New class of Electronics: Biodegradable, Reconfigurable, Transient, Self Destructing for Security and Biomedical applications

Consumer electronics constitute a rapidly increasing source of waste. Cell phones, tablets and the like are typically made of non-renewable, non-biodegradable, partly environmentally toxic materials. A report from United Nations University (UNU) found that the world produced 41.8 million metric tons of e-waste in 2014 — an amount that would fill 1.15 million 18-wheel trucks. Lined up, those trucks would stretch from New York to Tokyo and back. The Environmental Protection Agency estimates that only 15-20% of e-waste is recycled, the rest of these electronics go directly into landfills and incinerators.

Electronic waste isn't just waste, it contains some very toxic substances, such as mercury, lead, cadmium, arsenic, beryllium and brominated flame retardants. When the latter are burned at low temperatures they create additional toxins, such as halogenated dioxins and furans — some of the most toxic substances known to humankind. The toxic materials in electronics can cause cancer, reproductive disorders, endocrine disruption, and many other health problems if this waste stream is not properly managed. To overcome this challenge, Researchers have started developing Nontoxic Bio degradable materials and vanishing electronics that will be better for the environment.

While traditional electronic devices are non-renewable, non-biodegradable, partly toxic, non bio-compatible, fixed in form and function, Researchers are now designing a new class of electronics, called Transient electronics enabled by new materials, with the key attribute being the ability to physically dissolve into the surrounding environment at a well-controlled rate, with minimum or non-traceable remains, after a period of stable operation. Some are capable of self-destruction on command or in response to environmental conditions, such as temperature. Some are reconfigurable devices and circuits whose electronic structures continuously change over time.

In future these Transient materials shall have many potential applications including in zero-waste environment, bioelectronics, military and defense data security, hardware-secure memory modules, and sensors.

Graphene-enhanced technology created electronics that vaporize in response to radio waves

Researchers from Cornell University and Honeywell Aerospace have designed a graphene-enhanced transient electronics technology in which the microchip self-destructs by vaporizing – an action that can be remotely triggered – without releasing harmful byproducts. In addition to transient electronics, the technology might find application in environmental sensors that can be remotely vaporized once they’re no longer needed.

A silicon-dioxide microchip is attached to a polycarbonate shell. Microscopic cavities within the shell contain rubidium and sodium bifluoride. When triggered remotely by using radio waves, these chemicals thermally react and decompose the microchip. The radio waves open graphene-on-nitride valves that keep the chemicals sealed in the cavities, allowing the rubidium to oxidize, release heat and vaporize the polycarbonate shell. The sodium bifluoride releases hydrofluoric acid to etch away the electronics.

“Our team has also demonstrated the use of the technology as a scalable micro-power momentum and electricity source, which can deliver high peak powers for robotic actuation,” said the researchers.

Researchers produce Electronic Chip ‘As safe as fertiliser’

Research team, led by professor Zhenqiang ‘Jack’ Ma of University of Wisconsin-Madison in their paper, published in the journal Nature Communications, have succeded in developing electronic chips whose support is based describes the new device based on CNF, cellulose nanofibril, a material that is perfectly biodegradable. Researchers proved that CNF has the electronic properties required for the support.

In a typical semiconductor electronic chip, the active region comprises the top thin layer and is only a small portion of the chip, whereas more than 99% of the semiconductor materials are in the support. And in microwave chips for wireless functions, only a tiny fraction of the lateral chip area is used for the required active transistors/diodes, the rest being used only for carrying other non-active components. Therefore, a chip with wood fibrils as its support might reduce environmental pollution from discarded consumer electronics by more than 99%.

‘The majority of material in a chip is support. We only use less than a couple of micrometres for everything else,’ Ma says. ‘Now the chips are so safe you can put them in the forest and fungus will degrade it. They become as safe as fertiliser.’ Although, we comment, the remaining 1% of semiconductor materials might still prove to be a good reason for proper recycling.

Scientists develop dissolving battery

Prof Montazami with a team of scientists have developed the lithium-ion battery which is self-destructing, it is capable of dissolving when exposed to heat or liquid. Iowa State University mechanical engineering professor Reza Montazami said it was the first practical transient battery. It could be used to keep military secrets confidential, and in environmental monitoring devices.

It delivers 2.5 volts and can power a desktop calculator for 15 minutes. It measures 5mm in length, is 1mm thick and 6mm wide, and is similar to commercial batteries in terms of its components, structure and electrochemical reactions.

It contains an anode, cathode and an electrolyte separator within two layers of polyvinyl alcohol-based polymer. When dropped in water, the battery’s polymer casing swells and the electrodes are broken apart, causing it to dissolve. The entire process takes around half an hour. However, it contains nanoparticles which do not degrade, meaning it does not dissolve entirely.

“Unlike conventional electronics that are designed to last for extensive periods of time, a key and unique attribute of transient electronics is to operate over a typically short and well-defined period, and undergo fast and, ideally, complete self-deconstruction and vanish when transiency is triggered,” the scientific paper stated.

While this particular battery could not be used in the human body as it contain lithium, researchers have been examining how batteries could dissolve harmlessly within the human body, and prevent the pain of removal, for several years.

Biodegradable materials for Medical Implants

Electronic systems entirely built with biodegradable materials are of growing interest for their potential applications in systems that can be integrated with living tissue and used for diagnostic and/or therapeutic purposes during certain physiological processes. The devices can be degraded and resorbed in the body, so no operation is needed to remove them and adverse long-term side effects are avoided.

