A
tomic-scale, real-time character-
ization of solid-state catalysts un-
der gas-phase reaction conditions can
provide unique information about re-
action mechanisms. However, atomic-
scale resolution is extremely dif-
ticult 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 environmen-
tal transmission electron microscope
(E-TEM), Pratibha Gai, the JEOL Pro-
fessor and Yorkshire Forward Chair of
Electron Microscopy from the Univer-
sity of York, UK, with Edward Boyes,
who is co-director of the York JEOL
Nanocentre, has designed a new envi-
ronmental scanning TEM.

The E-STEM technology, pub-
lished in the June issue of Annalen der
Physik (DOI 10.1002/andp.201300068;
p. 423), enables characterization of sin-
gle atoms, small clusters, and nanopar-
ticles in dynamic experiments. The
instrument enhances the atomic-scale
resolution of the E-TEM, and now in-
corporates full scanning functionality,
aberration correction, diffraction analy-
sis, and high-angle annular dark-field
imaging. For in situ studies, the micro-
scope can operate at >500°C in pres-
ures of >0.1 mbar at the sample. Gai,
who co-directs the York JEOL Nano-
centre, said that the E-STEM “opens up
exciting new opportunities for observ-
ring 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 tem-
pertures 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 im-
portance of dynamic single atoms in
catalysis in the reaction conditions.”

Additionally, the temperature depen-
dence 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 hydro-
gen. 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 Univer-
sity, 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

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.

Crystalline reflectors enable
ultralow-thermal-noise optical
cavities

A
tomic 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 me-
tanical damping characteristics of tantala-
based high-reflectivity coatings, and has
been difficult to reduce. Now, G.D. Cole,
W. Zhang, and colleagues at the Univer-
sity of Vienna; Crystalline Mirror Solu-
tions; and JILA, the joint institute of the
National Institute of Standards and Tech-
nology and the University of Colorado,
Boulder, have demonstrated high-reflec-
tivity 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 al-
ternating dielectric layers of silica (SiO2)
and tantala (Ta2O5) deposited on trans-
parent substrates using ion-beam sputter-
ing. 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 fluc-
tuations and is controlled by the excess
mechanical damping of the tantala lay-
ers. For gravitational wave detectors, this
means that multi-kilometer-long optical
cavities have noise characteristics domi-
nated by optical coatings only a few mi-
crons thick. Previous efforts to minimize
this noise have involved adding TiO2 to
the tantala layer to reduce the mecha-
nical 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$_{x}$Ga$_{1-x}$As on a GaAs substrate. Then, using a lithographic process, they 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$_2$O$_5$-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

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**Bio Focus**

**Hard talk to stem cells for new bone growth**

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ynthetic 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.

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

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