TECHNOLOGY

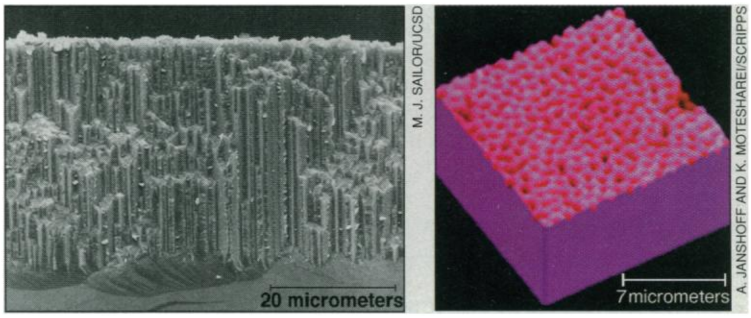
Versatile Chemical Sensors Take Two Steps Forward

Any scientist who has seen an episode of *Star Trek* has to be a bit covetous of 23rd century sensor technology. With a flick of a switch on his handheld "tricorder," Mr. Spock can instantly detect minute concentrations of any compound he's interested in. Sensor technology has a long way to go to reach that final frontier, but researchers are pushing it a bit closer to this science fiction fantasy. Two separate groups report that they have created new chemical detection schemes that promise to be compact, cheap, and versatile.

The new systems detect compounds when they bind to recognition molecules embedded in the sensor material, changing the way it interacts with light. One scheme, described on page 840 of this issue of *Science*, exploits the optical properties of a silicon chip that has a surface etched into a forest of pillars and pits; the other, reported in last week's issue of *Nature*, relies on an assemblage of tiny plastic spheres trapped in a polymer- and water-based gel. Both, says Thomas Bein, a chemist at Purdue University, are "exciting and interesting advances" over today's sensors, which tend to be costly, cumbersome, and specialized.

Bein and others note that the new sensors are based on dirt-cheap starting materials. Yet they can detect a wide range of compounds with high sensitivity—the silicon-chip sensor, for example, can detect DNA strands at concentrations of one part in a quadrillion, a sensitivity 100 times better than conventional sensors can achieve. As a result, they could pave the way to low-cost detectors for medical diagnosis, industrial monitoring, and environmental testing. "These new techniques are exactly what's needed to make [such sensors] take off," says David Grier, a physicist at the University of Chicago.

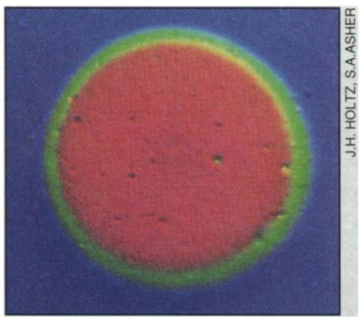
To make the silicon sensor, chemists M. Reza Ghadiri, Victor Lin, and Kianoush Moteshareí at The Scripps Research Institute in La Jolla, California, along with Michael Sailor and Keiki-Pua Dancil of the University of California, San Diego, start with a wafer similar to those that are turned into computer chips. A chemical etchant chews away some of the silicon, creating the forest of tiny silicon pillars. Next, the researchers use well-established chemistry to bind chemical recognition groups to the sides of these pillars. Then they expose the chip to a solution that may contain the target molecule and shine light on it.



Silicon forest. Side and top views of porous silicon, the basis of a new sensor.

Light striking the chip bounces off both the top of the pillars and the forest floor, 5 millionths to 10 millionths of a meter below the surface. Because light waves reflected from the forest floor have traveled farther, they emerge out of step with those that bounce off the top of the pillars. As a result, some of these waves cancel each other out, creating an interference pattern. This pattern is the key to the technique's sensitivity.

On their way to and from the forest floor, the light waves pass through the transparent pillars. How fast they travel depends on chemical interactions along the sides of the pillars. When target molecules—proteins, DNA, or small organic molecules—bind to the recognition molecules on the pillar surfaces, the electronic characteristics of the interface between the silicon and the solution change. That alters the electronic structure of the silicon itself, says Sailor, changing its refractive index—the speed at which light moves through it.



Telltale gel. A drop of solution containing a target ion changes the color of a gel-based sensor.

The index change shifts the relative timing of the two sets of reflected waves, altering the interference pattern produced when they merge. Because a modest change in the electronic structure of the porous silicon can have a large effect on the material's refractive index, the technique winds up having an extremely high sensitivity. "It's a pleasant surprise," says Philippe Fauchet, a porous silicon expert at the University of Rochester in New York. A charge-coupled device, similar to light detectors in video cameras, records the change in the interference pattern, which is fed into a nearby computer for interpretation.

Detecting new compounds is as simple as creating silicon chips with different chemical recognition groups attached, says Ghadiri. Down the road, the researchers expect to create sensor arrays in which each sensor carries a different concentration of recognition groups. These arrays should be able to go beyond detecting the target compound to measuring its concentration.

The gel-based sensor has similar advantages. Its developers—University of Pittsburgh chemists John Holtz and Sanford Asher—start with tiny polystyrene beads that have acid groups covalently bound to their surface. When the beads are immersed in water, the acid groups shed their positively charged hydrogens, leaving each sphere covered with a multitude of negative charges. Because of the repulsion between like charges, the beads struggle to put as much distance as possible between themselves and their neighbors, in the process forming a periodic array, like atoms in a crystal. Such a colloidal crystal, made with beads of just the right size, diffracts visible light, making it shine with an iridescent glow.

To transform this unusual crystal into a sensor, Asher and Holtz form a water-saturated polymer gel around the crystalline arrangement of beads. The polymer is festooned with chemical linking groups designed to recognize the target compound. The linker molecule is chosen so that when it binds to the target, the resulting complexes have a net electric charge.

When a drop of solution containing the target molecule is added, the complexes add to the density of repulsive charges in the material. This causes the gel to suck in water and swell. "The water would like to equilibrate the concentration of the [charges] throughout the solution," explains Asher. The influx of water pushes apart the polystyrene beads, changing the color of the light diffracted by the crystal.

"It's great stuff," says Grier. The Pittsburgh team has already shown that its gels can detect lead ions and glucose. And like the silicon sensor, the gel-based device can be tailored to detect a broad array of compounds, just by changing the chemical recognition groups on the polymer. Tricorders may be in for some competition.

–Robert F. Service