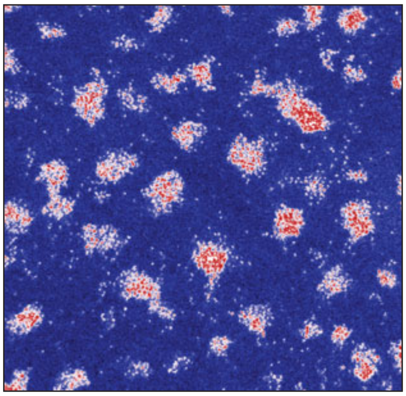
Single atoms imaged *in situ* with environmental STEM

Atomic-scale, real-time characterization of solid-state catalysts under gas-phase reaction conditions can provide unique information about reaction mechanisms. However, atomic-scale resolution is extremely difficult to achieve without the use of cryogenic temperatures and ultrahigh vacuum. Just a few months after receiving the L'Oreal-UNESCO Women in Science Award for developing the environmental transmission electron microscope (E-TEM), Pratibha Gai, the JEOL Professor and Yorkshire Forward Chair of Electron Microscopy from the University of York, UK, with Edward Boyes, who is co-director of the York JEOL Nanocentre, has designed a new environmental scanning TEM.



Environmental scanning transmission electron microscope (E-STEM) image reveals single Pt atoms dispersed on a carbon support under dynamic conditions. Image credit: Pratibha Gai, Edward Boyes, Leonardo Lari, and Michael Ward.

The E-STEM technology, published in the June issue of *Annalen der Physik* (DOI 10.1002/andp.201300068; p. 423), enables characterization of single atoms, small clusters, and nanoparticles in dynamic experiments. The instrument enhances the atomic-scale resolution of the E-TEM, and now incorporates full scanning functionality, aberration correction, diffraction analysis, and high-angle annular dark-field imaging. For *in situ* studies, the microscope can operate at >500°C in pressures of >0.1 mbar at the sample. Gai, who co-directs the York JEOL Nanocentre, said that the E-STEM "opens up exciting new opportunities for observing and studying reacting atoms."

To demonstrate the capabilities of the new microscope, Gai's research team examined Pt deposited on an amorphous carbon support. At temperatures of up to 400°C in 0.02 mbar hydrogen, the instrument was able to resolve both single Pt atoms and larger Pt nanoparticles. The persistence of isolated atoms can have ramifications for reactivity and particle growth, and Gai said that the work "reveals the importance of dynamic single atoms in catalysis in the reaction conditions." Additionally, the temperature dependence of the nanoparticle structures was observed, as the clusters evolved from disordered 1–2 layer discs to more cube-like configurations when heated for 30 minutes at 500°C under hydrogen. At this temperature, single atoms were not observed to the same extent due to either their incorporation into the larger particles or their increased mobility at the elevated temperature.

Mingwei Chen of Tohoku University, who was not involved with the work, asserts that the new E-STEM "is a promising technique to help us to solve many important catalysis-related questions." However, despite the vast improvement in operating pressure that the new E-STEM allows, both Chen and Gai agree that a further increase would be valuable. The pressures currently available to the instrument are enough to saturate the surface of the sample, but higher pressures would provide access to more catalytic reactions. Gai said that the research team is "going in stages" to improve the pressure range by orders of magnitude in the coming months.

Emily Lewis

Crystalline reflectors enable ultralow-thermal-noise optical cavities

Atomic clocks and gravitational-wave detectors involve some of the highest precision experimental measurements in the world. However, both have become limited by thermally induced noise in high-reflectivity mirrors used in optical interferometric cavities. This noise originates from the mechanical damping characteristics of tantala-based high-reflectivity coatings, and has been difficult to reduce. Now, G.D. Cole, W. Zhang, and colleagues at the University of Vienna; Crystalline Mirror Solutions; and JILA, the joint institute of the National Institute of Standards and Technology and the University of Colorado, Boulder, have demonstrated high-reflectivity compound-semiconductor-based crystalline mirrors with a factor-of-ten reduction in thermally induced noise. They report their findings in the July 21 online edition of *Nature Photonics* (DOI: 10.1038/NPHOTON.2013.174).

Current ultrahigh-precision optical interferometers use mirrors based on alternating dielectric layers of silica (SiO_2) and tantala (Ta_2O_5) deposited on transparent substrates using ion-beam sputtering. These exhibit optical absorptions as low as a few parts per million. The noise limit for optical cavities formed from these mirrors is dominated by "coating thermal noise," which is a consequence of the Brownian motion of the surface. This is driven by inherent thermal fluctuations and is controlled by the excess mechanical damping of the tantala layers. For gravitational wave detectors, this means that multi-kilometer-long optical cavities have noise characteristics dominated by optical coatings only a few microns thick. Previous efforts to minimize this noise have involved adding TiO_2 to the tantala layer to reduce the mechanical damping, but have only improved the noise floor by a factor of two.

