(continued from page 25)
between SrO and AlO_2 planes. Instead, all measurements to date have shown it to be insulating.

Jochen Mannhart and coworkers from the University of Augsburg and the Pennsylvania State University, using samples grown at relatively high oxygen pressures, found that one needs a minimum thickness of three unit cells of LAO deposited on the STO substrate before the interface will conduct electricity.[8] Such a steplike dependence of interface conductance on thickness of the LAO film is inconsistent with the presence of oxygen vacancies in significant numbers. Mannhart and coworkers were making a high-mobility transistor from the 2D electron gas at the STO/LAO interface. By applying a gate voltage to an initially insulating interface with just three unit cells of LAO, they could switch to a conducting state and back again.

For a different slant on the oxygen vacancy question, Alex Kalabukhov and his coworkers at Chalmers University of Technology in Göteborg, Sweden, studied the interface of STO with potassium tantalate ($KTaO_3$ or KTO).[9] In particular, they looked at an interface that was expected to have positive carriers if the dominant mechanism was the polar discontinuity. Hall measurements indicate that the charge carriers are negative; the result suggests the presence of oxygen vacancies.

Better characterization of the heterostructures can certainly help researchers understand what is going on at the interface, and a number of groups are working on such measurements. Techniques such as scanning transmission-electron microscopy can give clear pictures of the positions of the cations. As for the oxygen vacancies, current techniques to detect them are indirect and not yet capable of seeing vacancies below a certain density threshold.[10] It would also be nice to measure the charge distribution around the interface and, perhaps, to determine where the spins are. Are they indeed associated with the Ti^{3+} ions?

Strontium titanate was once touted as a substitute for diamond in jewelry, but it eventually lost out to other competitors. Perhaps the new interest in oxide interfaces gives a brighter shine to its future.

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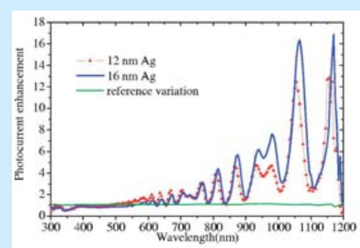
physics update

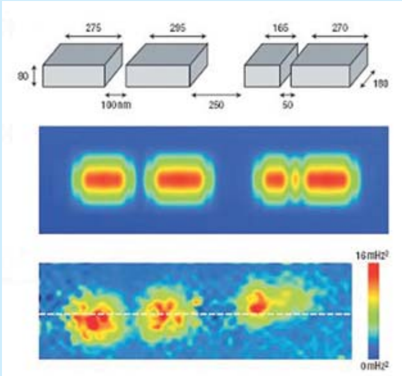
Supplementary material related to these items can be found at www.physicstoday.org.

Observing electron tunneling in real time. To escape an atom, an electron usually has to gain enough energy to climb out of the atom's Coulomb well. However, if the atom is bathed in an intense laser pulse, the pulse's strong electric field can lower the confining potential enough to allow the electron to tunnel to freedom. That hypothesis, proposed in 1965 by Leonid Keldysh, has now been verified, thanks to physicists' recent ability to control light on the time scale of electronic motion in atoms: attoseconds. Matthias Uiberacker of the Ludwig Maximilians University of Munich, Germany, and his collaborators blasted a gas of neon atoms with an attosecond UV pulse followed by an intense femtosecond red pulse. The attosecond pulse ripped off an inner electron and excited a second electron to the atom's periphery. Then the red pulse, consisting of just a few wave cycles with precisely controlled phase, could free the outlying electron by lowering the confining potential. When the three most intense peaks at the center of the red pulse coursed through the atoms, the tunneling probability neared 100%, and the electrons escaped in three steps. Each step took less than 400 attoseconds. (M. Uiberacker et al., *Nature* **446**, 627, 2007.) —BPS

Plasmon-assisted solar cells. Because of its ubiquity in electronics, silicon is the favorite semiconductor used in solar photovoltaic cells. But Si is a poor light emitter and absorber, and the efficiency of thin-film Si PV cells is even poorer than that of wafer-based thick cells. An important goal is to make the cells inexpensive by using thin films, but also to make them nicely absorptive. Scientists at the University of New South Wales in Australia have now enhanced the absorption of sunlight using surface plasmons generated on silver nanoparticles deposited on PV cells. SPs are collective oscillations of conduction electrons that can arise when light impinges on a metal particle whose size is on the order of the light's wavelength. Strong scattering occurs, and the SPs couple to the waveguide modes of Si; the light is effectively trapped. The researchers used this phenomenon in a PV solar cell to increase the cell's absorption efficiency. To create the particles, they deposited thicknesses of silver that ranged from 10 nm to more than 20 nm; during annealing, the silver coalesced into islands larger than 100 nm across. For 1.25-μm thin-film PV cells the group found a 16-fold absorption enhancement for light at 1050 nm, where Si normally absorbs poorly, and a 33% increase across all wavelengths of light (see the figure). For 300-μm-thick wafer PV cells, plasmon trapping increased full-spectrum absorption by 19%. According to Supriya Pillai, optimizing the nanoparticle size should bring additional improvements. The scientists also used plasmons to increase emission from thin-film LEDs. (S. Pillai et al., *J. Appl. Phys.* **101**, 093105, 2007.) —PFS



