'Building up' stretchable electronics to be as multipurpose as your smartphone

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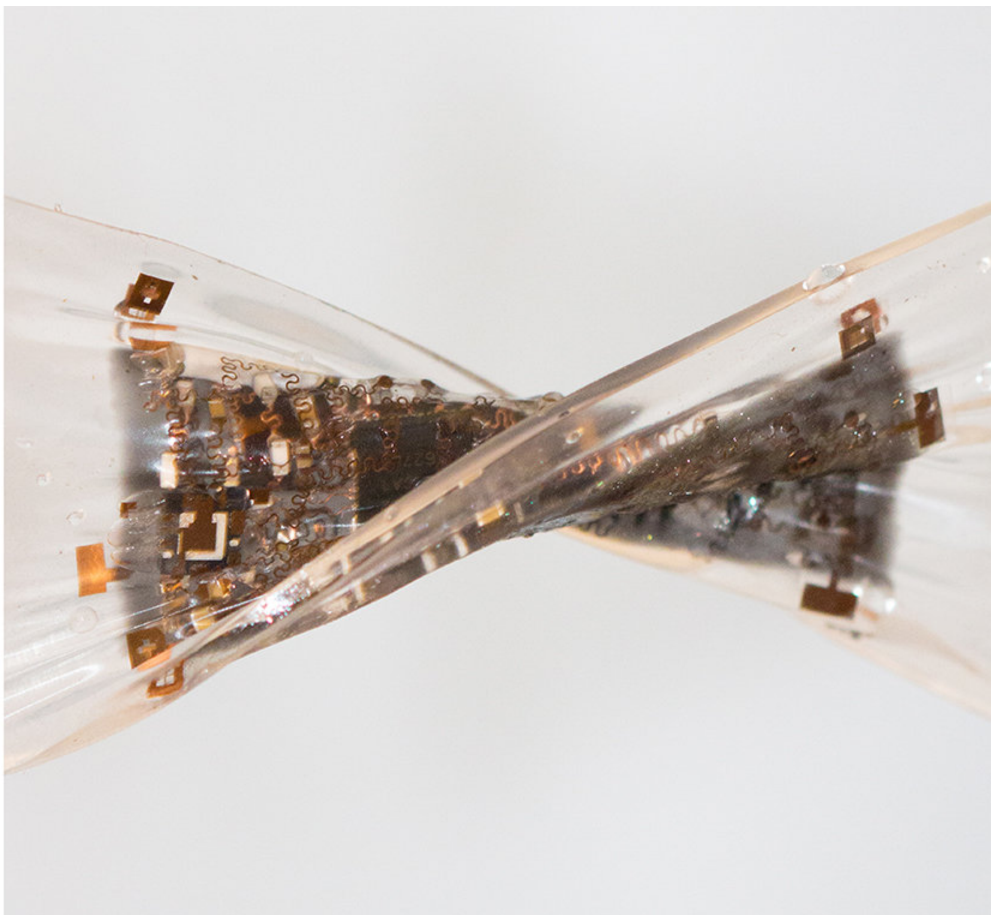


This '3-D stretchable electronic' device can stretch, bend and twist without compromising electronic function. Credit: Zhenlong Huang

