Bridging Macro and Nano

One of the most exciting directions for nanoscience and nanotechnology is the coupling of materials systems on different length scales to enable new ways to take advantage of the unique properties of nanoscale materials. Examples of this kind of hierarchical scaling can be seen throughout the current issue. Schrlau, Dun, and Bau demonstrate a new way to measure cellular behavior following direct introduction of therapeutics or other molecules.[1] Hollow carbon nanotubes (or nanopipes) have a unique shape that make them particularly interesting for use as nanoscale syringes, yet they also exhibit high electronic conductivity, flexibility, and excellent mechanical properties. Their carbon coat can be functionalized to modify wetting properties or to facilitate sensing capabilities. These characteristics would make them the ultimate vehicle for direct injection into single cells, and even into specific intracellular components of the cell, while simultaneously measuring the response of the cell membrane; however, the ability to connect nanotubes to the macroscopic world in a manner that would enable the measurement of current and manipulation of fluids has been elusive. Schlrau *et al.* demonstrate that, by incorporating isolated carbon nanotubes in drawn glass, it is possible to isolate the nanotube tip while encasing the rest of the tube in a micrometer-scale glass coating, introducing electrical leads within the glass sleeve for current measurements. The net result is a "carbon nanopipette", which can ultimately deliver therapeutics in minute and highly controlled quantities within the cell while immediately measuring the impact of the drug or other small molecule on the cell using its physiological response.

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Immunosensors also benefit from coupling nano and macro since they operate on the principle that a nanoscale event (such as the detection of minute levels of protein or disease biomarkers) will produce a macroscale response (*e.g.*, a visible color shift or measurable electrical current in the sensor). A challenge in immunosensor development is the ability to gain quantitative information on the presence of proteins over short time scales. Rusling and co-workers use a simple approach to achieve record-setting levels of detection of prostate-specific antigen (PSA), a protein associated with prostrate cancer.[2] Many current methods involve high-cost and sophisticated instrumentation, but these authors utilize a very simple solution; an electrostatically adsorbed monolayer of 5 nm gold nanoparticles is at the core of their detection device. The gold nanoparticles, assembled on a graphitic electrode using an electrostatic bilayer for adhesion, are modified with antibodies for PSA, then exposed to the sample. Following binding events, the surface is treated with a second set of antibodies that are bound to micrometer-sized magnetic beads. The large size of these beads provides surface area to which hundreds of molecules of horseradish peroxidase enzyme (HRP) are bound. The electrochemical detection is thus based on the electrochemical reduction of hydrogen peroxide by the HRP, enabling rapid and reliable measurement of PSA. The HRP molecules act as electrochemical amplifiers, enabling detection of very small amounts of protein in undiluted serum. In this case, the level of detection reaches the remarkably low level of 0.5 pg/mL, which is well below the level for normal noncancerous cells. This kind of detection can lead to new methods for early detection of cancer, improving chances of recovery, and will be applicable to other diseases as well.

Scanning tunneling microscopy (STM) has provided a window into the nanoscale world as a means of studying and examining materials assembly at surfaces and fine features and morphologies of a broad range of materials systems; however, it has been much more difficult to resolve dynamics of small molecules using STM. Besenbacher, Hammer, and co-workers present the ultimate dream of many chemists and nanoscientists: the ability to

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observe a chemical reaction in full, including the generation of intermediates, on a surface in real time.[3] Here, the reaction of O_2 with H atoms adsorbed on a titania surface is observed to proceed through several steps to form water. What is unique is the observation, identification, and tracking of H_3O_2, H_2O_2, and dimerized water molecules. Observations of such systems are rare, and here these reactions are observed on titania, a metal oxide of key importance.

This issue also includes new developments in the formation of regular and unique nanostructures *via* manipulation of mechanical strain. Please see the work on mechanical buckling of nanostructures by Lagally and co-workers,[4] and the corresponding Perspective on manipulation of two-dimensional inorganic and carbon structures by Rogers.[5] We also feature new work on standing waves in optical corrals by Odom, Schatz, and their co-workers,[6] and a related Perspective by Nordlander.[7]

It is an understatement to say that the nanoscale world holds promise for numerous applications and for generating new technologies. Yet one of the greatest challenges that we face as nanoscientists is the ability to realize that promise by finding ways to bridge the nanoscale to the macroscale. Through innovative research like that described in these pages, I believe we are well on our way.

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REFERENCES AND NOTES

1. Schrlau, M. G.; Dun, N. J.; Bau, H. H. Cell Electrophysiology with Carbon Nanopipettes. *ACS Nano* **2009**, *3*, 563–568.
2. Mani, V.; Chikkaveeraiah, B. V.; Patel, V.; Gutkind, J. S.; Rusling, J. F. Ultrasensitive Immunosensor for Cancer Biomarker Proteins Using Gold Nanoparticle Film Electrodes and Multienzyme-Particle Amplification. *ACS Nano* **2009**, *3*, 585–594.
3. Matthiesen, J.; Wendt, S.; Hansen, J. Ø.; Madsen, G. K. H.; Lira, E.; Galliker, P.; Vestergaard, E. K.; Schaub, R.; Lægsgaard, E.; Hammer, B. F.; *et al.* Observation of All the Intermediate Steps of a Chemical Reaction on an Oxide Surface by Scanning Tunneling Microscopy. *ACS Nano* **2009**, *3*, 517–526.
4. Huang, M.; Ritz, C. S.; Novakovic, B.; Yu, D.; Zhang, Y.; Flack, F.; Savage, D. E.; Evans, P. G.; Knezevic, I.; Liu, F.; Lagally, M. G. Mechano-electronic Superlattices in Silicon Nanoribbons. *ACS Nano* **2009**, *3*, 721–727.
5. Kim, D.-H.; Rogers, J. A. Bend, Buckle and Fold: Mechanical Engineering with Nanomembranes. *ACS Nano* **2009**, *3*, 498–501.
6. Babayan, Y.; McMahon, J. M.; Li, S.; Gray, S. K.; Schatz, G. C.; Odom, T. W. Confining Standing Waves in Optical Corrals. *ACS Nano* **2009**, *3*, 615–620.
7. Nordlander, P. The Ring: A Leitmotif in Plasmonics. *ACS Nano* **2009**, *3*, 488–492.