The Incredible Shrinking Tunneling Microscope

Micromachinists adapt scanning tunneling microscopes for sleuthing in a Lilliputian world

"A NUMBER OF THINGS WENT WELL OVER the [Mother's Day] weekend," Noel MacDonald beams. And not just for mothers; for MacDonald, the high point of the weekend of May 11 and 12 came at the National Nanofabrication Facility at Cornell University, where he and his graduate students made a breakthrough in modifying and miniaturizing scanning tunneling microscopes (STMs). If the group's minuscule engineering continues to flourish, STMs—already famous for mapping atomic and molecular-scale landscapes—may take on new roles as mite-sized sensors, able to detect chemistry, pressure, and motion in such environments as outer space and the chambers of the human heart.

"We're trying to build very small scanning tunneling microscopes on a silicon chip," MacDonald says. Ordinary STMs work by tracing an exquisitely fine stylus over a sample, detecting topography through tiny variations in a quantum-mechanical "tunneling current" that seeps between the surface and the stylus' tip. Although the business end of an STM is minute, the mechanisms that guide it can be almost as big as a breadbox. MacDonald and his team, which includes microprocessing expert Susanne Arney and device designer Jason Yao, are trying to collapse the whole package—including springs, drives, and gears—into a silicon speck that could fit on the cut end of a human hair. And they're trying to add new features to boot.

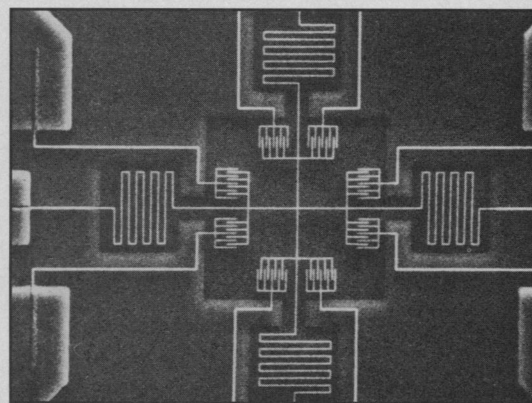
The Cornell team still has a long way to go to reach that goal, MacDonald acknowledged at a symposium titled "Nanostructures and Mesoscopic Systems," held in Santa Fe last week. But their success at linking several working components of the sub-Lilliputian devices has bolstered their confidence. "We feel we're getting there," MacDonald notes. Over Mother's Day weekend, the nanoengineers finally got one of their device's two nearly virus-sized silicon styluses to vibrate back and forth at 5,000,000 oscillations per second. Not only is that motion important for the sensing roles MacDonald and his graduate students have in mind for the microdevice, but it means that the mite-sized electrostatic "comb drives" and springs that pump the vibrations are in working order. A set of microdrives on a different version of the device, designed to subtly maneuver the stylus horizontally, also made a successful debut on Mother's Day weekend.

All this miniaturization—done with the same patterning and etching techniques used in the microelectronics industry together with more exotic techniques like electron-beam lithography—is more than a stunt. Other groups, including Calvin Quate and his colleagues at Stanford University, have been shrinking conventional STMs meant to image surfaces. MacDonald has something different in mind for his device. It's a tiny silicon nerve, able to sense its environment through its own vibration. The stylus weighs so little—probably well under a nanogram (a billionth of a gram)—that even the slightest shift in conditions should noticeably affect its motion. And those changes should show up as fluctuations in the tunneling current between the two opposed tips, MacDonald says.

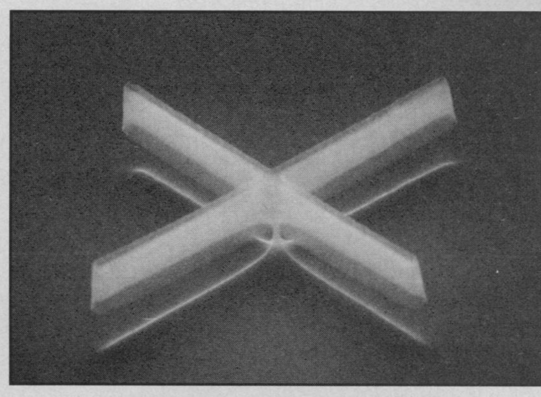
A small crowd of molecules sticking to the vibrating tip, for example, should be enough to boost its mass and slow the vibration. By modifying the microgizmos' tips or other components, the Cornell crew hopes to make them sensitive to a variety of environmental cues—light and motion, for instance—as well as chemicals. Monitoring the tunneling current between the two tips before and after sensing tasks will serve as a ready check on the sensor's reliability (though the workers have yet to demonstrate that they can keep track of a tip-to-tip tunneling current).

Each working device would be sensitive to only one feature, but the diminutive size of the whole assemblage—stylus pair, springs, and motors—means that many STM sensors could be clustered to pool their sensitivities. "We're out to make a generic sensor," MacDonald says. By micromachining an array of these mini-STMs on a single piece of silicon, MacDonald hopes to build an all-purpose STM-sensor on a chip that can hear, smell, taste, see, and feel. "I still have to prove all of this stuff," he admits.

As a first order of business, MacDonald plans to have his device measure its own behavior—specifically, the "internal friction" generated within the silicon by the motion of the stylus. The vibration produces mechanical stresses in the silicon beams supporting the tip, deflecting bonds and displacing defect atoms. If enough of these defects coalesce, microscopic cracks begin to form, perhaps damping the vibrational frequency of the tip. "On this scale not much is known, so we may be in for a few surprises," MacDonald says.



Noel MacDonald



Guts of a wee machine. *Springs and interdigitating "comb drives" spur vibration of a minute tip, hidden under the crossbeams. Tip is shown with its twin in the closeup at left.*

Lured by the prospect of new measurements and the sheer technical challenge, other like-minded researchers have been busy designing their own micromachined tunneling sensors. In the 7 January *Applied Physics Letters*, for example, William J. Kaiser and his colleagues at the Jet Propulsion Laboratory in Pasadena reported making a single-tip device that they hope to incorporate in compact, feather-weight guidance systems for spacecraft and seismometers for planetary studies. STMs may be on their way from probing the nanoworld to exploring distant planets. ■ IVAN AMATO