MEETING IEEE NANO 2001

Nanoscientists Look To the Future

WAILEA, HAWAII—About 150 researchers gathered here from 28 to 30 October to discuss the latest big developments in the science of small. In between dips in the ocean and mountain hikes, participants heard about efforts to manipulate nanosized objects and improve optical data storage. And one young scientist offered hope that the future is in good hands.

Expanding the Nano Toolbox

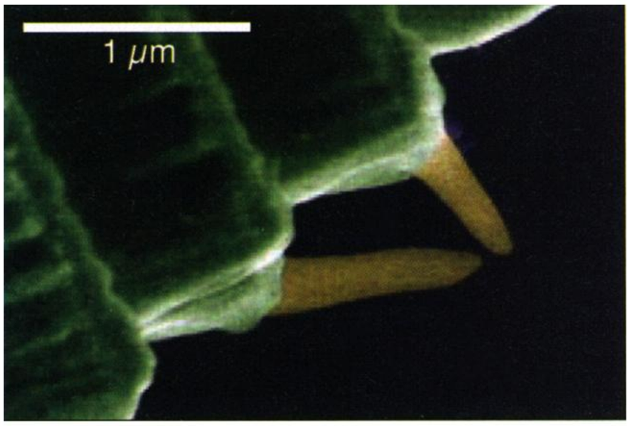
If you've ever tried to remove a splinter with blunt tweezers, you know the frustration facing nanotechnologists. So far they have been better at spotting tiny objects than at moving them about. But at the Hawaii meeting they announced two important advances for those hoping to manipulate nanosized objects: a set of custom-built nanotweezers and a movable platform capable of making successive steps just 2 nanometers long.

Together, the feats help lay the groundwork for a new era of manipulating objects in the nanoworld, says Metin Sitti, an electrical engineer at the University of California, Berkeley. "It's a very exciting time in the area of nanomanipulation. Lots of groups are making progress in this area," Sitti says.

One of those groups, led by Peter Bøggild of the Technical University of Denmark in Lyngby, reported a new way to custom-build nanotweezers to accomplish just about any nano-grabbing task. The tiny tweezers aren't the first to work on the nanoscale. In 1999, Harvard University chemist Charles Lieber and his colleagues made a set of nanotweezers by attaching a pair of carbon nanotubes atop separate electrodes on the end of a glass micropipette. By applying different electric voltages to the electrodes, Lieber's team could get the nanotube arms to pinch and release objects. But the technique creates a large electric field at the tweezer tips, which can alter the objects being manipulated. Moreover, the tweezers must be constructed one at a time, making the manipulation of nano-objects a slow and tedious process.

Bøggild's group took up both these problems at once. The researchers first used standard micromachining processes to carve a small slab of silicon into what look like tiny pliers with tips jutting off the edge of the slab. Applying a voltage to three electrodes —one between the arms of the pliers and one on either side—drives the cantilever arms of the pliers together and apart.

To turn the micropliers into nanotweezers, Bøggild's team used an electron beam from a scanning electron microscope to grow a tiny tweezer arm from the end of each of the cantilevers. The beam shattered hydrocarbon molecules present in a surrounding vacuum chamber, causing carbon deposits to build up at the focal point of the electron beam. By carefully directing the electron beam, the team angled the two tweezer arms together until the tips were some 25 nanometers apart. What's more, the initial micromachining processes can create electrode-driven plier arms by the batch. The work, Sitti says, is a "really good example of fabricating nanostructures."



Hold it. Custom-built nanotweezers will help engineers get a grip on the nano world.

But making nanotweezers is only half the challenge in manipulating objects in the nanoworld. The other half is moving them where you want them to go. To help accomplish this task, Takashi Shigematsu and Minoru Kuribayashi Kurowawa at the Tokyo Institute of Technology, along with Katsuhiko Asai at Matsushita Electric's Advanced Technology Research Labs in Kyoto, created a new "stepping drive," which uses sound waves inside crystalline substrates to nudge a small platform. Kurowawa has spent years improving such drives, and the latest model reduces the step sizes 10-fold over its predecessor, to a mere 2 nanometers each.

