permittivity. According to the theory, the collective plasmon oscillations became increasingly sensitive to the quantum nature of individual electron transitions as particle dimensions diminished. Despite a number of simplifying assumptions, such as infinite potential barriers, the energies of the model's LSPRs closely matched the EELS observations. This initial theory can be applied to other metals and geometries by making modifications to the key parameters in the dielectric function.

The research team now anticipates that researchers may be able to exploit the behavior of quantum-sized nanoparticles for a variety of applications. Because of their high-surface-area-to-volume ratios, these nanoparticles are ideal candidates for sensor and catalysis applications, particularly for events that involve interactions with very few photons or transferred electrons. Quantum-sized nanoparticles may also be of value in biological systems since they should be able to maneuver through cellular environments with greater ease than their larger counterparts.

Anthony S. Stender

Spin-orbital separation observed in a Mott insulator

Electrons in atoms can be described by three quantum numbers: spin, charge, and orbital. In an experiment performed at the Paul Scherrer Institute in Switzerland, these properties have now been separated. In one-dimensional systems, it is predicted that the electrons can separate into independent quasi-particles, which cannot leave the material in which they have been produced. While quasi-particles carrying either spin (spinons) or charge (holons or chargons) have already been identified, an international team of researchers led by experimental physicists from the Paul Scherrer Institute, Switzerland, and theoretical physicists from the IFW Dresden, Germany, have now succeeded in separating quasi-particles carrying the orbital degree of freedom (orbitons). These results are reported in the May 3 issue of *Nature* (DOI: 10.1038/nature10974; p. 82).

The electron's breakup into two new particles—spinons and orbitons—has been gleaned from measurements on the copper-oxide compound Sr_2CuO_3, a one-dimensional Mott insulator. This material has the distinguishing feature that the particles in it are constrained to move in one direction only, either forward or backward. Using x-rays, scientists have lifted some of the electrons belonging to the copper atoms in Sr_2CuO_3 to orbitals of higher energy, corresponding to the motion of the electron around the nucleus with higher velocity. By comparing the properties (energy and momentum) of the x-rays before and after the collision with the material, the properties of the newly produced particles can be traced.

"These experiments not only require very intense x-rays, with an extremely well-defined energy, to have an effect on the electrons of the copper atoms, " said Thorsten Schmitt, head of the experimental team, "but also extremely high-precision x-ray detectors."

"It had been known for some time that, in particular materials, an electron can in principle be split," said Jeroen van den Brink, who leads the theory team at the IFW Dresden, "but until now the empirical evidence for this separation into independent *spinons* and *orbitons* was lacking. Now that we know where exactly to look for them, we are bound to find these new particles in many more materials."

Observation of the electron splitting may also have important implications for high-temperature superconductivity, according to the researchers. Due to the similarities in the behavior of electrons in Sr_2CuO_3 and in copper-based superconductors, understanding the way electrons decay into other types of particles in these systems might offer new pathways toward improving the theoretical understanding of high-temperature superconductivity.

Nano Focus

X-ray microscope captures nanoscale structures in 3D

A new x-ray microscope probes the internal structures of materials smaller than human cells and creates unparalleled high-resolution, three-dimensional (3D) images. By integrating unique automatic calibrations, scientists at Brookhaven National Laboratory are able to capture and combine thousands of images with greater speed and precision than any other microscope. As reported in the April 2 issue of *Applied Physics Letters* (DOI: 10.1063/1.3701579; 143107), this full-field transmission x-ray microscope (TXM) rapidly combines two-dimensional (2D) images taken from every angle to form digital 3D constructs. The direct observation of structures spanning 25 nm will offer fundamental advances in many fields, including energy research, environmental sciences, biology, and national defense, according to the scientists.

"We can actually see the internal 3D structure of materials at the nanoscale," said Jun Wang, lead author of the article and head of the team that first proposed this TXM.

Wang's team specifically examined a 20-μm-wide sintered $LiCoO_2$ electrode from a lithium-ion battery, wherein the energy performance of the battery is related to the internal connectivity of the pores and particles within the electrode. The researchers took 1441 2D pictures of the electrode as the material was rotated

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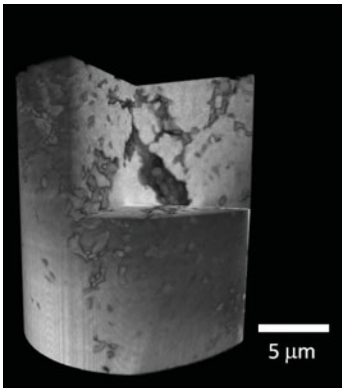

The three-dimensional reconstruction of a lithium-ion battery electrode, composed of 1441 individual images captured and aligned by the transmission x-ray microscope, reveals nanoscale structural details to help guide future energy research.

to capture every possible angle. These separate images were then combined to generate a single 3D construct of the specimen.