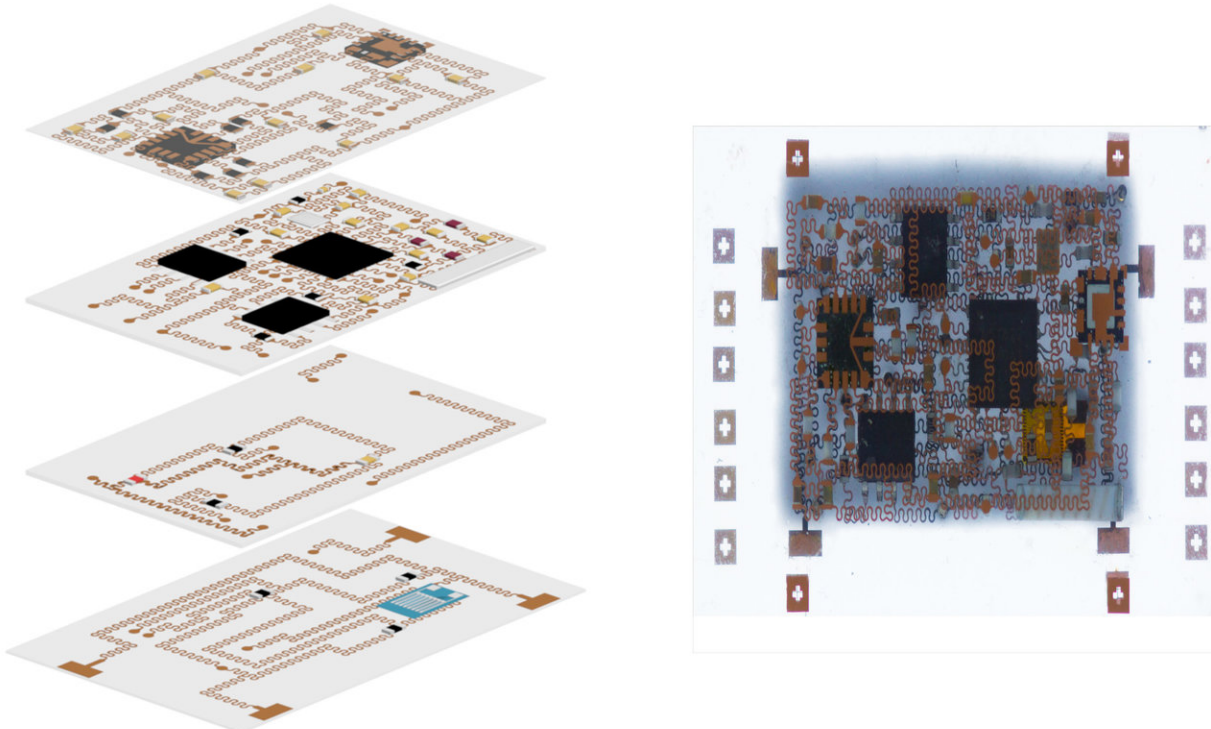
By stacking and connecting layers of stretchable circuits on top of one another, engineers have developed an approach to build soft, pliable "3-D stretchable electronics" that can pack a lot of functions while staying thin and small in size. The work is published in the Aug. 13 issue of *Nature Electronics*.

As a proof of concept, a team led by the University of California San Diego has built a stretchable electronic patch that can be worn on the skin like a bandage and used to wirelessly monitor a variety of physical and electrical signals, from respiration, to body motion, to temperature, to eye movement, to heart and brain activity. The device, which is as small and thick as a U.S. dollar coin, can also be used to wirelessly control a robotic arm.

"Our vision is to make 3-D stretchable electronics that are as multifunctional and high-performing as today's rigid electronics," said senior author Sheng Xu, a professor in the Department of NanoEngineering and the Center for Wearable Sensors, both at the UC San Diego Jacobs School of Engineering.

Xu was named among MIT Technology Review's 35 Innovators Under 35 list in 2018 for his work in this area.

To take stretchable electronics to the next level, Xu and his colleagues are building upwards rather than outwards. "Rigid electronics can offer a lot of functionality on a small footprint—they can easily be manufactured with as many as 50 layers of circuits that are all intricately connected, with a lot of chips and components packed densely inside. Our goal is to achieve that with stretchable electronics," said Xu.



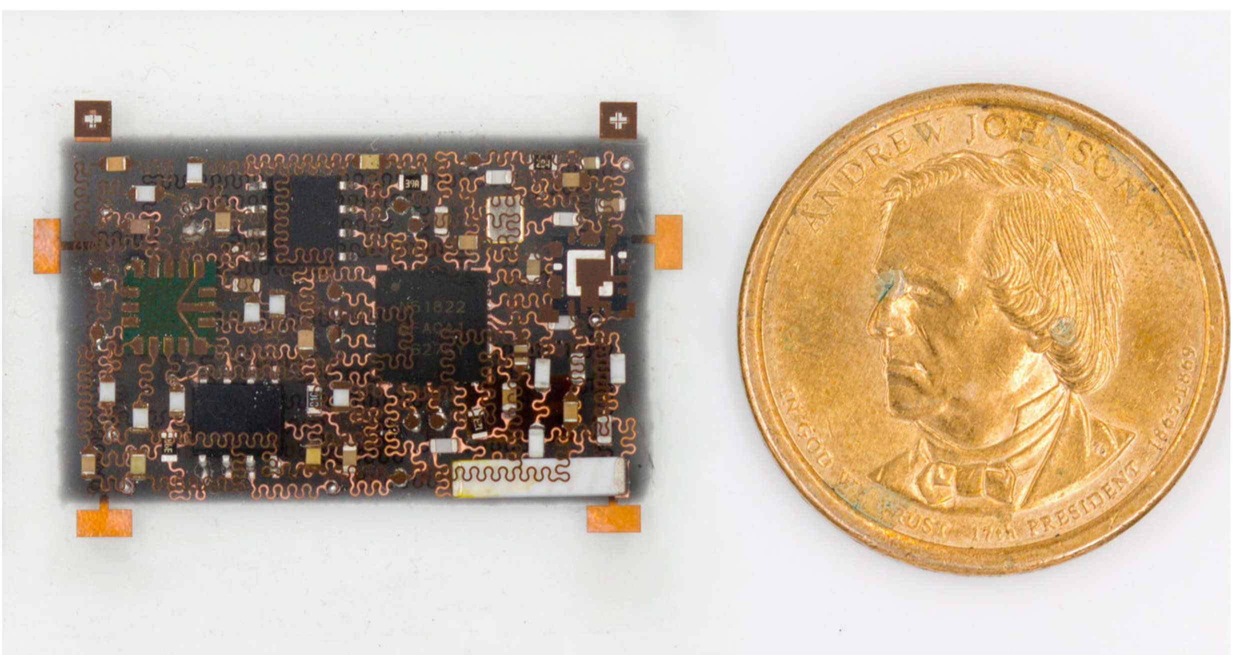
Four layers of stretchable circuits (left) are combined to create the full device (right). Credit: Zhenlong Huang

