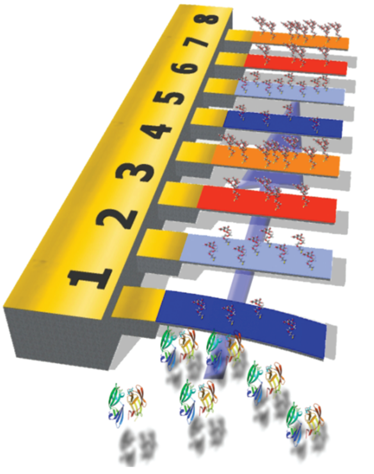
Cantilevers Bent on Elucidating the Glycome

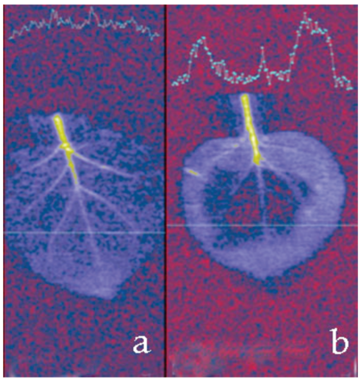
Researchers are becoming increasingly interested in the glycome, the entire complement of sugars present in nature. Studies have suggested that the glycome holds more diversity than both the genome and the proteome. However, understanding the variety of these biological sugars sheds little light on their biological function. Because carbohydrates regularly form complexes with other biological molecules, such as proteins and lipids, finding a way to identify these binding partners and quantify their interactions is essential to forming a more complete picture of the glycome.



In a step toward this goal, Gruber *et al.* (DOI: 10.1021/nn103626q) developed a biosensor to detect specific carbohydrate–protein interactions based on a cantilever microarray. The researchers attached various thiol-functionalized oligomannosides, including trimannose and nonamannose, to individual gold-coated cantilevers to form a carbohydrate-based sensing layer. Other cantilevers were functionalized with galactose as a reference. They then tested the sensing capacity of this microarray using the antiviral protein cyanovirin-N (CV-N), a protein shown to attach to nonamannose present on the HIV envelope and thereby prevent the virus from entering cells. Experiments showed that, upon introduction of CV-N, cantilevers functionalized with trimannose had 3–4 times the deflection of those functionalized with galactose, signaling a specific attachment of CV-N to trimannose. Tests with nonamannose showed an even stronger deflection, reflecting the protein's stronger affinity to this sugar. Tests with a second protein, concanavalin A, which also attaches to trimannose and nonamannose, confirmed the utility of the cantilever system. The authors suggest that their cantilever microarray could be useful for identifying a variety of other medically relevant carbohydrate–protein interactions.

Peering at Plants with Virus-Based Nanoparticles

Viruses can serve as capsules for nanoparticles, creating protein cages that surround their cargo. Researchers have used these virus-based nanoparticles (VNPs) for various biomedical applications, including vaccines, imaging, and drug delivery. One particularly useful property of VNPs is their ability to mimic the behavior of the original viruses in some cases, making them potentially useful as tools to study virus-induced physiological responses in organisms. This property could prove valuable in studying an area not yet exploited by VNPs: vascular transport properties in plants.

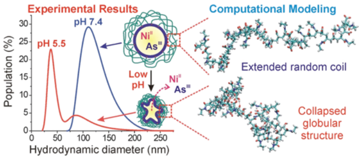


To test the feasibility of VNPs for this purpose, Huang *et al.* (DOI: 10.1021/nn200629g) allowed capsid proteins from Brome mosaic virus, a plant virus that infects a wide variety of grasses and other species, to surround cubic iron oxide nanoparticles functionalized with PEGylated phospholipids. These nanoparticles exhibited exceptional relaxivity in preliminary MRI experiments, opening the door to their use as contrast agents in imaging experiments. Sure enough, MRI validated that VNPs injected into *N. benthamiana* leaves spread from the injection site. Because some of the particles appeared to gather near cell nuclei, suggesting they retained some of their viral functions, the researchers then compared transport between VNPs and iron oxide nanoparticles without the viral protein coat. After injecting either type of particle into the petiole of a leaf, the researchers saw VNPs travel to the distal leaf edge. However, nanoparticles without the viral coat remained near the petiole, suggesting that the viral protein facilitates transport. The authors note that these VNPs could prove to be a valuable new tool in studying physiological processes important for plant growth and development.