The researchers hypothesized that mirrors based on epitaxial AlGaAs heterostructures might provide a path to reduced mechanical damping—and thus reduced thermal noise—while still providing ultrahigh reflectivity. Using molecular beam epitaxy, they deposited alternating layers of monocrystalline GaAs and $Al_{0.92}Ga_{0.08}As$ on a GaAs substrate. Then, using a lithographic process, the researchers formed 8-mm-diameter, high-reflectivity discs, which they removed from the growth wafer and direct-bonded to both planar and curved amorphous silica substrates. Next, using a Sr lattice clock laser with record frequency stability and an Yb fiber frequency comb, they measured the noise properties of an optical cavity formed from these mirrors. In close agreement with theory, they found a reduction of at least a factor of 10 in the coating noise at 1 Hz compared to state-of-the-art SiO_2/Ta_2O_5-based mirrors.

The results suggest that a new generation of room-temperature, ultrahigh-precision measurements may now be possible in atomic clocks, gravitational-wave detectors, and other systems. The researchers said that the fabrication technique does not appear to have any fundamental limits to achieving larger mirror sizes, and relatively simple techniques can likely be applied to tailor these mirrors to a wide range of wavelengths.

Colin McCormick

Bio Focus

Hard talk to stem cells for new bone growth

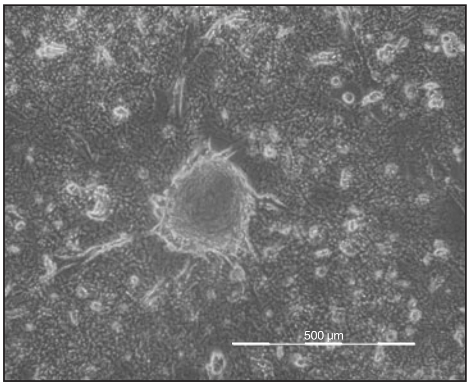
Synthetic materials have widely enabled medical repairs and replacements for damaged bones, such as in the use of fracture-supporting metal rods and artificial hips. These biomaterials are rapidly improving, but suffer from several limitations: they call for invasive surgery, are associated with painful recoveries, and lack the capacity to organically self-heal. With new developments in stem cell biology, tissue engineers dream of overcoming these traditional biomaterial limitations by ultimately regrowing injured bones, good as new.

The opportunity arises from the natural ability of stem cells to differentiate (i.e., transform themselves) into new bone-growing cells called osteoblasts, but the challenge lies in successfully coaxing this transformation to occur when, where, and in the way that one desires. A.H. Ambre, D.R. Katti, and K.S. Katti of North Dakota State University have recently approached this challenge by exploring the use of clay-based composites as potential scaffold materials for bone regeneration.

An ideal scaffold material would support the growth of stem cells, induce their differentiation to osteoblasts, and template osteoblast-directed mineralization into the desired bone-like biomaterial. In practice, achieving a scaffold that performs these functions is highly challenging, as stem cells respond differently to differing material surface structures and chemistries, and design rules are elusive at present.

In an article published in the September issue of the *Journal of Biomedical Materials Research A* (DOI: 10.1002/jbm.a.34561; p. 2644), the research team provides evidence that films comprising combinations of sugar derivatives (chitosan and polygalacturonic acid), alumino-silicate clay nanoparticles, and hydroxyapatite (HAP) may induce the differentiation of mesenchymal stem cells into osteoblasts on the film surfaces. The study shows that the method selected for composite synthesis affects the cell-directing properties of the resulting films, and determines whether the clay material makes a difference. If clay and HAP particles are added to a premixed solution of the two biopolymers, the resulting composite seems to support increased stem cell growth and differentiation relative to control materials with no clay-based mineral. However, if the mineral fraction is combined with chitosan first, followed by polygalacturonic acid addition, the clay-containing composite shows little difference in influencing cell behavior relative to clay-free counterpart materials.

These results are consistent with the researchers' prior work, which showed that polymer interactions at clay surfaces induce an "altered" nanoscale polymer phase near the mineral surface. The nature of these polymer-altering interactions would depend on the polymer's charged groups (e.g., amines and carboxylates), and distributions and availabilities of such groups will change if distinct polymers are first combined.



Mesenchymal stem cells grow on a clay-containing scaffold material. Reproduced with permission from *J. Biomed. Mater. Res. Part A* (2013), DOI: 10.1002/jbm.a.34561; p. 2644. © 2013 Wiley Periodicals, Inc.

The prospect of directly controlling stem cell differentiation with specially designed composite surfaces is attractive, as this would place biological control in the hands of materials engineers, and bypass the need for soluble chemical signals that are typically used to induce stem cell differentiation experimentally. Further, by appropriately tuning mechanical properties—through mineral additives such as clay, for example—scaffolds could be designed to support biological loads while stem-cell-directed bone growth is still in progress. Tissue engineers thus have a real incentive to study and tune clay–polymer interactions. Perhaps this will one day lead to designer surfaces that convincingly "talk" to stem cells, persuading them to pursue new lives as full-fledged biological bone.

Lukmaan A. Bawazer