Closing the biosensor gap

Biological and chemical sensors may one day find vital niches in nearly every aspect of our lives — from sniffing out methane gas leaks in homes and ensuring food freshness in the grocery store to keeping a tight rein on the delivery of therapeutic drugs and providing expeditious blood analyses in emergency rooms.

Today there is a rush of activity, both in the United States and in Japan, to develop such biosensors. One of the aims of this research is to devise more sensitive marriages between biologically active substances and electronic materials—since a sensor must be able to translate minute changes in glucose level, pH or other biological signals into electronic signals that are strong enough to be read by a meter, computer or alarm.

Researchers at Massachusetts Institute of Technology have taken a big step down this road with a molecular-based transistor, which they describe in the Sept. 2 Journal of the American Chemical Society. "I don't see how to put [electrical] wires directly on a molecule," says MIT's Mark S. Wrighton, "but we're getting close to that."

Unlike silicon transistors, which use three metal contacts — one to the gate, which turns the device on and off, and the others to the source and the drain, between which the output current flows — the molecular-based transistor consists of source and drain electrodes made of gold, spanned by a polymer that can become conductive when it interacts with the environment, which essentially acts as the gate.

The key to the new transistor, made by Wrighton, E. Tracy Turner Jones and Oliver M. Chyan, is its smallness. Using a technique from microelectronics fabrication called shadow deposition, the researchers have shrunk the distance between the source and drain from 1.5 microns in a previous version to 50 nanometers.

The smaller the source-drain gap, the lower is the electrical resistance of the material in the gap and the greater is the output current. At 50 nm spacing, says Wrighton, it becomes possible to bridge the electrodes with polymers that are biologically sensitive but that are very poor conductors.

The polymers Wrighton has in mind can be oxidized and reduced depending on environmental conditions such as pH. These particular "redox" materials are most conductive when half their molecules are reduced and the other half are oxidized. Any more or less oxidation turns the polymer into an insulator, shutting down the current and switching off the device.

The attractive property of these polymers is that they possess a very narrow band of oxidation states that will cause a current to flow. As a result, polymer transistors can, in principle, be designed to respond — with sensitivity and speed superior to that of other biosensor approaches — to specific chemicals or environmental changes while ignoring stronger oxidants and reductants. This enables the researchers to use biology as a starting point, to choose biologically interesting molecules and to make these into polymers that can be incorporated in their transistor.

"We've not demonstrated any of the sensor applications yet," says Wrighton. "But we've done the basic science necessary to move in that direction."

According to Larry R. Faulkner at the University of Illinois in Urbana-Champaign, Wrighton's work is part of a larger drive among chemists to learn how to build molecular assemblies that are smaller than the several-thousand-angstrom regime of microelectronics and are larger than 20 angstroms — a size that encompasses most single molecules and that has been the traditional focus of chemists. "We know this can [be done] because biology is organized on this scale," he says. And in biological systems, molecular arrays can perform all sorts of important tasks, from catalyzing reactions very efficiently to storing information.

Perhaps molecular-based devices will do similar things someday. Wrighton and Faulkner say they strongly doubt that these devices could ever compete with semiconductors in electronics applications. But for applications requiring the transfer of information between the electronic and biological worlds, such as artificial eyes or ears, says Faulkner, Wrighton's kind of work shows promise.

— S. Weisburd

The slow road to ceramic engines

Ceramic materials appear to have many of the properties necessary to improve the fuel efficiency of diesel engines. Unlike metals, they can withstand high temperatures without weakening, and they are good insulators. Ceramics, however, are brittle and may readily fracture or shatter. This failing has slowed the development of ceramic engines and engine parts. In recent years, most manufacturers and researchers have concentrated on developing ceramic parts for a few specific applications and for insulating an engine's cylinders to cut down heat losses.

Now a National Research Council study concludes that merely adding a layer of ceramic insulation improves fuel economy by only a few percent. "While the outlook for substantial gains in fuel economy was less encouraging than previously reported," says mechanical engineer Phillip S. Myers of the University of Wisconsin in Madison, who chaired the study committee, "we found considerable potential for use of ceramics in other places in the engine besides insulating the cylinder." Such applications, by lowering friction and by substituting lighter, harder materials for metals, could add up to significant savings. Myers and several members of his committee presented their conclusions last week at a seminar at the National Academy of Sciences in Washington, D.C.

What's needed is a systems approach, says committee member John H. Johnson of the Michigan Technological University in Houghton. "We need to integrate new technologies, materials and electronics. Together, that would have an impact on fuel economy."

For instance, insulating an engine isn't the only way to minimize heat losses. Hot gases, instead of escaping in the exhaust, could be diverted to drive a turbine and increase the engine's power. Furthermore, by keeping heat losses to a minimum, an engine can run at a higher temperature, using fuel more efficiently. But even if higher operating temperatures are achieved, few lubricants can survive long periods at such temperatures, says Myers. "We need to develop new lubricants."

Despite the difficulties in developing efficient diesel engines, the study recommends that research on "low heat rejection" engines continue. The U.S. Army, which along with the Department of Energy sponsored the study, has 25,000 tracked vehicles, such as tanks, and 250,000 trucks and other wheeled vehicles. A fuel-economy improvement of 5 to 10 percent, combined with the energy savings from operating a smaller cooling system, would allow greater design flexibility. Vehicles with improved diesel engines would likely be more reliable and better able to survive combat conditions.

The situation is more complicated for cars and light trucks that aren't powered by diesel engines. Raising operating temperatures in conventional engines increases the likelihood of engine knock (SN: 9/13/86, p.165).

"Engine developments come not as revolutions but as small-increment changes," says Myers. The problem is that, unlike Japan and several European countries, "we [the United States] don't have a national, coordinated effort," he says. "And we don't have quite the innovative spirit seen abroad."

Adds Johnson, "We've got the technologies. It's a matter of putting them all together. That takes a great commitment of resources."

— I. Peterson