Cage Battle against Cancer

The current paradigm for cancer chemotherapy is heavily based on small molecules. Though these pharmaceuticals have proven extremely useful, they have several drawbacks, including lack of specificity leading to undesirable side effects and toxicity that limit more effective dosing. Consequently, some researchers have explored the idea of delivering pharmaceuticals using nanoscale liposomal vehicles. These vehicles have already been used to investigate the delivery of As^{III} and Ni^{II}, two ions shown to possess potent anticancer activity with synergistic effects. Though liposomes containing both ions have better *in vivo* antitumor activity compared to those with just As^{III}, Ni^{II} is delayed after As^{III} release, potentially limiting synergistic effects.

In an effort to create a better release system, Lee *et al.* (DOI: 10.1021/nn200478m) developed liposome delivery vehicles for As^{III} and Ni^{II} surrounded by pH-sensitive polymer cages designed to release drugs in the acidic environment found in tumors. When the researchers incubated these polymer-caged nanobins (PCN) at pH 4.0, they released significantly more Ni^{II} compared to bare liposomes (BL) holding the same ions. Though the amount of As^{III} released from the PCN was only about half that of the BL, the PCN were significantly more toxic to HeLa cells. To understand how the polymer cages enhanced drug delivery, the researchers ran Monte Carlo and molecular dynamics simulations. Results showed that acidic conditions cause the cages to squeeze the liposomes, destabilizing the liposome membrane and leading to enhanced drug release. The authors suggest that their polymer cages could hold significant advantages over bare liposomes for cancer drug delivery.



Published online **May 24, 2011**

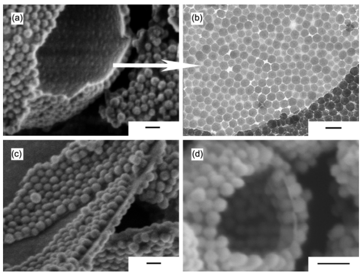
10.1021/nn201501h

©2011 American Chemical Society

Toward Creating Customizable Colloidosomes

■ Fluid interfaces are a natural attachment site for solid colloidal particles. Consequently, microcapsules made of this material can be fabricated at oil–water emulsions, known as Pickering emulsions, through a variety of means, including van der Waals interactions, chemical cross-linking, and polymerization. These so-called colloidosomes, named for their analogy with liposomes, can be used for various encapsulation applications and smart coatings. These applications rely on the ability to tune colloidosomes' characteristics, including wall thickness, porosity, stiffness, and chemical composition. Being able to produce a potentially useful bilayer wall remains an experimental challenge, with most reported colloidosomes having either a monolayer or a thick multilayer shell.

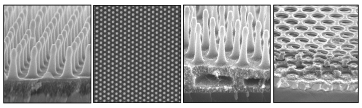
Seeking a way to create customizable colloidosomes, Wang *et al.* (DOI: 10.1021/nn200436s) developed a new method to synthesize colloidosomes made completely from silica with tailored size, shell structure, mechanical strength, and permeability. The researchers started with a Pickering emulsion stabilized by silica nanoparticles. They then added a solution of hyperbranched polyethoxysiloxane (PEOS), a silica precursor polymer, which acted as an interfacial glue that linked the particles together into spheres. Various microscopy and spectroscopy techniques showed that the resulting colloidosomes had diameters ranging from several hundred nanometers to several micrometers with 10–15 nm shells. By varying the weight ratio of silica nanoparticles to water, the researchers were able to customize the shell structure as monolayers or bilayers, with bilayer shells showing significantly more rigidity and less permeability. The authors suggest that this novel method to create colloidosomes opens a new avenue for designing functional inorganic microcapsules.