It is this reconstruction process that has previously limited the widespread application of transmission x-ray microscopy to nanotomography. Traditional methods require manual alignment of each 2D projection, or use software to slowly interpret the shifts. To achieve this, the sample has to have sharp internal features or be marked to provide guidelines, which can place restrictions on the materials that can be studied in this way. Such manual alignment procedures are extremely time-consuming, which limits the number of 2D images that can be employed, leading to reduced resolution of the final 3D images.

With the TXM, the specimen is mounted on top of a platform with three sensors that measure nanometer shifts in any direction as the sample rotates and the microscope takes pictures. The computer recording the images, after calibration using a gold sphere, then automatically compensates for any shifts and accurately assembles the images into the final 3D construct. The process takes only four hours, which owes more to the x-rays available from a synchrotron source than the microscope itself or the computer speed.

While this work has focused on alternative energy fuels and storage solutions, the new technology associated with this TXM will undoubtedly lead to its widespread use in examining biological, environmental, and materials samples.

Nano Focus

Multifrequency force microscopy improves sensitivity and resolution over conventional AFM

Science and technology at the nanoscale has benefited greatly from the atomic force microscope (AFM), which provides images by measuring the deflection of a probe—a very sharp tip attached to a flexible cantilever—as it scans across the surface of a sample. In conventional dynamic force microscopy (the most common form of AFM), a specific frequency is used to both vibrate the cantilever and measure the tip's deflection, but information about the sample that is encoded in the nonlinear deflection at other frequencies is irretrievable.

A solution to this problem is found in multifrequency force microscopy, where the excitation and/or deflection measurement is carried out at two or more frequencies. With acquisition times similar to those for conventional AFM, multifrequency force microscopy has the potential to overcome conventional force microscopes' limitations in spatial resolution. Recently, R. Garcia and E.T. Herruzo from the Instituto de Microelectrónica de Madrid, Madrid, Spain, have reviewed the development of five different types of multifrequency force microscopy—multiharmonic AFM imaging, bimodal AFM, band excitation, torsional harmonic AFM, and nanomechanical holography—and examined their applications in an article published in the April 1 issue of the online journal *Nature Nanotechnology* (DOI: 10.1038/NNANO.2012.38).

Multiharmonic AFM imaging is straightforward in that the higher harmonic components generated from conventional dynamic AFM are recorded and plotted. However, it is difficult to detect higher harmonics in air with the forces required for high-resolution imaging, requiring the development of special cantilevers. In liquid, where higher harmonics are easier to detect, a bacterial S-layer with 0.5 nm spatial resolution was imaged, as well as nanoscale mapping of the local stiffness and viscoelastic dissipation in living cells.

By using two excitation frequencies tuned to match two of the flexural eigenmodes of the cantilever, **bimodal AFM** separates topography from other interactions influencing the tip motion, such as magnetic or electrostatic forces, and is compatible for use in air, liquid, and ultrahigh vacuum. Operating at very low forces (50 pN) in liquid, bimodal AFM was used to obtain non-invasive imaging of isolated proteins.

The aim of **band excitation** is the acquisition of different dynamic curves while the topography of the surface is recorded. A synthesized digital signal is introduced that spans a continuous band of frequencies, while the response is monitored within the same or even larger frequency band. Although it generates a large amount of data and requires sophisticated controllers, either of which may prevent widespread application, band excitation has probed electromechanical coupling in soft biological systems by distinguishing among damping, Young's modulus, and electromechanical contributions. Ion diffusion in electrochemical batteries has also been studied with band excitation.

In **torsional harmonic AFM**, the topographic image is from conventional amplitude modulation AFM, but the tip–surface force is obtained simultaneously by integrating the higher harmonics of the torsional signal. The cantilevers are specially designed so that the tip is offset from the cantilever axis, which is beneficial for creation of torque around the axis of the cantilever and enhancing a large number of higher harmonics needed

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