MEETING BRIEFS

Capturing Sound, Light, and Strength With New Materials

Physicists, chemists, and other scientists gathered in Boston from 28 November to 2 December for the fall meeting of the Materials Research Society (MRS) to explore everything from the behavior of single atoms to bulk structures. Among the more than 4000 papers and posters presented, attendees learned about novel devices that convert light directly to sound, new techniques for studying minuscule structures called quantum dots, and organic-inorganic hybrid materials.

The Sound of Light

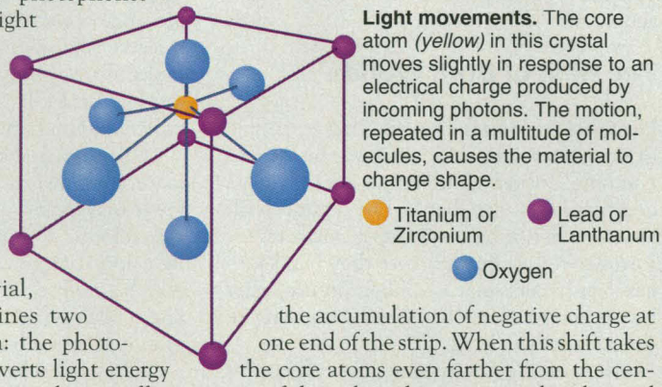
The headlong rush toward the information age has hit its share of bumps. Communication companies, for instance, can transmit voice data at the speed of light through fiber-optic telephone cables. But in order to hear the sound coded in those light pulses, the flashes must be converted into slower electric signals, which make a tiny mechanical arm vibrate, creating a sound. Researchers have long wanted to cut out the electronic go-between and flatten that particular bump. And at the Boston meeting, Pennsylvania State University materials scientist Kenji Uchino told his colleagues he has taken the first step toward making "photophones" that convert flashes of light directly into sound.

Uchino made a vibrating arm, or resonator, much like those in today's phones, using one of a relatively new class of "photostriction" materials that convert light directly to mechanical movement. The material, known as PLZT, combines two well-known phenomena: the photovoltaic effect, which converts light energy into electricity, and the piezoelectric effect, which transforms electrical energy into physical motion.

PLZT is a crystalline compound made of lead, lanthanum, zirconium, titanium, and oxygen, to which Uchino added trace amounts of tungsten-oxide. The material has a crystal structure of repeating cubes with either a titanium or a zirconium atom in the core of each cube. These atoms aren't quite at the center of the cube. At room temperature they're shifted slightly to one side, and researchers have known that they can make the bulk of the core atoms shift to the same side by applying a brief electric field to the crystal. This creates an asymmetry that researchers believe is the key to the material's transformative abilities.

Although there is still uncertainty about the exact mechanism, Uchino believes the material converts light to electricity when incoming photons excite electrons orbiting the lanthanum and tungsten atoms. The energized electrons, each with a negative charge, begin to move through the crystal lattice. And because the crystal has a nonsymmetric structure, these electrons tend to travel to one end of the material. The accumulation of electrons gives this end of the PLZT material a negative charge relative to the other end, creating an electric voltage.

The voltage produces a mechanical effect, causing the material to change its shape. The positively charged titanium and zirconium atoms shift once again, drawn toward the accumulation of negative charge at one end of the strip. When this shift takes the core atoms even farther from the centers of the cubes, this causes each cube, and therefore the entire crystal lattice, to lengthen. The effect can be reversed with outside intervention: If a negative charge is applied to the other end of the strip, the core atoms shift back toward the center of each cube, causing the entire lattice to contract.



Light movements. The core atom *(yellow)* in this crystal moves slightly in response to an electrical charge produced by incoming photons. The motion, repeated in a multitude of molecules, causes the material to change shape.

To translate this alternative expansion and contraction into vibrations, Uchino started with two 20-millimeter-long strips of PLZT, one with the core titanium and zirconium atoms nearest the top of each cube and one with the core atoms closer to the bottom. He bonded the two strips back-to-back and connected them electrically, using metal electrodes at the top and bottom.

Uchino then alternately flashed a light on each side. When light illuminated the left-hand strip, which had core atoms nearer the top, it produced an electric field with a negative charge on top, drawing those atoms further out and expanding the strip. At the same time, the negative charge was transmitted to the top of the right-hand strip via the electrode. There it pulled the core atoms, which had been closer to the bottom, back toward the center, shrinking the strip. As a result, the device bent to the right. When light illuminated the right-hand strip, the effect was reversed. So by rapidly alternating the light from one side to the other, Uchino made the device vibrate back and forth up to 80 times per second.

