Electron microscopy comes into focus

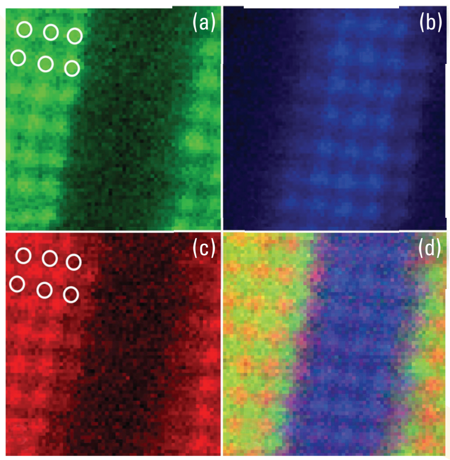
Atomic-scale chemical imaging gets much clearer.

David Muller's lab at Cornell University is well stocked with stuffed eels. He's not a biologist, but rather a physicist, and in this case the toys are not a reference to the sinuous fish but to a technique called electron energy loss spectroscopy, or EELS. The technique is commonly used in electron microscopy to provide information about the identity of an atom. EELS "gives you a fingerprint of what type of atom you have," explains Muller. "From the EELS spectrum you get the bonding information about that particular atom . . . but you also get the unique chemical identity."

But it can be painfully slow to scan over a large surface area. Now, Muller and John Silcox, also of Cornell University; Matt Murfitt, Niklas Dellby, and Ondrej Krivanek of Nion Co.; and colleagues at Chungnam National University (Korea) and the University of Tokyo have demonstrated the capabilities of a new electron microscope with improved electron optics that allow EELS spectra to be collected much faster and at a higher resolution (*Science* **2008**, *319*, 1073–1076).

Scientists have known since the 1930s that electron lenses have inherent defects called aberrations, which limit the resolution of the resulting images. Krivanek compares this problem to the complications that astronomers encountered after the launch of the Hubble telescope. "When it went up, the first pictures came back very fuzzy," he says. "They had spherical aberration in the primary mirror. What it amounts to is that the mirror was shaped very precisely to the wrong equation. . . . In electron microscopy until about 1995, we were basically looking at things through the uncorrected Hubble."

But in the case of electron microscopy, instrumentalists didn't shape things incorrectly; rather, electron lenses could not be shaped without aberration. Fortunately, the escalation of computing power in the mid-1990s revolutionized optics by permitting the design of much more complicated "multipole" lenses to correct the aberrations. "There really has been an explosion of capability that's been driven by the changes in manufacturing and in availability of computers, both to do electron optical calculations to figure out these systems . . . and in workstation computers for helping control the system during the experiment," says Philip Batson of IBM.



EELS images of a $La_{0.7}Sr_{0.3}MnO_3/SrTiO_3$ multilayer showing (a) La, (b) Ti, (c) Mn, and (d) a merged image of all three. The white circles show the position of La columns. (Adapted with permission. Copyright 2008 American Association for the Advancement of Science.)

Krivanek and Dellby began building electron optics with increasingly complex aberration correction and fitting them onto existing electron microscopes. But they soon realized that they would have to design a new instrument from scratch. "In a way, it was like putting a 300 horsepower engine into a little Toyota Corolla," says Krivanek. "We knew all along that increased precision was now starting to make demands on the electron microscopes that they could no longer keep up with."

The result is the Nion instrument used in the current work. This system not only has the highest-order aberration correction (fifth order) to date but also includes other features that improve its function, such as a more intense electron source and better electron collection lenses.

The researchers can speed acquisition of spectra by bombarding their sample with a better-focused beam containing more electrons and collecting more scattered electrons in the detectors. "We can scan the probe fast so we don't have to worry quite so much about making the atoms pose for us," explains Silcox. "They will drift away, but we can move faster so we catch them."

"In my opinion, the paper can be considered as a milestone . . . because it demonstrates convincingly that spectroscopy of single atom columns is possible," says Harald Rose of the Technical University of Darmstadt (Germany). Still, Rose says he was surprised that even with fifth-order aberration correction, the resolution of the instrument is not subangstrom. "They should get 0.5 or 0.3 Å resolution, but they have a resolution of perhaps between 1 and 1.3," he says.

"We could have easily tuned things for better resolution, but the extra resolution would have been wasted," notes Krivanek. "The point of this work was to maximize the signal so as to speed up the experiment, and we were not trying for the best resolution."

The giant leap in technology that this electron microscope represents is impressive, according to Batson. He says it's all the more notable for the speed with which the technology has improved. "This particular machine, to have done that in the short period—it's probably been ~8 years—is really quite remarkable."

—Jennifer Griffiths