Nano Focus

Nanomechanical mass sensor boasts yoctogram resolution

Diverse fields of study, ranging from surface science to mass spectrometry, benefit from using nanomechanical sensors to weigh ever-smaller masses. In such sensors, the resonance frequency of a nanoscopic cantilever changes when additional mass is adsorbed onto its surface. As reported in the April 1 issue of the online journal *Nature Nanotechnology* (DOI: 10.1038/NNANO.2012.42), J. Chaste and co-workers at the Catalan Institute of Nanotechnology and the Institute of Materials Science of Barcelona have built a sensor that achieves a resolution of 1.7 yg (yg = 10^{-24} g), which is approximately the mass of one proton and is two orders of magnitude lower than anything previously reported.

At the center of their experimental system is a sensitive, suspended carbon nanotube (CNT) resonator, which is fabricated using conventional nanofabrication techniques. The nanotube is suspended over a narrow (~150 nm wide) trench. The operation of the setup relies on monitoring the variation in the resonance frequency of the nanotube when additional mass is adsorbed onto its surface. Annealing the nanotube by passing a large current through it is pivotal to improving the mass sensitivity; this current-induced cleansing removes stray molecules that are posited to diffuse between trapping sites, and dramatically reduces fluctuations in the resonance frequency. The resonator motion is driven and detected through the low-noise frequency modulation mixing technique at liquid He temperatures and at ultrahigh vacuum.

The remarkable sensitivity of the device was used to monitor molecular adsorption onto the carbon nanotube. The expected downward shift in the resonator's natural frequency was observed as naphthalene molecules were introduced into the device, with different shifts being attributed to the location of the adsorption along the nanotube. The scientists could also analyze the temperature-dependence of Xe adsorption onto the CNT, showing that the process is thermally activated and that the binding energy agrees with theoretical values (~130 meV).

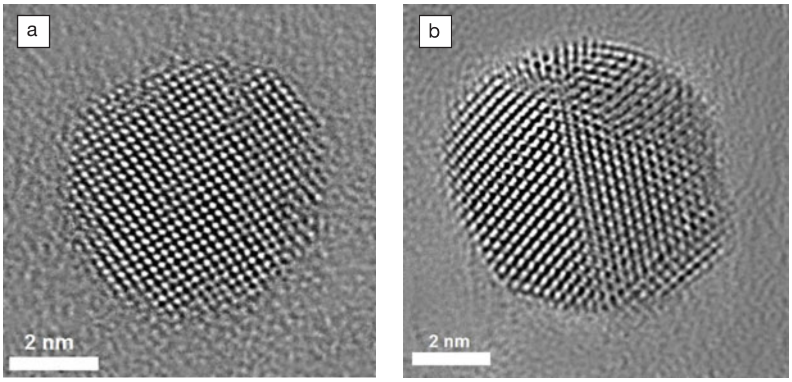
It is envisaged that such sensors could be used for investigation of molecular diffusion along nanotubes, high sensitivity magnetometry measurements of magnetic nanoscale objects, and the development of mass spectrometers based on nanotube resonators.

Rich Louie

Nano Focus

Plasmonic behavior of quantum-size metallic nanoparticles as investigated with STEM-EELS

The plasmon resonances of metallic nanoparticles can be exploited in many applications ranging from photovoltaics to the destruction of cancer cells, molecular detection, and solar energy harvesting. While the behavior of larger nanoparticles has been well-studied, research into the behavior of quantum-sized metallic nanoparticles (<10 nm in diameter) has been hindered by weak signals that are considerably broadened with decreasing nanoparticle size.



Aberration-corrected transmission electron micrographs of silver nanoparticles synthesized free of stabilizing ligands: (a) 6 nm diameter, (b) 7 nm diameter. Reproduced by permission from *Nature* **483** (2012), DOI: 10.1038/nature10904; p. 421. ©2012 Macmillan Publishers, Ltd.

As reported in the March 22 issue of *Nature* (DOI: 10.1038/nature10904; p. 421), J. Scholl, A.L. Koh, and J. Dionne of Stanford University have adopted a unique approach to investigate the localized surface plasmon resonance (LSPR) properties of nanoparticles in the quantum-size regime. The researchers examined the behavior of individual silver nanospheres with diameters ranging from 2 nm to 20 nm using aberration-corrected transmission electron microscopy (TEM) imaging in conjunction with monochromated scanning TEM electron energy-loss spectroscopy (STEM-EELS). The silver nanospheres were synthesized without ligands to ensure that ligand damping effects did not influence the experiments.

LSPR spectra were collected by focusing the STEM's electron beam at the edge of each sphere. The LSPR blue-shifted from 3.3 eV to 3.8 eV as the sphere diameter was decreased from 20 nm to 1.7 nm. This compares with a shift of only +0.03 eV predicted by classical Mie Theory over the same size range. The bulk plasmon resonance can also be detected with the STEM-EELS technique and exhibited a blueshift as the particle size decreased, although with a smaller magnitude than the surface plasmon resonance spectra.

To explain the observed behavior, the researchers developed an analytical model rooted in quantum theory that accounts for changes in the metal's electric 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