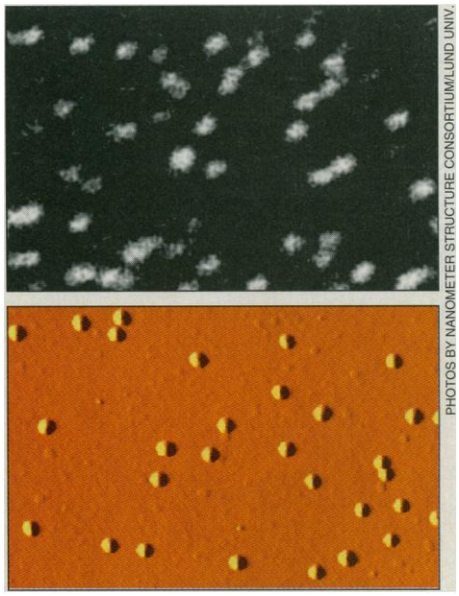
"That [frequency] is barely in the audible range" of the human ear, says Uchino. "We need to increase the frequency at least two to three times to easily hear the sound." Nevertheless, several of his colleagues were impressed by the early results. "These materials are interesting because they have so many properties packed into one material and by composition tailoring you can design their behavior," says Sarita Thakoor, a solid-state physicist at the Jet Propulsion Laboratory in Pasadena, California. Thakoor hopes to use similar materials in tiny remote-controlled robots that use light to power their movements. And Uchino has already begun efforts to make the resonator vibrate faster. If he's successful, his efforts could make the journey to the information age a smoother ride.

Flashy Quantum Dots

In the early 1940s, a song called "Polkadots and Moonbeams" was a hit for Frank Sinatra. Now materials scientists are singing about dots and beams, but to a different tune. In this case, the dots are quantum dots: tiny islands of semiconductor material that trap and confine electrons and other charged particles. The "beams" are photons given off by the particles that, once trapped in the dots, combine to emit light at various wavelengths. This has raised the prospect of using quantum dots to engineer precisely controlled tunable semiconductor lasers and light-emitting diodes, a quarry being hotly pursued by electronic companies worldwide.

But while researchers have developed several ways to make quantum dots, until now it has been impossible to measure the light emitted from an individual dot, and so it has been difficult to figure out which dot gives off which wavelength of light. At the MRS meeting a group of researchers led by physicist Lars Samuelson from Sweden's University of Lund reported that they've taken a big step toward finding out more about today's dots and beams by developing a series of techniques to focus on the luminescence of individual dots.

These techniques are "very powerful," says Chris Palmstrom, a materials scientist at the University of Minnesota. "It's exciting



PHOTOS BY NANOMETER STRUCTURE CONSORTIUM/LUND UNIV.

A thousand points of light. Photons captured by a spectrometer *(top)* are emitted from quantum dots imaged by an atomic force microscope *(bottom)*.

because now you can look and see how these things are behaving." The ability to image individual dots and gauge their behavior, says Samuelson, "will help us to ... better understand these materials and create novel devices."

The dots used by the Swedish researchers are beads of indium-phosphide (InP), 400 angstroms wide and 30 angstroms tall, spaced at least 1000 angstroms apart (one angstrom is approximately the size of a hydrogen atom). The dots are buried in a semiconducting crystal of gallium-indium-phosphide (GaInP).

Because of the quantum properties of the different semiconductor materials, charged particles can reside at lower energy states in the InP beads than in the surrounding material. And because these negatively charged electrons and positively charged "holes"—essentially the absence of an electron—prefer lower energy states, electrons and holes in the vicinity of the dots shed energy and flow inside, just as water flows down a hole. Once inside, they can combine to give off either a photon or heat.

In the past, researchers triggered the emission of photons from dots by shining a 0.1- to 1.0-millimeter-wide beam of laser light—the narrowest permitted by conventional laser optics—on the outer surface of the crystal. The light frequency is chosen so that its photons are not energetic enough to interact with particles in the GaInP, passing straight through to the quantum dots, where they excite electron-hole pairs. The result: an emitted photon. These photons are channeled to a spectrometer that measures their wavelength.