The new device developed in this study consists of four layers of interconnected stretchable, flexible circuit boards. Each layer is built on a silicone elastomer substrate patterned with what's called an "island-bridge" design. Each "island" is a small, rigid electronic part (sensor, antenna, Bluetooth chip, amplifier, accelerometer, resistor, capacitor, inductor, etc.) that's attached to the elastomer. The islands are connected by stretchy "bridges" made of thin, spring-shaped copper wires, allowing the circuits to stretch, bend and twist without compromising electronic function.

Making connections

This work overcomes a technological roadblock to building stretchable electronics in 3-D. "The problem isn't stacking the layers. It's creating electrical connections between them so they can communicate with each other," said Xu. These electrical connections, known as vertical interconnect accesses or VIAs, are essentially small conductive holes that go through different layers on a circuit. VIAs are traditionally made using lithography and etching. While these methods work fine on rigid electronic substrates, they don't work on stretchable elastomers.

So Xu and his colleagues turned to lasers. They first mixed silicone elastomer with a black organic dye so that it could absorb energy from a laser beam. Then they fashioned circuits onto each layer of elastomer, stacked them, and then hit certain spots with a laser beam to create the VIAs. Afterward, the researchers filled in the VIAs with conductive materials to electrically connect the layers to one another. And a benefit of using lasers, notes Xu, is that they are widely used in industry, so the barrier to transfer this technology is low.



The device compared to a US dollar coin. Credit: Zhenlong Huang

Multifunctional 'smart bandage'

The team built a proof-of-concept 3-D stretchable electronic device, which they've dubbed a "smart bandage." A user can stick it on different parts of the body to wirelessly monitor different electrical signals. When worn on the chest or stomach, it records heart signals like an electrocardiogram (ECG). On the forehead, it records brain signals like a mini EEG sensor, and when placed on the side of the head, it records eyeball movements. When worn on the forearm, it records muscle activity and can also be used to remotely control a robotic arm. The smart bandage also monitors respiration, skin temperature and body motion.

"We didn't have a specific end use for all these functions combined together, but the point is that we can integrate all these different sensing capabilities on the same small bandage," said co-first author Zhenlong Huang, who conducted this work as a visiting Ph.D. student in Xu's research group.

And the researchers did not sacrifice quality for quantity. "This device is like a 'master of all trades.' We picked high quality, robust subcomponents—the best strain sensor we could find on the market, the most sensitive accelerometer, the most reliable ECG sensor, high quality Bluetooth, etc.—and developed a clever way to integrate all these into one stretchable device," added co-first author Yang Li, a nanoengineering graduate student at UC San Diego in Xu's research group.

So far, the smart bandage can last for more than six months without any drop in performance, stretchability or flexibility. It can communicate wirelessly with a smartphone or laptop up to 10 meters away. The device runs on a total of about 35.6 milliwatts, which is equivalent to the power from 7 laser pointers.

The team will be working with industrial partners to optimize and refine this technology. They hope to test it in clinical settings in the future.

More information: "Three-Dimensional Integrated Stretchable Electronics," *Nature Electronics* (2018).

Provided by University of California - San Diego