DISSOLVING ELECTRONIC CIRCUITS

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Abstract- For most of us, an ideal electronic device is durable and long-lasting. An interdisciplinary team of researchers, though, has developed a new class of circuits that forces us to rethink our concept of what electronics can do in the world. A new class of electronics can dissolve and disappear on a pre-set schedule, within a few minutes or a few years, depending on when you want them to go away. This paper introduces us into a new field called "transient electronics". These electronics are there when you need them, and after they've served their purpose they disappear. This approach to electronic construction is a 180-degree shift from traditional engineering philosophy. This revolutionary concept has many applications in fields such as medical implants, environmental monitors and consumer electronics.

Key words: AFM, FDA, Nanomembrane, RIE, SOI

I. INTRODUCTION

An interdisciplinary team of researchers namely John Rogers, at the University of Illinois, Urbana – Champaign and Fiorenzo Omenetto, at the Tufts University and researchers from Northwestern University have demonstrated "transient electronics", which dissolve into nothing after a pre-determined amount time. Until now, building an electrical circuit for biodegradability and performance needed some compromise but not now. Dissolving circuits are tiny, fully bio compatible yet high performance electronic devices that dissolve harmlessly in fluids/surroundings after functioning for a precise amount of time. These devices are polar opposite of conventional electronics whose IC's are designed for long term physical and electronic stability.The basic idea in this circuit is to fabricate implants that are not only electronically active but that can degrade over time. This integration is achieved over here.In traditional silicon circuits, charge flow along the top layers of the material. So building a circuit using ultrathin silicon retains the device performance while retaining the device performance but improving the solubility in fluids. The ultrathin sheets of silicon from the wafer are stamped onto silk layers. Then the magnesium electrodes and Mgo dielectrics are patterned and then the whole circuit is wrapped in silk protein.The thickness of this silk layer determines how long the circuit lasts. Once the silk layer disintegrates, the silicon starts dissolving in water and soon there will be no circuit remaining. The circuit is thus resorbed into the surroundings.The applications may range from a medical implant designed to deal with potential infections needed only for a couple of weeks post-surgery to consumer electronics which is need for a year or two due to the consumer's appetite for latest gadgets. Hence, E-waste which is a major problem today can be minimized. Porous silicon nanospheres might be useful containers for drug deliveries and stents containing magnesium hold open blocked arteries.

II. DISSOLVING ELECTRONIC CIRCUITS

Most electronics are built to withstand deterioration, but a team of scientists have used silk and ultra-thin slices of silicon to create an electronic circuit that is intentionally impermanent and will dissolve in water. Imagine an electronic medical implant that, like dissolvable stitches, could disintegrate after it is no longer needed. Physicians and environmentalists alike could soon be using a new class of electronic devices: small, robust and high performance, yet also biocompatible and capable of dissolving completely in water. Biodegradable electronics could enable a dramatic rethinking of how circuits can be used safely and conveniently. Sensors could monitor the status of an environmental clean-up site, and then dissolve harmlessly. Doctors could implant a medical device to kill bacteria in a wound, without the need for follow-up surgery to remove it. Biodegradable circuits could even help curb the growing problem of "e-waste," a result of consumer appetite for the latest gadgets, which regularly turns cell phones and laptops into electronic detritus.

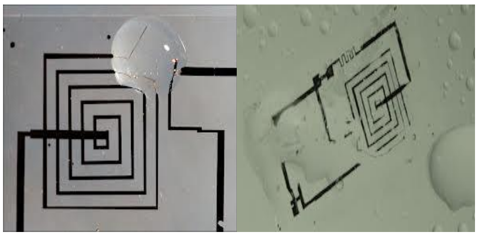

Fig1:shows dissolving electronic circuit.

III. FABRICATION

Doped single crystalline silicon nanomembranes (thickness ~300 nm, p-type) were fabricated from silicon-on-insulator (SOI, SOITEC, France) wafers to serve as active materials for the semiconductor devices. Stable, silicon-based electronics might not seem like the most biodegradable objects. While silicon may appear to be impermeable, eventually it dissolves in water. The rate of dissolution was increased by using only nanomembranes of silicon. To this super-thin silicon, small amounts of magnesium is added for electrical conduction To make the whole circuit to be biodegradable, slices of silicon thinner than a human hair were used and substituted other materials found in the body, including magnesium, to take the place of other circuit elements. Individual Si NMs formed by this process were transfer printed to a spin cast film of silk on a silicon wafer (as a temporary 'carrier' substrate). Gate and interlayer dielectrics (MgO, or SiO2), as well as electrodes and interconnects (Mg) were deposited by electron-beam evaporation through high resolution stencil masks.
Mg was either deposited directly or, for improved yields and adhesion strength, with an 5 nm layer of Ti.