Magnetic resonance force microscopy has reached 90-nm resolution. MRFM maps the spins in a sample that is mounted on an ultrasensitive silicon cantilever hanging vertically over a sharp magnetic tip. If the tip's magnetic field is highly inhomogeneous, an applied radio-frequency field will resonate with the spins in a highly localized region of the sample, and the cantilever will deflect due to the resulting forces. To achieve the nanoscale resolution, John Mamin, Dan Rugar, and their colleagues at the IBM Almaden Research Center in San Jose, California, made tips with magnetic gradients of more than a million teslas per meter and held the samples about 45 nm away. The test objects being imaged consisted of tiny islands of calcium fluoride evaporated onto the cantilever tip. The image shows a schematic (top), a simulation (middle), and the experimental result (bottom). Separations of 100 nm could be clearly resolved. Previously, the same group of physicists had used a similar setup to detect the magnetic resonance of a single unpaired electron in a sample (see PHYSICS TODAY, September 2004, page 21). But now they are detecting much weaker nuclear spins. The nuclear advantage lies in its generality: Many materials have nuclear magnetic moments, but relatively few have unpaired electron spins. The nuclear MRFM experiment effectively explored a 650-zeptoliter volume, some 60 000 times smaller than the best conventional magnetic resonance imaging capability. Rugar thinks that their current apparatus can now detect 200 nuclear spins, which brings the group closer to their ultimate goal of imaging molecules at the single nuclear spin level. (H. J. Mamin et al., *Nat. Nanotechnol.* **2**, 301, 2007.) —PFS



Newton's second law of motion passes another test. Physicists at the University of Washington used a swiveling torsion pendulum (shown here), in which the restoring force is provided by a very thin twisting tungsten wire. The pendulum, which had a natural period of 795 seconds and an amplitude decay time of 15 days, is inside a vacuum chamber that was installed on an air-bearing turntable. Newton's law implies that for small oscillations, the pendulum's frequency should be independent of the amplitude. Looking for slight departures from that independence, the Washington researchers operated the pendulum for 20 days at various amplitudes, some as small as 13 nanoradians; at such tiny twists, Brownian excitation of the pendulum was a considerable factor in interpreting the results. The researchers found the second law to be valid down to accelerations as small as 5×10^{-14} m/s^2. That is a 1000-fold improvement in sensitivity over the best previous test, carried out back in 1986. The new result tightens the constraints on speculative modifications of Newtonian dynamics that, for example, try to account for the rotation curves of galaxies or for the ongoing mystery surrounding an apparently unaccounted-for acceleration in the trajectory of the two very distant Pioneer spacecraft. (J. H. Gundlach et al., *Phys. Rev. Lett.* **98**, 150801, 2007.) —PFS

Gravity Probe B **(*GP-B*)** has measured the geodetic effect—the warping of spacetime in the vicinity of and caused by Earth—with a precision of 1%. The tiny effect was observed via the precession of gyroscopes onboard the craft, which is in a polar orbit around Earth. The observed precession rate, 6.6 arcseconds per year, is consistent with the prediction of general relativity and with the only other measurement of the effect, which used the Earth–Moon system orbiting the Sun. Once certain subtle disturbance torques on the gyroscopes are better understood, *GP-B* scientists expect the precision of their geodetic measurement to improve to 0.01%. The first results were reported at the April meeting of the American Physical Society by Francis Everitt (Stanford University). The other major goal of *GP-B* is to measure frame dragging: When Earth rotates, general relativity predicts that it drags space and time around with it, causing a different gyroscopic precession, perpendicular to and 1/170 as strong as the geodetic precession. Everitt said that *GP-B* saw "glimpses" of frame dragging in the early analysis of the data; the researchers expect to report a credible, thoroughly cross-checked measurement at the final results presentation now scheduled for December 2007. The four gyroscopes are the most spherical objects ever made: The ping-pong-ball-sized orbs are out of round by no more than 10 nm. They are electrostatically suspended in a small case (shown here) spun up to speeds of 4800 rpm, and held in a vacuum of 10^{-14} torr. Coated with niobium, the balls are rotating superconductors at a few kelvin, and develop tiny magnetic dipole moments that can be read out to fix the spheres' instantaneous orientations. (See http://meetings.aps.org/Meeting/APR07/Event/64567 for the abstract.) —PFS

Morphing wings help birds control gliding. With an articulated skeleton under muscular control, birds are able to change the amount their wing feathers overlap and accordingly alter their wings' shape and size, independent of whether the wings are flapping. To learn more, researchers in the Netherlands did wind-tunnel studies of the common swift (*Apus apus*), which spends most of its time in the air—even roosting on the wing—and has an extensive gliding repertoire. They found that wings fully extended outward are optimal for slow glides, lazy turns, and low metabolic cost. Indeed, swifts actually roost at a sedate 8–10 m/s with their wings outstretched. Wings swept backward toward the tail (see the figure) improved not only gliding at higher speeds but also agility. In particular, swept wings can bear a higher load and thus can tolerate the increased centripetal acceleration during high-speed turns at up to 30 m/s. The researchers used their data to develop a semiempirical model that correlated well with radar measurements on roosting swifts in the field. Wing morphing could help control the flight of future aircraft. (D. Lentink et al., *Nature* **446**, 1082, 2007.) —SGB ■