But a multitude of dots can lie underneath even a 0.1-millimeter-wide circle of light. As a result, photons are emitted from thousands or even millions of dots at a time, and the spectrometer captures a broad band of emissions, not the wavelength coming from an individual dot. To view the luminescence from individual dots, Samuelson and his colleagues developed three techniques. The first is simply to shine the laser through a narrow window. The Swedish researchers coated the GaInP with an additional layer of metal, out of which they carved a tiny 0.0005-millimeter hole, thereby sharpening the laser's focus. Because the dots are spaced more widely than this, only one dot at a time falls under the focus. And, sure enough, according to the spectrometer, the photons coming from the target formed a peak that was up to 1000 times sharper than the band previously seen.

The two other techniques involve injecting electrons into individual quantum dots with the probe of a scanning electron microscope or a scanning tunneling microscope. Here, too, the probes can focus on an individual dot. The particles they inject excite electron-hole pairs in the GaInP, which then fall into the dot and ultimately give rise to luminescence. As researchers create different dots and measure the different types of photons that emerge, Palmstrom suspects that the day of designer dots, made to emit a particular type of photon, is not too far off.

The Best of Both Worlds

Hardness and flexibility, whether in people or in materials, are difficult characteristics to combine. Inorganic materials such as glass and ceramics are hard. But under high stress—when a baseball hits a window, for instance—they break before they bend. Organic polymers such as rubber, on the other hand, bend before they break. But they're not usually very hard.

Materials combining these properties would be very desirable, because they might be nearly as rigid as glass but able to take strain by bending and bouncing back. They would make dandy impact-resistant glass, among other products. Over the last decade, researchers have been working hard to combine inorganics and organics to achieve this kind of hybrid versatility. But bringing these hybrid materials to commercial reality has proven difficult.

Nevertheless, chemical companies have been quietly working away, guarding their results to maintain a competitive edge. At the Boston meeting, the DuPont company gave attendees a peek into one corner of the secretive world of commercial research on organic-inorganic materials. Ken Sharp, an inorganic chemist with the company, outlined a hybrid dubbed a star-gel that has recently been granted a patent.

These hybrids owe their novel properties to the way their components combine. Inorganic compounds are typically hard because their constituent atoms, such as the silicon and oxygen atoms in ceramics, are bound to one another in a rigid three-dimensional lattice. Hydrocarbons in organic polymers, on the other hand, typically form two-dimensional chains: Bound in fewer dimensions, these chains have room to bend and flex without breaking.

Star-gels end up somewhere in between these rigid and flimsy extremes. Although their inorganic and organic building blocks are arranged in a 3D network—resembling something like a 3D mesh—this network is not as rigid as the lattice of an inorganic ceramic. The reason is twofold: There are fewer connections between the star-gel components than there are between ceramic components, and the star-gel molecules contain subunits that act as tiny shock absorbers.

Sharp and his colleague Mike Michalczyk start to make one type of star-gel by using commercially available molecular building blocks with a single silicon atom in the center attached to four reactive hydrocarbon chain arms. These hydrocarbon chains are the shock absorbers. To link each chain arm to another molecular building block, the researchers add reactive molecules called triethoxysilanes to the end of each arm. In the presence of water and other chemicals, these molecules form up to three bonds to similar molecules on the arms of neighboring building blocks. Molecules in glass, in contrast, typically form bonds to four others.

This extra freedom allows the connecting material between the building blocks to move in response to stress, helping the material deform. The result: materials that can take up to five times the strain that glass can take before breaking. But unlike glass—and like rubber—dried star-gels are able to compress and spring back to their original shape.

"These are all-around remarkable materials," says Albert Yee, a materials scientist and engineer at the University of Michigan, Ann Arbor. "The ingredients used are very inexpensive, and the [manufacturing] process is simple. So I'm optimistic they can become commercial sometime soon."

One obstacle to commercial use, however, is that liquid byproducts, such as alcohol, are generated when the triethoxysilanes link up. To form a solid, the researchers must evaporate this liquid, and for large volumes, evaporation can take a long time. As a result, Sharp says, the materials are more likely to be used as protective films or coatings, which allow the liquid to evaporate more quickly than they would from a bulk solid. "You would never want to build a bathtub out of this stuff," he concludes.

–Robert F. Service