IV. PREPARATION OF SUBSTRATES, ENCAPSULATION LAYERS AND PACKAGES.

B. mori silkworm cocoons were cut and boiled in a 0.02 M Na2CO3 solution to extract the glue-like sericin proteins. Sheets of transparent silk material were made on which the circuit could be built. The whole schematic was wrapped in silk protein from silkworm cocoons to support the circuit. But the silk was not used straight from the cocoon. First, naturally made silk is dissolved. Then controlled the reformation of the crystals to determine their structure. Different silk crystal structures result in different dissolution times. So by selecting the precise silk crystals they were creating, the researchers could generate a substance that would fade away after a particular interval. This specific silk is used to coat the whole device. For silk encapsulation, several cycles of coating and treatment were repeated: dipping the samples into a silk solution, drying at 65 °C, treating with methanol to increase beta sheet content and then drying. Multiple coating and subsequent methanol treatments were to increase the total thickness of the silk films. The silk-based material can be programmed to dissolve over a predetermined time period .The silk is water-soluble, but its dissolution rate can be controlled. It is used as a protecting layer to go on top of our water-soluble electronics. Once the electronics no longer need to be protected, the silk starts dissolving and then the 3circuit goes along with it. The protein-based silk used in the electronic devices casings is not to be confused with the material used in clothing. A protein from the silk cocoon is extracted and its properties adjusted to serve the purpose.

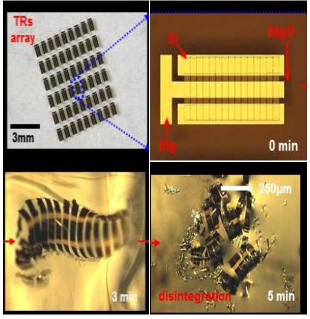

Fig2: Image and electrical characterization of transient electronic devices designed to disintegrate, as a means to accelerate the rate of transience. **(A)** Image of a 6×9 array of silicon transistors (first frame). Each transistor uses arrays of Si nanoribbons for the active channel regions (second frame). These nanoribbons disintegrate into individual pieces in the early stages of dissolution, as shown in the third (3 min) and fourth (5 min) frames.

V. DISSOLUTION TEST FOR SILLICON

A series of dissolution tests of Si NMs were performed to study the detailed kinetics of the process. The test structures for this purpose consisted of arrays of NMs in 3 × 3 µm square geometries, formed on SOI wafers by photolithography and RIE. We investigated thicknesses of 35 nm, 70 nm, and 100 nm. The samples were placed into 50 mL of 1.0 M phosphate buffered saline (PBS, pH 7.4, Sigma-Aldrich, USA) at either room temperature or temperatures close to those of the human body (37 °C). The samples were removed from the PBS solution every two days to measure the height of the Si NMs by atomic force microscopy. The PBS solution was replaced every other day.

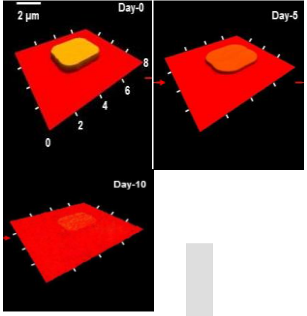

Fig3. Surface topography associated with Si NMs at various states of dissolution in PBS, evaluated using atomic force microscopy (AFM) for three different initial thicknesses.

