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SELF-ASSEMBLING MICROELECTRONICS

Novel fabrication concepts spring from familiar chemistry ideas

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Applying principles of chemistry to microelectronics, researchers have devised a scheme for coaxing tiny circuit components to spontaneously self-assemble. Unlike present lithography methods that inherently produce two-dimensional electronic devices, the new procedure generates 3-D products. It eventually may be used to fabricate complex logic and computational circuits that are more densely packed or have different types of connectivity than those made using today's techniques.

Developed by Harvard University chemists, the new process has been used to construct electronic circuits from millimeter-sized "soccer balls"--polymer beads patterned with electrical contacts, wires, and other parts. But rather than piece together the circuits sequentially, the researchers devised ways to make the elements assemble spontaneously while adopting ordered and predetermined structures, much the way nature grows crystals from atoms or molecules [*Science*, **289,** 1170 (2000)].

Harvard University chemists coax millimeter-sized polymeric "soccer ball" building blocks coated with tiny circuit components such as copper dots, wires, and LEDs to assemble into microcircuits, one of which is shown sitting on a penny. The resulting type of connectivity (serial or parallel) is designed into the patterns on each building block and is verified by tracing glowing LEDs. The technique demonstrates a possible role for self-assembly in microelectronics. [David Gracias/Harvard University]

In one demonstration, the research group, which consists of postdoctoral associates David H. Gracias and Tricia L. Breen, graduate student Joe Tien, undergraduate Carey Hsu, and chemistry professor George M. Whitesides , fabricated a circuit with serial connectivity. In another example, the team prepared a structure that was wired in parallel.

"The work is absolutely amazing," exclaims Tobin J. Marks , professor of chemistry and of materials science and engineering at Northwestern University . "It illustrates a completely new way to create electronic circuits of all sorts in three dimensions. It is highly creative."

Ralph G. Nuzzo , professor of chemistry and of materials science and engineering at the University of Illinois, Urbana-Champaign, points out that there is some 3-D quality to modern microelectronic devices, but that the third dimension is generally built up via sequential planar fabrication steps.

"Microelectronics is based on very sophisticated technology. But that technology isn't unlimited," Nuzzo says. Researchers agree that in the near future manufacturers will be unable to shrink transistors and other semiconductor devices any further using present fabrication techniques. That means the number of circuit elements that can be packed into a tiny space is expected to hit a ceiling soon.

Three-dimensional fabrication presents an interesting way to think about future advances, such as increasing the density of transistors in an integrated circuit, Nuzzo comments. "When you deal with volumes--not areas--there's a different calculus that comes into play. That idea is beautifully demonstrated in this work."

Using photolithography and etching methods, the Harvard chemists pattern sheets of a flexible polyimide composite with copper dots, contact pads, and wires. Then they glue the patterned strips onto the faces of polymeric soccer balls. After attaching light-emitting diodes (LEDs) to the contact pads, the team coats the dots and wires with solder.

To turn the collection of patterned soccer balls into a continuous electronic circuit, Gracias and coworkers gently agitate the little structures while they are suspended in an aqueous solution where the temperature is kept above the solder's melting point. Interfacial forces between solder dots cause like-patterned faces to recognize one another and to assemble in an ordered dot-to-dot manner, the researchers say. As the patterned faces draw sufficiently close to one another, the molten solder dots fuse together, connecting the polyhedra.

By selecting certain patterns of solder dots to join pairs of polyhedra faces, the group can choose whether the networks are wired in a serial or parallel manner. Electrical continuity and details of the wiring configuration were verified using light from the LEDs.

"This approach is obviously in its infancy," Marks notes. "However, it is easy to imagine numerous applications in the construction of exotic three-dimensional multifunctional devices."

Now that the group has shown by way of a simple demonstration that the new fabrication technique can be used to build 3-D electronic structures from millimeter-sized components, Gracias says, the next challenges lie in the areas of miniaturization and automation.

"Chemistry offers a host of good ideas about how to build complex structures," Whitesides comments. In fact, the synthesis approach to problem solving is so ingrained in chemistry, he says, that chemists may take for granted the power of that approach. But concepts like structural order and self-assembly that aren't commonplace outside of chemistry and materials science may prove potentially important to fields such as microelectronics.

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