# Biodegradable electronics here today, gone tomorrow

**Dissolvable electronic materials could be used in medical implants and environmentally friendly gadgets.**

Katherine Bourzac

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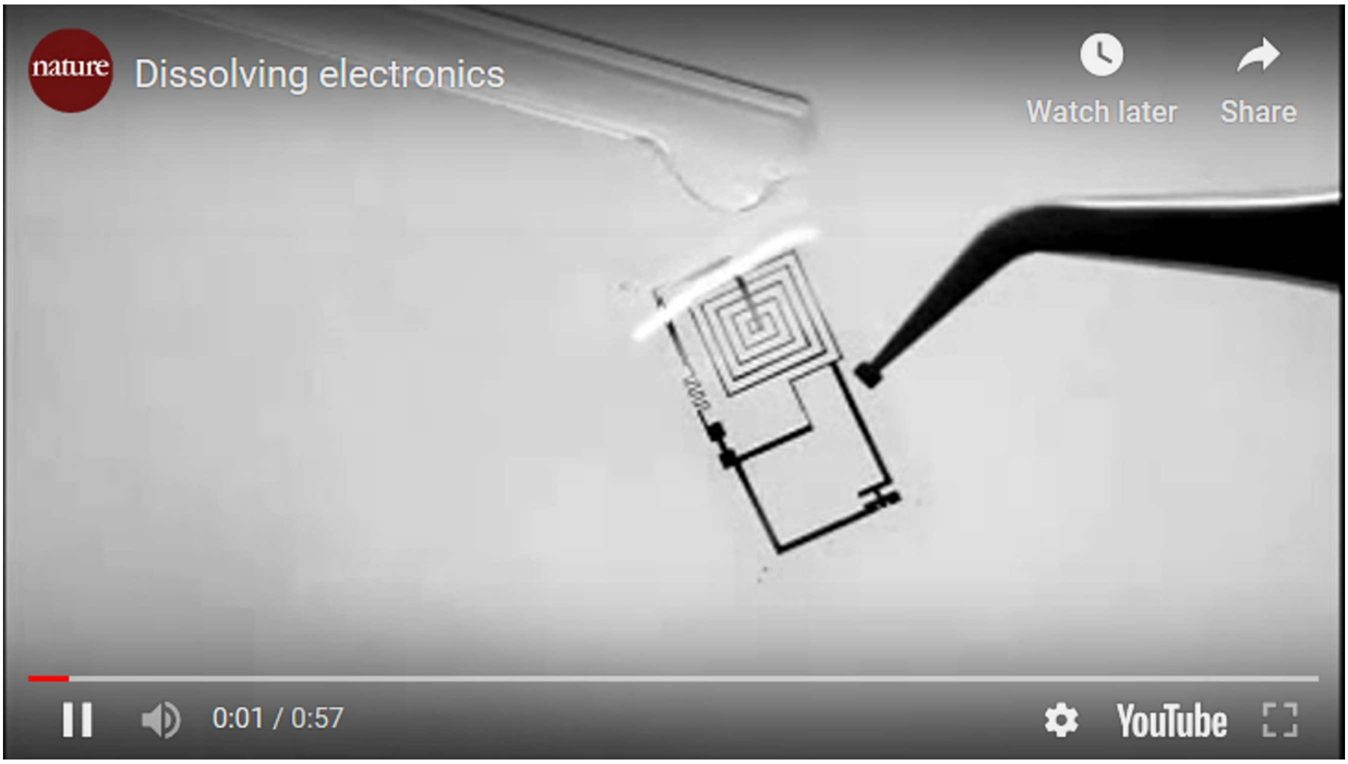


A team of researchers has designed flexible electronic components that can dissolve inside the body, and in water. The components could be used to make smart devices that disintegrate once they are no longer useful, helping to alleviate electronic waste and enabling the development of medical implants that don't need to be surgically removed.

So far, the team has designed an imaging system that monitors tissue from within a mouse, a thermal patch that prevents infection after a surgical site is closed up, solar cells and strain and temperature sensors. The project is led by John Rogers, a materials scientist at the University of Illinois at Urbana-Champaign, and Fiorenzo Omenetto, a biomedical engineer at Tufts University in Medford, Massachusetts. The two say that after several years of work, they and their colleagues can now make just about any kind of dissolving, high-performance electronic or optical device. Their work is described today in *Science*[1].

The project really took off in 2009, when the researchers brought together[2] Rogers' expertise on flexible silicon electronics and Omenetto's tough, biocompatible silk. The silk is made by processing and moulding proteins from silkworm cocoons to make thin sheets that conform and stick to tissues, such as the surface of the brain. By changing the processing conditions, Omenetto can control how long it takes the silk proteins to break down when wet. The researchers then placed Rogers' silicon integrated circuits together with light-emitting diodes and other electronic devices on Omenetto's silk. They've since demonstrated numerous devices, including brain interfaces that take very sensitive electrical measurements, but although the devices showed no adverse effects in early animal tests, they didn't completely dissolve — the metals were left behind. And having silicon floating around under the skin is not ideal, says Omenetto.

**Tuning the system**

Now, the researchers have figured out how to make every part of the system disintegrate. Rather than using stable metals such as copper or silver for electrical connections, they turned to magnesium. Magnesium is conductive, but it is also very reactive — especially in wet conditions — so isn't often used in electronic circuits. For dissolving electronics, however, that is an advantage. The team use magnesium to connect integrated circuits and to form antennas and wires that allow the devices to be powered from outside the body.

The other key is treating the silicon correctly. The team had something of a eureka moment about the material. “You don’t think of silicon as water soluble”, he says, because it would take 1,000 years for an average silicon wafer to dissolve. The thin silicon membranes in the dissolvable devices are less than 100 nanometres thick, and dissolve at about 4.5 nanometres a day. The team can control the degradation of the devices by tuning the properties of the silk, and by changing the thickness of the silicon and other materials.

Other researchers developing biodegradable electronics tend to work with organic materials rather than silicon because they break down more readily. However, their electrical and optical properties aren’t as good, and they are not compatible with the manufacturing techniques currently used by the semiconductor industry. Rogers says that he is excited to stay with silicon, “the 800-pound gorilla” of semiconductors.

Now that they have all the necessary materials, the next challenge is how to use them. “What diseases are we going to treat?” asks Christopher Bettinger, a materials scientist at Carnegie Mellon University in Pittsburgh, Pennsylvania.

With funding from the US Defense Advanced Research Projects Agency in Arlington, Virginia, the group is now working with a manufacturer to scale up production of the silicon–silk components. Rogers says that medical implants, which don’t need to be as sophisticated as, for example, mobile-phone microprocessors, will probably be the first products.

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## References

1. Hwang, S.-W. *et al*. *Science* **337**, 1640–1644 (2012).
2. Kim, D.-H. *et al*. *Appl. Phys. Lett.* **95**, 133701 (2009).