Tests showed that this system could distinguish between six different bacterial biofilms, including those combined with mammalian cells in a wound model. The authors suggest that this tool could help target treatment of biofilms and avoid broad-spectrum antibiotics.



Making E-Skins More Humanlike

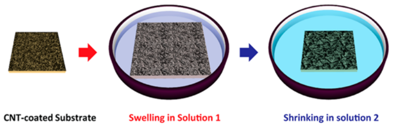
Natural human skin provides an ideal model for electronic skins, with the ability to sense a wide variety of stimuli including pressure, shear, strain, vibration, temperature, and pain. Mechanoreceptors are particularly important in distinguishing the magnitude, location, and direction of contact forces—critical information for successfully manipulating an object. To facilitate the tactile-sensing capabilities of human skin, researchers have used several different approaches, including resistive, capacitive, piezoelectric, and triboelectric sensors. Some tactics have combined mechanical and physical sensors on various substrates. However, these electronic skins were either able to detect only one type of mechanical stimuli or were unable to distinguish between multiple mechanical stimuli and their directions.

Taking a different tact, Park *et al.* (DOI: 10.1021/nn505953t) sought to mimic human skin even more directly by using interlocked microstructures reminiscent of natural skin's epidermal–dermal ridges. To create this system, the researchers synthesized microdome arrays using carbon nanotube composite elastomer films cast into micromolds. By engaging two films with the microdome patterns facing each other, they made interlocking geometries. Tests showed that various mechanical stimuli, such as normal pressure, shear, stretching, bending, and twisting forces each deformed the arrays in unique ways, forming characteristic patterns of changes in electrical resistance that allowed the researchers to distinguish among them. This electronic skin could also detect the direction of intensity of mechanical stresses. The authors suggest that their stretchable electronic skin could find use in a variety of applications that monitor motion and stress distribution, including robotic skins, prosthetic limbs, and rehabilitation devices.



New Cell-Growth Substrates Crinkle the Competition

The local environment, including nano- and microsized topographic features on substrates, can influence patterns of cell growth and behavior. Such "bio-interfaces" have been shown to enhance cell adhesion and survival, hinder cell migration and swimming, guide cell polarization and alignment, alter the structure of microbial biofilms, and promote cell differentiation. Such properties can, in turn, affect the performance of devices and materials that rely on cells. Because cells naturally explore and communicate using subcellular structures at the scale of tens to hundreds of nanometers, such as filopodia and flagella, creating secondary features on substrates at this length scale could lead to interesting and promising behavior for cells plated there.



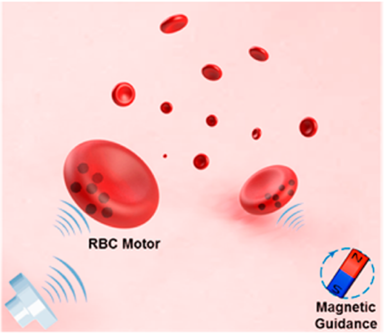
To test this hypothesis, Xie *et al.* (DOI: 10.1021/nn504898p) developed a novel method for synthesizing substrates with crinkles at this length scale, at tens of nanometers in width and hundreds of nanometers in height. They created these novel substrates by solution coating polyurethane substrates with a carbon nanotube (CNT) thin film. They then immersed this CNT-coated substrate first into a liquid solvent that allowed the film to swell, and then into a second solvent that caused it to shrink. As strain is released, the film buckled into folds with tunable sizes depending on the strength of the swelling solvent. Tests showed that neurons grown on this crinkly substrate grew to a higher density and had greater polarization than those grown on flat substrates, and exoelectrogenic microorganisms transferred electrons more efficiently. The authors suggest that these crinkled films have potential for a wide variety of applications that involve cell growth.

10.1021/nn5070698

Red Blood Cells Rev Their Motors

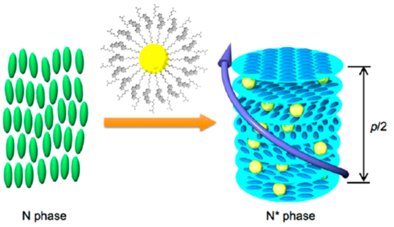
■ While many recently reported nano- and micromotors rely on a catalytic mechanism that uses hydrogen peroxide fuel for self-propulsion, the need for chemical fuel disqualifies them from a host of practical applications. Thus, the focus has shifted to developing fuel-free alternative methods for propulsion, including externally applied magnetic or ultrasound fields. These new motors could be used in a variety of biomedical applications, including directed drug delivery, biopsy, cleaning clogged arteries, precision nanosurgery, or localized diagnosis in remote anatomical areas. However, to be suitable for these applications, they must have high biocompatibility and perform well in undiluted biological media, characteristics that most current wholly synthetic motors do not yet display.