VI. ADVANTAGES

The advantages of dissolving circuits are:

1. We can decide when we want the circuit to disappear. The thickness of the silk coating and silicon used can be decided. Thus rate of dissolution can be chosen.
2. Transient electronics offer robust performance comparable to current devices , but they will fully resorb into their environment at the prescribed time. These circuits are there when you need them and disappear once they have served the purpose. They are flexible and easily broken down and eliminated by the body than other forms of the semiconductor.
3. Biodegradable circuits help curb the growing problem of E-waste which is increasing with the changes in technology.
4. Magnesium is biocompatible and naturally occurs in body. Extremely thin layers of silicon are dissolving in small quantities of water and are biocompatible. The silk protein is a plastic like biodegradable material.
5. The research for this was done in close collaboration and consultation with clinicians and hence can be used in bioinstruments.
6. They are better compared to circuits using organic material as we used silicon which has better electrical and optical properties than organic materials.
7. The current size of these devices is remarkably small as we use thin membranes of silicon. They are merely tens of nanometre thick. They could be made larger for human use. By minimizing the size, we can minimize any adverse effect on the body.
8. The level of silicon and magnesium contained in these circuits are well below the maximum safety levels, so they are suitable for the body.
9. Silk protein is one of the strongest and most robust material and thin sheets of silk stick to tissues such as surface of brains.
10. Due to small size, the cost of materials is less. Also, silk is cheaper than silicon, which is used hence the cost of materials comes down further.

VII. APPLICATIONS

1. MEDICAL APPLICATIONS

Research Projects Agency, and outside scientists said military applications were possible. The device serves, 1. Surgical site infection is a leading cause for the risk for readmission to the hospital — put a therapeutic device in there, and it's a perfect example of a kind of function where transient electronics would be useful. Many steps remain before such devices could be used in the human body, including conducting safety tests and making decisions about what would be the most useful application. The work was supported by the Defence Advanced a useful function, but after that function is completed, it to simply disappear by dissolution and resorption into the body. The research team demonstrate this possibility with a resorbable device that can heat the area of a surgical cut to prevent bacterial growth. They implanted the heat-generating circuit into rats.

2. Currently, surgeons are reluctant to implant medical monitoring devices (say, to check for an infection post-surgery) because of the difficulty of extracting them. But an implant made out of transient electronics that performed a diagnostic or monitoring function for a set period of time, and then dissolved

safely in the body, could become a routine way for a doctor to follow up on a patient's progress after surgery. Other transient devices could monitor temperature or muscle activity, or deliver medicine internally. And, in the future, the devices may be able to perform life-saving diagnostic or therapeutic functions, such as monitoring a patient's condition and lot more.

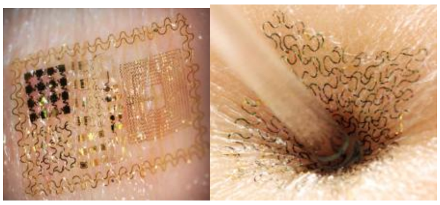

Fig4: shows implantation of a circuit in the infection area of a human.

3. In rats, the researchers team successfully implanted a silk package containing magnesium inductive coils and silicon microheaters at surgical site in a mouse. (Silicon and magnesium are biocompatible. Porous silicon nanospheres might be useful containers for drug delivery and stents containing magnesium hold open blocked arteries.) **.**Female BALB/c mice (6 - 8 weeks old) and female albino Sprague-Dawley rats were anesthetized with an intraperitoneal injection of a ketamine/xylazine mix. The depth of anaesthesia was monitored by palpebral and withdrawal reflexes to confirm that the animal had reached "stage 3" of anaesthesia. The back was shaved and cleaned at the incision site with 70 % ethanol, followed by a betadine surgical scrub. Once stage 3 was confirmed, a small longitudinal incision was made through the skin and the sterile implants (ethylene oxide sterilized) were inserted. The incision was closed with a Dexon 4 5-0 suture. The animal was monitored until ambulatory and given a dose of analgesia (Buprenorphine subcutaneously) as soon as surgery was completed. Wireless signals activated the device, which warmed the tissue about 5°Celsius and killed bacteria in the wound. The device dissolved after 15 days, leaving some longer-lasting silk fibres behind. The coupling frequency for wireless power transmission was ~70 MHz. The experiment simulates an antibiotic-free way to prevent infections at an incision immediately after surgery, Rogers says. Other teams are working on a rival approach: developing an implantable device that could deliver, on demand, a drug to the inner ear of a patient with tinnitus, using degradable circuits made of polymers that conduct electricity instead of silicon. . The disposable circuits could also be employed to control the delivery of drugs to specific spots in the body at designated times.

Fig5: shows implantation of a circuit into a rats body.