Robert Shull, a physicist at the National Institute of Standards and Technology in Gaithersburg, Maryland, calls the ultraprecise stage "an enabling technology for making manipulations on the nanometer scale." It's also a device that should work well with the nanotweezers. "All of these nanomanipulators will need to be able to move with that kind of resolution," Shull says. "You need something that can move in a controllable fashion. This appears to have that."

Taking Nanowires Beyond Gold

Mariangela Lisanti is having a very good year. Last December, she won the Siemens Westinghouse Science and Technology Competition and a $100,000 college scholarship for work that reveals how electrons dart through wires just a few atoms thick. In March, the same project earned her another $100,000 scholarship and top honors at the Intel Science Talent Search, as well as a visit to the White House to meet President George W. Bush. In May, she pulled in several more awards at Intel's International Science and Engineering Fair, including an invitation to attend the 2001 Nobel Prize awards ceremony next month in Stockholm. And last month she delivered a plenary talk here alongside other nanotechnology notables, including 1996 chemistry Nobelist Richard Smalley. Not bad for someone who just started her freshman year at Harvard. "She is very impressive," says Phaedon Avouris, a nanotechnology pioneer at IBM's T. J. Watson Research Center in Yorktown Heights, New York.

Lisanti says modestly that these honors were unexpected. But an outside observer might have guessed. While at Staples High School in Westport, Connecticut, Lisanti was valedictorian, captain of the math team, founder and captain of the school's engineering team, and a concertmaster of the chamber and symphonic orchestras. Fluent in Italian and Spanish, she received numerous awards in language as well as in science competitions and was named a Governor's Scholar, the highest academic distinction in Connecticut.

Lisanti says she's dreamed of winning a science fair for years. But getting there took perseverance. Her high school didn't have much tech-heavy equipment, so she asked her teachers for names of area professors who might mentor her. After several rejections, she hooked up in 1999 with Mark Reed, the chair of the electrical engineering department at Yale and a pioneer in molecular electronics. "Actually, my first answer

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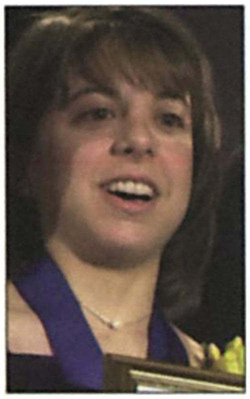


Fast start. Freshman Mariangela Lisanti is racking up science awards.

was no," Reed confesses. "But after a short conversation I became convinced she could handle it."

In 1997, Reed's group became the first to measure the flow of electrons through a single molecule (*Science*, 10 October 1997, p. 252). The team created an ultrathin gold wire, broke it, and then used chemical techniques to deposit gold-binding molecules in the gap. Under such conditions, electrons no longer flow in a chaotic stream as they do in large wires. Rather, they shuttle one by one in an orderly fashion that reveals their underlying quantum-mechanical nature.

Reed's technique works beautifully for gold contacts, but it is laborious and difficult to adapt for testing different metals. "We sought to develop a new technique that could collect larger data sets and work with other metals," Lisanti says.

Reed challenged Lisanti to find a mechanical scheme for repeatedly making and breaking a connection between pairs of nanowires, each of which would need to remain connected to measurement electrodes. After some thought, Lisanti suggested using the tiny vibrations of a ceramic crystal—which are used in door buzzers to create sound—to drive the movements of a small platform that in turn moved the wires in and out of contact. Reed gave his approval, and after a summer of 60- to 80-hour weeks, Lisanti got the setup to work.

"As the wires pull apart, the break is not abrupt," Lisanti says. "They reduce to only one atom, and so you can see the quantization" of electrons flowing between the wires. Not only did the setup work with various types of metal wires, but its speed enabled Lisanti to amass millions of measurements of electrons shuttling between nanowires. The volume of experiments turned out to be vital, because each measurement shows a slightly different behavior, due to the precise position of individual atoms at the junction.

Lisanti found some surprising patterns. Most startling was the conduction of electrons between gold nanowires, when the junction between the two wires was still relatively intact and contained numerous gold atoms. Although one might expect the conductance to increase linearly as more and more atoms connect the adjacent wires, Lisanti found instead that it jumped up at regular intervals. That pattern suggested that there were certain "magic numbers" of gold atoms that conduct electrons better than other configurations. Lisanti and Reed have since hypothesized that the magic numbers are related to stable configurations in which the gold atoms are completely surrounded by their neighbors. In contrast, preliminary results suggest that copper nanowires don't show such islands of stability.

