materials," said John Rogers, a materials science and engineering professor at the University of Illinois at Urbana-Champaign commenting on this study. Other possibilities to power edible electronics have been demonstrated recently, he said. These include mechanical energy harvesters; degradable solar cells; and RF antennas and rectifiers that could be used to power devices from outside the body. But, he said, batteries are an important power supply option.

"This new system appears to offer a scalable route to high power output," Rogers said. "Successful integration of these batteries with electronics and sensors and wireless communication components, all of which now appear possible due to rapid advances in chemistries and materials, can enable devices that go into the body and then naturally disappear."

Prachi Patel

Quantitative STEM technique extracts 3D atom stacking information from 2D image

The properties of electronic devices are often affected by the positioning of dopant atoms, where these may be evenly distributed or present in the form of small clusters. The ability to determine the exact locations of dopant atoms in a host lattice is one example of the three-dimensional (3D) structural information that can facilitate the optimization of new electronic devices, particularly nanoscale devices.

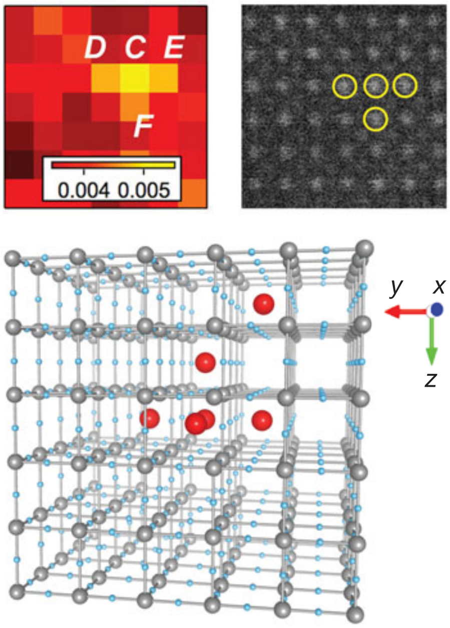
Obtaining 3D information with atom-scale resolution is a real challenge in conventional scanning transmission electron microscopy (STEM). "The typical method to obtain 3D information is 3D tomography, but this requires taking different images and tilting of the sample which is difficult to do and limits resolution to a few nanometers. While people have used that technique to make computer-reconstructed images of, e.g., nanoparticles, it does not give truly quantitative atomic resolution," said Jinwoo Hwang, first author on an article published in the December 27, 2013 issue of *Physical Review Letters* (DOI:10.1103/PhysRevLett.111.266101).

Currently a postdoctoral researcher in Suzanne Stemmer's group at the University of California–Santa Barbara (UCSB), Hwang and his co-authors from UCSB and the University of Melbourne, Australia, used a different method based on a quantitative STEM technique. Their experimental system can measure absolute intensity in the STEM image, which is dependent on the number and depth of the dopant atoms in each atomic column lying perpendicular to the image plane. By comparing the measured intensities with simulated images, they were able to determine the detailed 3D atomic arrangement of Gd dopants in a Gd-doped $SrTiO_3$ sample with an uncertainty less than one unit cell.

$SrTiO_3$ was used as the model system for the electron microscopy study performed at UCSB. While an interesting material in itself, the method could also be used for other materials. Hwang said, "Applications could be the study of dopant atoms in Si transistors or of dopant distributions in nanoparticles and nanowires, where it would be of strong interest to know if they segregate to surfaces or interfaces."

One of the issues is that only samples a few nanometers thick can be analyzed in this way. This requirement comes from maximizing the dopant visibility, and also from electron channeling effects that cause oscillations of the intensity; both scale with the atomic numbers of the lattice constituents. To get to this thickness and to avoid surface damage (that would be induced by ion-beam milling), mechanical polishing was used. The good news is that for Si, thicker films of 10–12.5 nm can be used because of its lower atomic number.

However, applying this technique to device characterization may still prove challenging. According to Wilfried Vandervorst, Head of the Materials and Components Analysis Department of IMEC, Belgium, "In a real device structure, we want to look at different regions which typically are inhomogeneous. The technique is in essence equivalent to 3D tomography, only instead of different images there is a need now to make different material slices out of the sample. So it will be interesting to compare with other techniques, [such] as the 3D atom probe, that may get the same result without that requirement."



From two to three dimensions: 2D projected Sr column intensity (I_{Sr}) map (top left) and high-angle annular dark-field (HAADF) image (top right) of a Gd-doped $SrTiO_3$ crystal area. Bottom figure gives a 3D reconstruction of the most probable Gd dopant configuration in columns C–F perpendicular to the surface (indicated by yellow circles in the HAADF image). Reproduced with permission from *Phys. Rev. Lett.* **111** (2013), DOI: 10.1103/PhysRevLett.111.266101. © 2013 American Physical Society.

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