Metal Oxide Template Washes Away with Water

■ Metal oxide films are expected to play big roles in applications such as photonics, sensing, and electrochromics. In many of these potential uses, controlling the films' nanometer-scale features will be essential. Though many bottom-up strategies have been used to synthesize one-dimensional nanostructured metal oxides, transfer molding holds several advantages, including better control over patterning, lower cost, and easier device integration. Thus far, researchers have used this method to implement patterning of titanium silicates with sub-200 nm features and aspect ratios of up to 2.5 using perfluoropolyether elastomers.

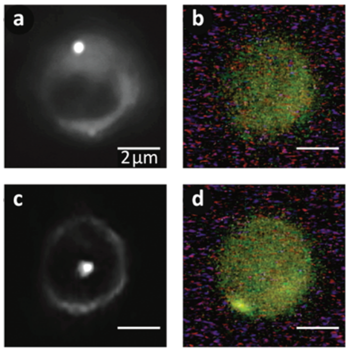
In an effort to pattern smaller metal oxide features at higher aspect ratios, Bass *et al.* (DOI: 10.1021/nn2006514) investigated using water-soluble poly(vinyl alcohol) (PVA) as their template material. The researchers created hard masters with either 135 or 50 nm features on silicon wafers. They then used these masters to create PVA templates. After spin-coating solutions containing TiO_2 precursor and acetic acid onto the templates and bonding the coated templates onto a substrate, the researchers partially condensed the metal oxides with UV radiation, then dissolved away the PVA template with warm water. Thermal treatment resulted in well-ordered metal oxide pillars with high aspect ratios of nearly 5:1. The researchers proved the generalizability of this approach by creating similar SnO_2 and organosilicate pillars by the same technique. These molded layers could be stacked to create multilayer, mixed-material structures. The authors note that using water-soluble templates represents a low-cost, environmentally friendly way of creating patterned metal oxide materials for new devices.



Nanoparticle "Golden Bullets" Perforate Model Cells

■ Getting biological molecules, such as proteins, DNA, and RNA, into cells is a pivotal part of many aspects of biomedical research. Scientists have crafted a variety of creative ways of bypassing the cellular membrane, including electroporation, lipoplex and polyplex injection, and "gene gun" technology. One method attracting increasing attention is photoporation, in which a laser beam increases membrane permeability. However, this technique requires high peak laser powers, which can damage untargeted cell regions.

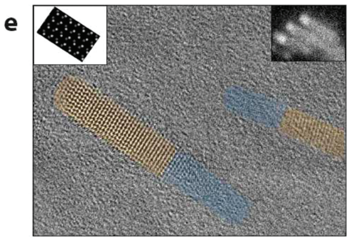
Seeking a new, less harmful strategy for increasing membrane permeability, Urban *et al.* (DOI: 101.1021/nn201132a) developed a novel approach in which gold nanoparticles are picked up by a focused laser beam and propelled through the membrane, effectively punching holes that can be used for targeted delivery. Using giant unilamellar vesicles, popular models for cells with gel-phase membranes at room temperature, the researchers initially tested this technique by immobilizing gold nanoparticles on the vesicle membranes. At low laser power densities, the nanoparticles diffused on the membranes, indicating a transition to the fluid phase, then were pushed through to the inside of the vesicles. Some nanoparticles escaped from the vesicles over the next few minutes, suggesting that their entry holes remained open for some time. In other experiments, the researchers used the laser beam to capture gold nanoparticles in solution, propelling them toward the vesicles. These nanoparticles also punched holes in the vesicles' membranes, with 100% of the vesicles showing perforation. The authors note that this novel technique could provide an easy, less damaging method to perforate cell membranes for biological research.



Breaking Symmetry with Ion Exchange

Several applications, including catalytic systems, sensors, light-emitting diodes, and photovoltaics, could benefit from proposed aligned arrays of semiconductor nanorods with compositional changes along the rod lengths. While researchers have been able to achieve some parts of this goal—creating arrays of colloidal nanorods of a single composition, or synthesizing rods of asymmetric composition without organization into arrays—creating organized films with broken symmetry remains a challenge.