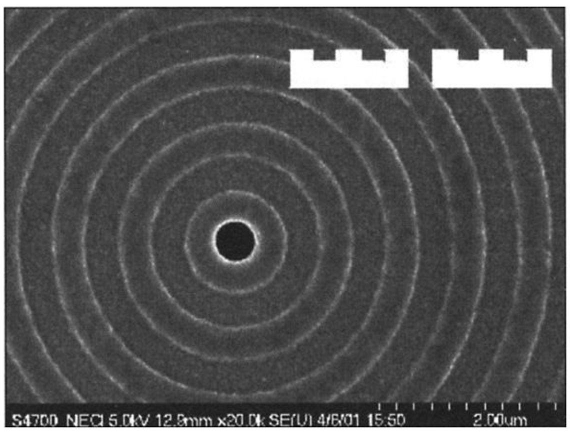
Lisanti hopes someday to continue her experiments with Reed to see how general the phenomenon that she discovered is. But for now she's just trying to settle into her new life as a college freshman, in between trips to Hawaii and Stockholm.

Lighting the Way Ahead for Data Storage

Engineers hoping to pack longer movies onto DVDs are up against a formidable challenge: overcoming the physics of light. The devices use a laser to highlight tiny spots burned into the heart of a plastic disk. Unfortunately, researchers can make these spots only so small—about 400 nanometers—before the lenses and optical detectors can no longer see them. That's because diffraction causes light waves to spread out, blurring the image.

Over the past decade, scientists have come up with a specialized technique, called a near-field scanning optical microscope (NSOM), that can spot features as small as 100 nanometers by placing the aperture of a detector so close to a surface that light bouncing off doesn't have room to diffract. But these microscopes do such a poor job of collecting light, it takes them too long to see spots in a rapidly spinning disk, making them useless for data storage.

At the meeting, a group led by Kelly Pellerin and Tineke Thio of the NEC Research Institute in Princeton, New Jersey, reported a way to help NSOMs pick up the pace. The team created a specially designed aperture that funnels surrounding light effectively enough to increase light transmission 150-fold. The NEC researchers say they are working on improvements that should produce a 1000-fold enhancement, which may be enough to make NSOMs useful for data storage. "It's a powerful concept," says Calvin Quate, an expert on scanning microscopes at Stanford University in Palo Alto, California. If the improved version works, Quate adds, "it would be terribly important."



Bull's-eye. Capturing light through a special corrugated aperture may pack 50 times as much information onto DVDs.

NEC's light funnel takes advantage of an electrical effect called surface plasmon resonance, which occurs when light strikes a metal surface. Under the right conditions, this light causes electrons in the metal to oscillate back and forth. These oscillating electrons can dramatically boost the electromagnetic field at the edge of a small aperture in the film, a change that in turn helps light pass through. In 1996, NEC's Thomas Ebbesen and colleagues showed that by patterning a metal film with an array of tiny holes precisely arranged to increase the electron resonance, they could pass 1000 times as much light through the film.

In their current work, Ebbesen—now at Louis Pasteur University (ULP) in Strasbourg, France—along with ULP's Henri Lezec and Thio and her colleagues at NEC, wanted to see if he could find a similar way to get more light through a single hole, which would be easier to integrate with an NSOM. To do so the researchers patterned a silver film to look something like a miniature bull's-eye, with a 400-nanometer hole surrounded by successive rings of corrugations in a silver film. When hit with light with a wavelength of about 800 nanometers, the corrugations created a sharp electron resonance effect and increased the ability of light to make it through the hole 150-fold compared with an aperture without the surrounding rings. That's still not enough to allow an NSOM to spot tiny dots on a spinning DVD, says Thio. But she adds that the team is already working on an improved version by following a seeming paradox: Making the aperture smaller should increase the amount of light that gets through, because it will enhance the electric field around the hole.

The NEC group has yet to try creating such a structure on the tip of an NSOM. But that's another upcoming project, Pellerin says. If it works, the good news is that it may lead the way to DVDs that can store 50 times more data than the current variety. The bad news is that it means we'll all have to buy new DVD players to use them.

—ROBERT F. SERVICE

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