Seeking a high-performing biologically friendly substitute, Wu *et al.* (DOI: 10.1021/nn506200x) turned to red blood cells (RBCs) as the starting material for a new type of micromotor. After using a hypotonic dilution and encapsulation method to load iron oxide nanoparticles into RBCs, the nanoparticles aggregated asymmetrically into large magnetic particles. These larger particles provided an uneven geometry that allowed the RBCs to be propelled by pressure waves from external ultrasound while also providing a net magnetization that enabled magnetic alignment and guidance. Such magnetic control could be switched on and off with an external magnet, allowing the RBCs to be periodically reoriented. Tests showed the feasibility of controlled movement of these micromotors in diverse media ranging from phosphate buffered saline (PBS) buffer solution to undiluted whole blood. The authors suggest that these findings showcase the promise of using cell-based micromotors for a variety of *in vitro* and *in vivo* biomedical applications.



A New Twist on Gold Nanoparticle Chirality

■ Combined nanoparticles and chiral molecules have demonstrated potential in a variety of applications, including as biological probes and sensors, for stereoselective separations and catalysis, and in nonlinear optics and metamaterials with a negative index of refraction. It has also been shown that introducing these materials as dopants into achiral liquid crystals can influence them to have chiral condensed phases with unique optical properties that have additional applications. Previous research to sense and quantify the chirality of chiral ligand-capped metal nanoparticles verified that chiral, thiol-functionalized gold nanoparticles can transfer their chirality to achiral nematic liquid crystals. However, these experiments used (*S*)-naproxen as the chiral capping agent for the nanoparticles, prohibiting a true quantification of their chiral induction strength due to (*S*)-naproxen's limited miscibility in liquid crystals.

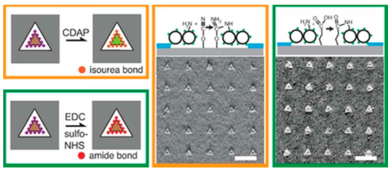


Seeking a better test of chirality transfer, Sharma *et al.* (DOI: 10.1021/nn504980w), who authored the previous study with (*S*)-naproxen, changed the capping agent to cholesterol and synthesized both two sizes of nanoparticles made in the presence of a chiral bias and one nanoparticle with cholesterol later conjugated to its surface. Their tests demonstrated that having a chiral bias during nanoparticle formation produced more pronounced chiral effects in condensed, nematic liquid crystal phases compared to those capped later with cholesterol. The researchers also showed that the smaller nanoparticles with a lower number of attached chiral ligands induced significantly more chirality. The authors suggest that these findings could have powerful implications for the use of functionalized metal nanoparticles as chiral catalysts, chiral discriminators, and chiral metamaterials.

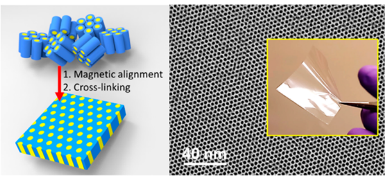
Helping DNA Origami Nanoarrays Stick Their Landing

■ In recent years, researchers have harnessed the qualities of DNA to create complex nanoscale geometries that are easily decorated with a variety of functional materials, turning them into devices in the laboratory. A powerful illustration of capacity is DNA origami, a method to create two- or three-dimensional structures that has already been used to assemble prototype electronic and optical devices, biosensing assays, and custom single-molecule instruments for biological research. Although these applications demonstrate the potential for DNA nanostructures, characterizing and integrating these devices has been challenging because DNA origami structures are synthesized in solution. Consequently, using simple surface deposition leads to arbitrary arrangements of devices with random orientations. Thus, finding a way to position and orient DNA nanostructures on planar substrates is crucial to their future applications.

In a new study, Gopinath and Rothemund (DOI: 10.1021/nn506014s) built on previous research that positioned individual DNA origami at binding sites on diamond-like carbon and SiO_2 substrates by adjusting this technique's parameters to optimize attachment and orientation. By varying the concentration of DNA origami structures in solution, altering the concentration of Mg^{2+}, increasing the pH, and keeping incubation time to a single hour, the researchers achieved attachment of single structures to 94% of binding sites on SiO_2, with about 90% having the correct orientation. Additionally, the researchers identified two methods for covalent attachment that avoid relying on Mg^{2+}, which can cause aggregation in components of some types of DNA origami devices. The authors suggest that this method for better placement could broaden the potential for DNA origami even further.