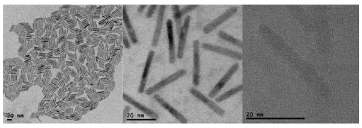
In a new study, Rivest *et al.* (DOI: 10.1021/nn2001454) demonstrate a new method to create asymmetrical semiconductor nanorod arrays by partially converting single composition nanorod arrays through cation exchange. The researchers started by creating a film of densely packed colloidal CdS nanorods through self-assembly. They then soaked this film in a methanolic salt solution containing only enough Cu^+ ions to replace Cd^{2+} ions to a desired depth in the array. Rutherford backscattering spectroscopy and various microscopy techniques confirmed that copper ion exchange occurred selectively only in the top ends of the nanorods, resulting in asymmetrical nanorods composed of CdS in the bottom half and Cu_2S in the top half. Electrical measurements showed that in the dual-layer film, rectification increased with greater conversion to Cu_2S. After soaking the film in a different cation, Pb^{2+}, the rectification direction reversed, demonstrating precise control of the film's electrical performance with varied composition. The authors note that this method can be generalized to a variety of other nanorods of different chemical compositions, providing an inexpensive, solution-processed method that could be useful in photocatalysts, sensors, and optoelectronics.



Shedding Light on Colloidal Semiconductors with Photoluminescence

Colloidal semiconductor nanocrystals could potentially revolutionize opto-electronic devices, including LEDs, lasers, and photovoltaic cells. To incorporate these materials into devices, strict control of charge carrier localization is necessary. One way to achieve this is through core/shell heterostructures that combine semiconductors with different energy gaps. In materials that exhibit type-1 band alignment, the core is surrounded by a shell with a wider band gap. This contrasts with type-II heterostructures, which separate the band extrema, and hence the excitons, in different materials. A recently discovered class of heterostructures, in which a CdSe core is surrounded by a CdS shell, behaves between type I and II, leading to high quantum yields. However, researchers still know little about the band alignment in this material and how it influences radiative recombination processes.

To shed light on this new material, Rainò *et al.* (DOI: 10.1021/nn2005969) worked with CdSe/CdS dot-in-rod heterostructures. Experiments showed that these structures have almost no thermally induced quenching of photoluminescence, allowing the study of charge carrier localization through time-resolved photoluminescence measurements. Testing different core diameters, the researchers found a significantly longer exciton lifetime in smaller cores, suggesting a different degree of electron wavelength localization and delocalization in the heterostructure, which changes the radiative lifetime. The researchers also found that, when they increased the temperature from 70 to 300 K, the radiative lifetime increased, suggesting a decrease of the conduction band offset with higher temperatures. The authors suggest that learning how to control the electron localization and delocalization in similar dot-in-rod materials could eventually lead to efficient and low-cost light-emitting devices.



Understanding the Auger Process

Transition metal ions, such as Mn^{2+}, play key roles in electroluminescent devices based on impact excitation. In this phenomenon, a conduction-band electron excited by an electric field transfers some of its energy to a dopant ion, which often gives off a photon as it moves back to a ground state. The opposite process is Auger de-excitation, in which energy transfers from an excited dopant ion, which drops to the ground state, to a charge carrier. Because this process can limit the efficiencies of electroluminescent devices, understanding when and how it occurs is pivotal to improving device performance. However, this process has not been thoroughly investigated in Mn^{2+}-doped devices.

To gain a better understanding of Auger de-excitation in these materials, White *et al.* (DOI: 10.1021/nn200889q) investigated various electrochemical techniques to control photoluminescence in Mn^{2+}:CdS quantum dot films. Comparing doped and undoped quantum dot films, the researchers observed that the doped films were significantly more sensitive to Auger quenching, leading to complete and reversible photoluminescence quenching. The researchers suggest that this de-excitation can be explained by transfer of energy from Mn^{2+} to a conduction-band electron, which is primarily aided by the long Mn^{2+} excited lifetime, and less so by strong *s*–*d* exchange and the large density of acceptor states at acceptable energies. Auger quenching occurred at low charging levels, suggesting that Auger de-excitation could provide insight into electron mobilities in other quantum dot films with low carrier densities. The authors note that these results emphasize the need to take Auger processes into consideration to optimize the efficiencies of doped semiconductor-nanocrystal-based devices.