Flexible "smart" clothing material such as the sample shown above could be made from carbon-based electronics printed with inkjet printers.

Rodrigo Reyes Marin/AFLO/Newscom

Your future smartwatch might be printed with an inkjet printer

By Gabriel Popkin | Nov. 1, 2016 , 3:00 AM

Imagine getting the latest smartwatch or a high-tech heart attack warning detector from your inkjet printer. Researchers have taken a step in this direction by printing cheap, reliable arrays of transistors—the key components of modern electronics—and using them to carry out elementary computing tasks. The work might someday help usher in a new era of organic, flexible consumer electronics.

Instead of the usual silicon, the new circuits were fashioned out of organic—or carbon-based—compounds. And whereas others have printed and stacked organic electronic components using a mix of inkjet printing and other deposition methods, the new work uses just an inkjet printer for the entire process. “I cannot think of another [device with at least two layers] where everything was done with inkjet printing,” says Ananth Dodabalapur, an electrical engineer at the University of Texas in Austin who was not involved in the work. “This is a good demonstration.”

New commercial electronic devices must be compact, durable, and amenable to mass production. Nearly all mass market devices rely on microchips of the chemical element silicon, on which manufacturers etch ever smaller transistors—essentially electrical switches that can be used to fashion logic circuits for computers.

But silicon chips have some disadvantages. Silicon wafers are stiff, so it’s difficult to make silicon-based circuitry flexible. Many think that **flexible, wearable electronics** built from organic materials could open up new applications for electronics. For example, flexible electronics could gather vital medical data such as the stiffness of arteries, which can help predict heart attacks, and brain electrical activity, which can signal oncoming epileptic seizures.

To help realize that potential, Sungjune Jung, an electrical engineer at Pohang University of Science and Technology in South Korea, and colleagues set out to see whether they could simply print working networks of organic transistors. To cram in as many transistors as possible, they designed transistors that could be stacked on top of each other, rather than placed side by side on a chip, effectively packing two transistors into the space usually occupied by one.

that would control the current in both transistors, and, finally, the compound that would form the current-carrying parts of the other transistor. Between the layers of transistors they deposited thin films of a protective material called parylene. The device included more than 100 transistors, enough to form logical circuits that completed several basic computations, including adding two numbers.

Jung's device hit a number of key benchmarks. **All the transistors worked, even 8 months after production**—an impressive feat for organic electronics, which often degrade quickly. Moreover, the process required temperatures no higher than 120°C, compared with many hundreds of degrees on a typical silicon wafer fabrication line, the team reports in *ACS Nano*.

Still, the printed devices are far from competing with silicon. The team was able to pack about five transistors into a square millimeter, whereas integrated circuit chips in today's computers cram millions into the same space. "Our technology, in terms of transistor density, is at the stage of silicon technology in the late 1960s or early 1970s, when the first microprocessors came out," Jung says.

Because the researchers were aiming to demonstrate a concept rather than prototype a product, Jung's team printed its circuit on stiff glass. But he says they have already printed similar components on flexible plastic, and plan to publish that result soon. Dodabalapur also notes that by some metrics, the new device lags behind what others have already achieved with organic circuits. For example, the type of computing logic the team used requires more transistors than other approaches, largely wiping out gains from more closely packing the components. And the transistors operated relatively slowly and inconsistently, he says. Moreover, although it's possible to use inkjet printing for every step in the manufacturing process, he says, "I don't see any advantage … to restrict oneself to one printing or patterning technique."

But such imperfections might be ironed out as a product moves to commercialization, says Janos Veres, a flexible electronics expert at PARC, a research institution in Palo Alto, California. He applauds the study for showing a novel way to print and protect organic circuit components, and imagines future labels or sensors containing stacks of not just two, but many transistors, perhaps working in concert with silicon chips or other technologies. "Ultimately we do see the opportunity to print microchips," he says.

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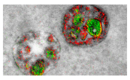

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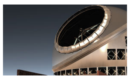

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