Tiny Pores, Large Length Scale Membranes



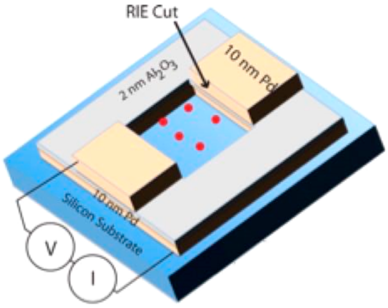
■ To take full advantage of the properties of self-assembled soft materials, researchers must learn to control their morphology over large length scales precisely and reliably. This ability is particularly important for applications including nanostructured, porous polymer membranes, which rely on uniform alignment of their pores parallel to the macroscopic transport direction for best performance. Currently, conventional fabrication techniques for producing polymer membranes lead to pores of random size and orientation, which can limit their permeability and selectivity.

In a new study, Feng *et al.* (DOI: 10.1021/nn505037b) report a novel way to synthesize macroscopic polymer membranes with uniform 1 nm pores by magnetically aligning and cross-linking a liquid crystalline mesophase. The researchers used the wedge-shaped amphiphilic monomer (Na-GA3C11) as the building block for forming thermotropic and lyotropic liquid crystalline mesophases with densely packed, monodisperse cylindrical pores. With an external magnet, they directed self-assembly of this system, then cross-linked it with light. Using high-resolution transmission electron microscopy, the researchers showed that the resulting robust, transparent polymer film had pores with physical continuity over macroscopic distances that aligned vertically to the exterior surfaces of the film. Ion-transport tests demonstrated that these novel films increased conductivity 85-fold over nonaligned materials with randomly oriented nanopores. The authors suggest that this technique could be used to create self-assembled soft materials suitable for a variety of applications, including membranes for the selective removal of organic and ionic contaminants from feed streams and new types of functional nanocomposites with long-range order.

Giving DNA Nucleotides a New Read

■ Next-generation DNA sequencing techniques have proven to be powerful tools for reading large portions of genomes. However, much of the human genome consists of repeated sequences that are difficult to assemble using these methods. As an alternative, nanopore sequencing holds potential for long reads of single DNA molecules. This method involves sensing changes in the degree to which ion current is blocked as DNA strands pass through a pore. However, this technology currently senses multiple nucleotides at once, leading to reading errors. To overcome this limitation, some researchers have suggested a variety of options for reading DNA through solid-state fixed gap tunnel junctions.

Seeking a better method for reading DNA, Pang *et al.* (DOI: 10.1021/nn505356g) developed a fixed-gap tunnel junction that builds on a previously reported method called recognition tunneling. Here, they used a layered structure with Pd and Al_2O_3 on a Si wafer. Into this, they cut a 2 nm gap and functionalized it with recognition molecules that form weak hydrogen bonds with DNA nucleotides. Experiments showed that when they flowed solutions containing each of the four naturally occurring DNA nucleotides, this device produced both a background current that depended on the analyte and increased with its concentration and signal spikes that differed in character for each analyte. The authors suggest that the addition of a nanopore could make similar devices a viable option for long and reliable DNA sequence reads.



Picking Up Good Vibrations

■ Vibrations are one of the most common mechanical motions that people experience regularly, generated by machinery, running vehicles, buildings, bridges, and ocean waves, among many other sources. Having a way to collect this energy would not only provide a way to power devices but could also give information on the operating status of machinery and infrastructure. Currently, most vibration sensors are equipped to measure frequency. However, quantitatively measuring vibrational amplitude has proven far more challenging because it requires a linear relationship between the sensing signal and the amplitude, something most sensors do not have.

Seeking a way to resolve this disparity, Wang *et al.* (DOI: 10.1021/nn5054365) developed a way to use triboelectric nanogenerators (TENGs) to measure vibration amplitude while also collecting vibrational energy. The researchers constructed a vertical contact-separation TENG with a laser-cut acrylic skeleton. Two of its plates were coated with Al, which served as stationary electrodes. In between, another sheet coated on both sides with fluorinated ethylene propylene (FEP) films served as the freestanding triboelectric layers, connected with springs to the Al-coated layers to catch vibrations. To enhance the triboelectric charge density, these FEP surfaces were etched to create nanowires structures, which increased the surface roughness and effective surface area. The researchers show through theoretical, analytical, and experimental studies that the linear characteristics of this TENG's electrical output can effectively report vibrational amplitude as well as vibrational frequency. Additionally, this TENG also harvested energy from vibrations, allowing it to power itself. The authors suggest that such a device broadens the applications of TENGs as active sensors and energy harvesters.