2. ENVIORNMENTAL SENSORS

Transient circuits could be used in environmental monitoring situations, such as using wireless sensors that are applied after an oil spill to track ground conditions before dissolving after a set period of time. Monitors could also be placed on buildings or roadways to detect gradual structural deformation over time.

3. CONSUMER ELECTRONIC DEVICES

Transient circuits could even make their way into consumer electronics—a phone's inner circuitry could perhaps be designed to dissolve in the presence of a particular liquid—to combat the increasing amount of electronic waste that's produced as we frequently upgrade phones or other devices.

Because silicon is naturally abundant in the environment and the conducting material, magnesium, is biocompatible—and naturally occurs in the body—the researchers believe that the circuits will not harm our health or the environment when they dissolve. Scientists have designed solar cells, radio oscillators, photo detectors, digital cameras, strain sensors, temperature sensors etc.

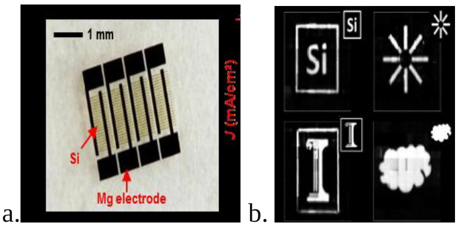

Fig6. (a) Image of solar cells that use ~3 µm thick bars of Si and Mg interconnects (left). Current density and power

measured from a representative device as a function of voltage (right) when illuminated using light from a solar simulator. **(b)** Various images obtained using a passive matrix, 8 × 8 array of transient photo detectors, operated in a mode in which the object is scanned recorded images are collected.

4. MONITERING E-WASTE

The term e-waste is applied to all waste caused by discarding electronic devices, especially consumer electronics. E-waste is a major concern in areas of personal computing and wireless devices that are quickly discarded by consumers. The lifespan of these electronics are short-lived due to rapid technological advances and lower costs to purchase each year. Consumers generally buy new instead of reusing because their electronic device quickly becomes obsolete or it may be cheaper to purchase new. All electronic scrap components, such as CRTs, may contain contaminants such as lead, cadmium, beryllium, or brominated flame retardants. Even in developed countries recycling and disposal of e-waste may involve significant risk to workers and communities and great care must be taken to avoid unsafe exposure in recycling operations and leaching of material such as heavymetalsfrom landfills and incinerator ashes .Imagine the environmental benefits if cell phones, for example, could just dissolve instead of languishing in landfills for years. Thus transient electronics provide best solution for monitoring e-waste.

5. MILITARY APPLICATIONS

1. Jeffrey Borenstein, a biomedical engineer at Draper Laboratory, said the techniques could potentially be used to design sensors that would be implanted in soldiers to monitor their health remotely, allowing medical care to be deployed more rapidly on the battlefield.

2. This technique of dissolving electronics circuits is used in clandestine listening devices, sending recorded conversations back to military operatives and then vanishing before they can be found.

3. DARPA working to bring dissolvable, 'transient electronics' to the military:

DARPA's been hard at work on dissolvable, biodegradable electronics for some time now, the agency is unsurprisingly thinking about how this technology can be applied to the military. DARPA is hoping to develop "transient electronics," systems that are "capable of physically disappearing in a controlled, triggerable manner," that function similarly to the "commercial-off-the-shelf" systems currently used. The benefit to the military is two fold — DARPA believes it is "nearly impossible" to both track and recover all of the electronic microsystems the military distributes, and there's also an environmental impact to be aware of. Ideally, these devices could be dissolved in a number of ways: by a set program, a remote trigger, or a trigger that responds to the environment. Particularly unconventional is DARPA's vision of devices that could "reabsorb into the body" — electronics that could monitor soldiers in the field and disappear into the body when their usefulness has past.

VII. CONCLUSION

Still in the very early stages of development, the technology shows a whole lot of promise, and the potential uses of which could reach far beyond sole medical purposes. In future, the devices may be able to perform lifesaving diagnostic or therapeutic functions such as monitoring a patient’s condition or treating post-surgical infection, e-waste can be reduced, environmental hazards like oil spills can be reduced and also soldier’s health on the battle field can be monitored. Environmental and consumer product devices are likely to become available prior to their medical counter. parts, which will require much more testing and approval by the FDA before being implanted in humans. . Thus “transient electronics” has become a boon to the world.

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