Water-soluble silicon leads to dissolvable electronics

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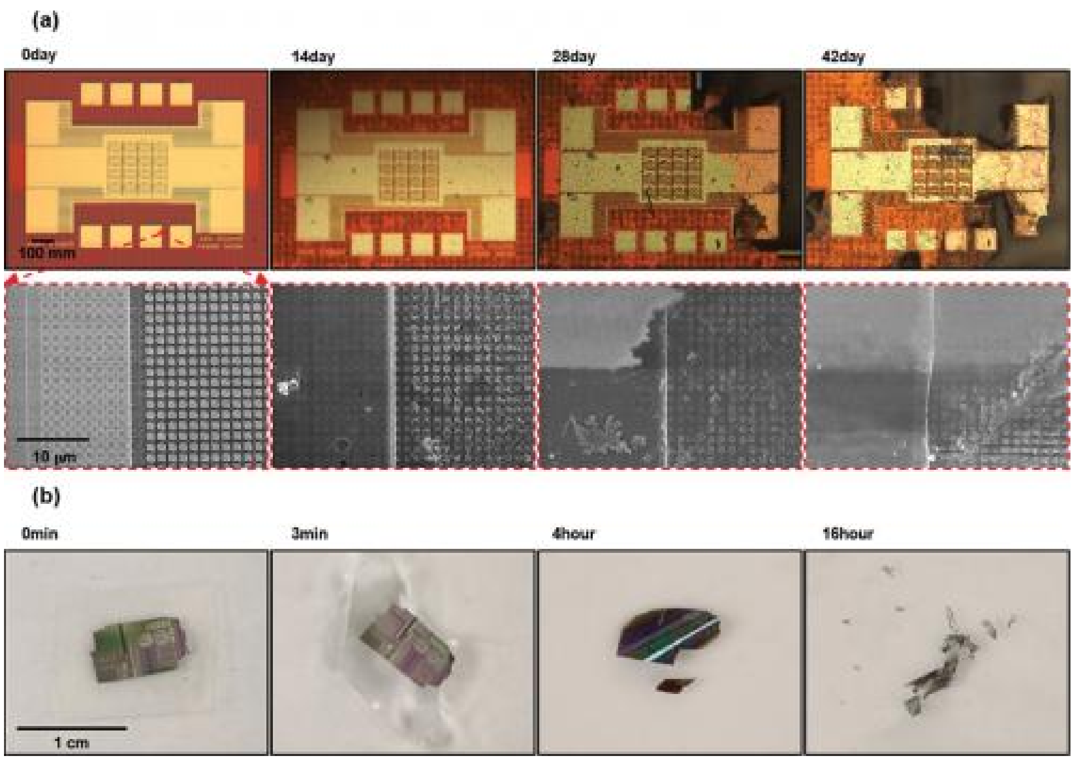

(a) Optical and SEM images of a transient CMOS circuit dissolving at various times over 42 days. (b) Optical images of an ultrathin CMOS circuit on a silk substrate dissolving over 16 hours. Both circuits are immersed in phosphate-buffered saline solution at 70 °C and pH 10. Credit: Yin, et al. ©2015 AIP Publishing LLC

(Phys.org)—Researchers working in a materials science lab are literally watching their work disappear before their eyes—but intentionally so.

They're developing water-soluble integrated circuits that dissolve in water or biofluids in months, weeks, or even a few days. This technology, called transient electronics, could have applications for biomedical implants, zero-waste sensors, and many other semiconductor devices.

The researchers, led by John A. Rogers at the University of Illinois at Urbana-Champaign and Fiorenzo Omenetto at Tufts University, have published a study in a recent issue of *Applied Physics Letters* in which they analyzed the performance and dissolution times of various semiconductor materials.

The work builds on previous research, by the authors and others, which demonstrated that silicon—the most commonly used semiconductor material in today's electronic devices—can dissolve in water. Although it would take centuries to dissolve bulk silicon, thin layers of silicon can dissolve in more reasonable times at low but significant rates of 5-90 nm/day. The silicon dissolves due to hydrolysis, in which water and silicon react to form silicic acid. Silicic acid is environmentally and biologically benign.

In the new study, the researchers analyzed the dissolution characteristics of silicon dioxide and tungsten, which they used to fabricate two electronics devices: field-effect transistors and ring oscillators.

Under biocompatible conditions (37 °C, 7.4 pH), dissolution rates ranged from 1 week for the tungsten components, to between 3 months and 3 years for the silicon dioxide components. The dissolution rates can be controlled by several factors, such as the thickness of the materials, the concentration and type of ions in the solution, and the method used to deposit the silicon dioxide on the original substrate.

As shown in the microscope images, the circuits do not dissolve in a uniform, layer-by-layer mode, but instead some places dissolve more rapidly than others. This is due to mechanical fractures in the fragile circuits, which cause the solution to penetrate through the layers more in some locations than in others.

Although organic electronic materials are also often biodegradable, silicon-based electronics have the advantages of an overall higher performance and the use of complementary metal-oxide-semiconductor (CMOS) fabrication processes that allow for mass-production.

"The most significant finding is that there exist choices in materials, device designs and processing sequences that allow transient electronics to be produced in conventional silicon fabrication facilities," Rogers told *Phys.org*. "The immediate consequence is a cost-effective, high-volume route to manufacturing."

Transient electronics could have a very wide range of novel applications, particular in the medical field. For example, they could be used to make catheters that dissolve; biodegradable sensors that monitor the kidney, heart, and lungs; and water-soluble electronics that monitor bacterial infections after surgery.

As for environmental applications, transient electronics could be used as sensors that transmit data from remote locations, and then degrade into the soil to eliminate waste.

The researchers plan to work toward these applications in the near future.

"We are working on building more advanced circuits, and doing so with commercial foundries, and on back-end assembly techniques that will allow these circuits to be deployed on a range of biodegradable polymer substrates," Rogers said.

More information: Lan Yin, et al. "Materials and fabrication sequences for water soluble silicon integrated circuits at the 90 nm node." *Applied Physics Letters*. DOI: 10.1063/1.4905321