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Foldable, Stretchable Circuits

Researchers have made sheets of high-performance silicon circuits that can bend, fold, and even stretch around complex shapes.

By Kate Greene

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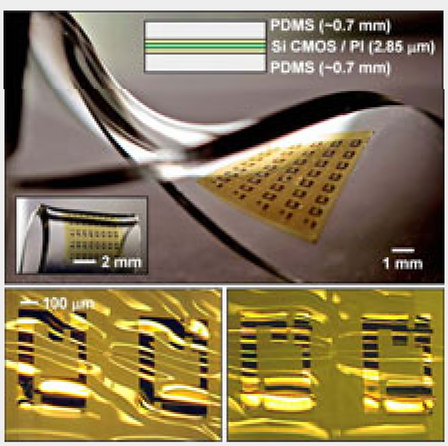

Stretching silicon: The top image is of a twisted silicon circuit on a flexible polymer. Below it are optical micrographs of inverters--circuit components--from the above circuit. The ripples in the circuit are due to the fact that it was affixed to the polymer when the polymer was stretched. Seen here, the polymer is in a relaxed state.
Credit: Science / AAAs

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- See the buckling of an ultrathin silicon-circuit component.

Researchers at the University of Illinois, Urbana Champaign, and Northwestern University, in Evanston, IL, have shown that electrical circuits can be made to fold and stretch and still match the performance of circuits built on rigid wafers. Made of thin sheets of silicon on plastic or rubber, these bendable circuits could pave the way for such applications as wearable computers and implantable health monitoring systems.

John Rogers, a professor of materials science at the University of Illinois, and his colleagues have demonstrated that it is possible to use ultrathin silicon to build entire sheets of foldable and stretchable circuits made of devices such as transistors, amplifiers, and logic gates. The results were published in this week's *Science*. Previously, Rogers made foldable and stretchable ribbons of silicon transistors, but the new work shows that it is possible to use the technique to put sheets of complex circuits on stretchable surfaces. "We expanded on the notion at the circuit level to make the entire circuit system as thin as possible," Rogers says. "The entire thickness is 1.5 microns, and that includes the plastic substrate, metallization, silicon, dielectrics--everything. A circuit with that thin a form factor is naturally bendable just by the mechanics."

Bendable electronics aren't new: researchers have previously stamped, printed, and sprayed circuitry on plastic sheets. However, these circuits are made of organic semiconductor materials--useful for applications such as transistors in roll-up

In 2005, Rogers found a way to make single-crystalline silicon--the kind used to make computer chips--fold and stretch by adhering ultrathin ribbons of it to strained rubberlike substrates, and then letting the rubber snap back into place. (See "Stretchable Silicon.") Because the silicon was so thin--only a few hundred nanometers thick--it buckled, without breaking, into waves on the rubber that could be restretched again and again.

The new work exploits that ultrathin geometry to make two types of circuits. One type is merely foldable: silicon-based circuits were placed on unstrained plastic sheets, resulting in circuitry that can fold up like a piece of paper. To ensure that the circuit would work well no matter what direction it is twisted or bent, the researchers place the silicon, or whatever part of the circuit is most fragile, at a distance between the top and bottom of the circuit sheet that experiences the least amount of strain. Placing the fragile components of the circuit in the appropriate place within the circuit sheet optimizes the electronics and allows them to work as well as those on a solid wafer, says Rogers.

The researchers made a second type of circuit by taking the optimized circuit sheets and bonding them to prestretched rubber that was extended in both directions. When the rubber is allowed to relax, the silicon layer buckles in a complex, wavy pattern, Rogers says. "We understand completely, through extensive analytical and computational modeling presented in the paper, how those wavy shapes form and how the layouts of the circuits...determine [the waves'] spatial geometries," he says. While the foldable circuits are fully optimized, he says that his team is still working to optimize the stretchable circuits. Since the researchers can locate positions across the circuit where the wavy structures will form when the rubber is released, Rogers says, they can choose these locations so that they do not overlap any fragile or strain-sensitive components of the circuit. This aspect is a refinement to the current work, he notes, and it will appear in a future paper.

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The research offers "a completely new circuit concept," says Zhenqiang Ma, an electrical-engineering and computer-science professor at the University of Wisconsin-Madison. Ma has previously built ultrafast silicon transistors on bendable substrates, which operate at high frequencies, making them useful for antennas built onto the wings of airplanes, for instance. (See "Record-Breaking Speed for Flexible Silicon.") While Rogers's transistors are slower, his integrated circuits have the advantage of being designed with the wavy geometry of thin silicon in mind, so that they can be optimized on a stretchy substrate.

Rogers says that one field in which the foldable, stretchable circuits could be useful is neuroscience. (See "TR10: Personalized Medical Monitors.") He is working on a project that could enable a thin sheet of electronics to wrap around the brain, monitoring electrical activity for indicators of future seizures in people with epilepsy. In addition, Rogers and his colleagues are building latex surgical gloves with integrated electronics that could add sensing functionally or, in some cases, provide tactile feedback for training surgical students.

"There are many applications for these new types of circuits," says Ma. "In some of the applications ... stretchable and foldable integrated circuits may be the only choice." He adds that the new integrated-circuit concept "has filled an important application gap" that rigid, chip-based circuits can't fill.

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