# ALL-NATURAL ELECTRONICS

**Materials scientists are coming up with ways to make circuits from paper, beeswax, DNA, and other biological materials**

**The United Nations estimates** that people throw away about 50 million metric tons of electronics every year. One way to lessen the problem, some scientists say, may be to use biological materials—including plant dyes and DNA—to build devices that are biodegradable and biocompatible.

"We have to be ashamed" of the amount of e-waste humanity produces, Mihai Irimia-Vladu told a symposium on organic bioelectronics at the December meeting of the Materials Research Society, in Boston. Irimia-Vladu, a materials scientist at Joanneum Research in Weiz, Austria, has used cellulose as a dielectric layer in an inverter circuit and shellac as a dielectric in organic field-effect transistors. Many other biological materials could be transformed into suitable dielectrics, he says, including aloe, silk, and egg whites. Beeswax and carnauba wax—derived from a species of palm tree—could make dielectrics that are also hydrophobic, which might be useful in some applications, Irimia-Vladu says.

Using biological materials to build electronics would be environmentally friendly, he says, in part because their ability to biodegrade would lead to less trash piling up. Additionally, such materials could be nontoxic, unlike some of their inorganic counterparts, and they could take less energy to produce. He imagines building OFETs in hard gelatin capsules or on caramelized sugar for biomedical applications. Another researcher, Marc in het Panhuis, head of the soft materials group at the University of Wollongong, in Australia, is working on conductive, 3D-printable gelatins that could be used to make circuits for sensors that could be swallowed.

And it's not just conductors and insulators that can be made using biodegradable substances. "There are natural materials that have semiconductor properties," Irimia-Vladu says. He's done research showing that both indigo, a plant-based dye, and Tyrian purple, a dye originally derived from snails, have charge-carrier transport properties that make them promising for high-performance circuits.

Other researchers are turning to an even more basic level of biology in the search for electronic materials. Andrew Steckl, director of the Nanoelectronics Laboratory at the University of Cincinnati, has been working on organic LEDs that use DNA as an electron-blocking layer to decrease the devices' power consumption. Eliot Gomez, a Ph.D. student in Steckl's lab, told the meeting that Steckl's group has now gone one step further. They've integrated thin films made of the nucleic acids that make up DNA—adenine, guanine, cytosine, and thymine, as well as uracil, used in RNA—into OLEDs. The advantage of using individual nucleic acids rather than the entire DNA molecule is that different acids have different electronic properties. Guanine and adenine, for example, are better at transporting holes and blocking electrons, while the opposite is true for the other three.

Gomez says that OLEDs using these nucleic acids for the electron-blocking layer had efficiencies of up to 76 candelas per ampere and luminance of 130,000 candelas per square meter, as compared with 31 cd/A and 100,000 cd/m$^2$ for their standard devices.

Gomez's hope is to make an all-natural OLED, but it's a tall order. "The OLED structure has multiple layers with very demanding requirements," he says. "We need a lot more natural materials at our disposal."

Researchers at Åbo Akademi University, in Turku, Finland, are developing environmentally friendly components for printing logic circuits on paper. Fredrik Pettersson, an Åbo Akademi Ph.D. student, told the meeting that they've replaced an ionic liquid in a new kind of transistor with a mixture of choline chloride (a nutrient) and organic compounds such as urea, glycol, or vitamin C.

The transistor still uses a less environmentally benign organic semiconductor. But the group has found a way to minimize the amount of semiconductor needed. They do this by mixing it with an insulator and allowing the semiconductor and insulator to separate during coating, so that they wind up with the insulator on the paper and a thin layer of semiconductor on top. Because the insulator prevents contaminants in the paper from leaching into the semiconductor and degrading its performance, they can use less semiconductor material and, as a bonus, get transistors that switch much faster and require less current. The group made a NOR gate and a 1-bit memory cell with such a transistor, Pettersson said. The Finland-based researchers have also made paper-based supercapacitors.

Pettersson hasn't studied whether the new, more benign transistor biodegrades. But that might not be necessary. There can be various definitions of "environmentally friendly electronics," points out Joanneum Research's Irimia-Vladu. "There are different shades of green," he says. —NEIL SAVAGE

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