University of Illinois's Biodegradable Battery

Scientists at the University of Illinois at Urbana–Champaign, led by Rogers, have been developing a new class of electronics devices that can dissolve completely into the environment after carrying out the desired function.

Researchers have developed biodegradable battery which degraded completely in water after three weeks, could be used to power temporary medical implants and other limited-duration electronics.

The key enabling technologies for the development of transient electronics are circuits made from extremely thin sheets of silicon, electrodes made from water soluble metals like magnesium, zinc and tungsten, polymers like cellulose and rice paper as insulators and silk for packaging.

The biodegradable demonstration battery developed by John Rogers and his colleagues utilized magnesium foil anode and phosphate-buffered saline electrolyte. The researchers are now conducting further studies, centered on developing degradable polymer-based materials that would make suitable platforms for other electronic components, including work on transient LED transistor technology.

The technology has potential to create a revolution in medical devices: In place of present biological implants that require risky surgery to remove them, future biological implants shall degrade once their function has been fulfilled. Many other medical applications are being researched, from temporary sensors that can monitor conditions inside the body to sensors that can be stored with food to indicate when the food is getting spoiled. The technology is also promising in many commercial applications like environmentally friendly wireless sensors and cellular phones

Tiny electronic Implants Monitor Brain Injury, Then Melt Away

John A. Rogers, at the University of Illinois at Urbana-Champaign, and Wilson Ray, at the Washington University School of Medicine, are developing new class of small, thin Brain implants that can function as electronic sensors to monitor critical health parameters like temperature and pressure within the skull after a brain injury or surgery and then melt away when they are no longer needed, eliminating the need for additional surgery and reducing the risk of infection and hemorrhage.

“This is a new class of electronic biomedical implants,” said Rogers, who directs the Frederick Seitz Materials Research Laboratory at Illinois. “These kinds of systems have potential across a range of clinical practices, where therapeutic or monitoring devices are implanted or ingested, perform a sophisticated function, and then resorb harmlessly into the body after their function is no longer necessary.”

After a traumatic brain injury or brain surgery, it is crucial to monitor the patient for swelling and pressure on the brain.

Current monitoring technology is bulky and invasive, Rogers said, and the wires restrict the patent’s movement and hamper physical therapy as they recover. Because they require continuous, hard-wired access into the head, such implants also carry the risk of allergic reactions, infection and hemorrhage, and even could exacerbate the inflammation they are meant to monitor.

“If you simply could throw out all the conventional hardware and replace it with very tiny, fully implantable sensors capable of the same function, constructed out of bioresorbable materials in a way that also eliminates or greatly miniaturizes the wires, then you could remove a lot of the risk and achieve better patient outcomes,” Rogers said. “We were able to demonstrate all of these key features in animal models, with a measurement precision that’s just as good as that of conventional devices.”

The new devices incorporate dissolvable silicon technology developed by Rogers’ group at the U. of I. The sensors, smaller than a grain of rice, are built on extremely thin sheets of silicon – which are naturally biodegradable – that are configured to function normally for a few weeks, then dissolve away, completely and harmlessly, in the body’s own fluids.

“The ultimate strategy is to have a device that you can place in the brain – or in other organs in the body – that is entirely implanted, intimately connected with the organ you want to monitor and can transmit signals wirelessly to provide information on the health of that organ, allowing doctors to intervene if necessary to prevent bigger problems,” said Rory Murphy, a neurosurgeon at Washington University and co-author of the paper. “After the critical period that you actually want to monitor, it will dissolve away and disappear.”

Biodegradable Power Generators Could Power Medical Implants

Now researchers have developed a biodegradable power source, they call biodegradable triboelectric nanogenerator (BD-TENG) that harnesses the phenomenon known triboelectricity, the most common cause of static electricity. When two different materials repeatedly touch and then separate, the surface of one material can steal electrons from the surface of the other.

They have designed a multilayer structure that is composed of biodegradable polymers (BDPs) and resorbable metals; the BD-TENG can be degraded and resorbed in an animal body after completing its work cycle without any adverse long-term effects. One BDP layer is a thin flat film, while the other layer is a sheet coated with rods up to 300 nanometers high. The layers are separated from one another by blocks of biodegradable polymer; they generate electricity when they are pushed together and pulled apart. The electricity-generating process relies on the relative contact separation between two BDP friction layers, in which a unique coupling between triboelectrification and electrostatic induction gives rise to an alternating flow of electrons between electrodes

In the lab, the researchers found that their biodegradable nanogenerator could achieve a power density of 32.6 milliwatts per square meter. They discovered that it could successfully power a neuron-stimulation device that helps control neuron growth. “Our results open the gate to fully degradable electronic devices,” says study co-author Zhong Lin Wang, a materials scientist at the Beijing Institute of Nanoenergy and Nanosystems. “A whole device can be absorbed in body and would not need to be removed through additional surgery.”

By fabricated BD-TENG with different materials, the researchers can tune the lifetime of their nanogenerator from hours to years, depending on the needs of the implantable electronics it is designed to power. They suggest that future devices could be powered by the mechanical energy from heartbeats or respiration.

Future Robots could be made from Biodegradable smart materials

Researchers at the Italian Institute of Technology (ITT) in Genoa are working to develop biodegradable smart materials for Humanoid's robot's skin. So far they have utilized bioplastics manufactured from food waste. What makes their material unique is that unlike normal plastics, which are made from petroleum products, these are made from industrial food waste.

'These biodegradable materials, natural materials, they are very flexible so they can be used for robotic skins,' explained Dr Athanassiou.'But they can be also very hard so they can be used for internal parts of a robot. "And also, in this flexible skin – robotic skin let's say – we can incorporate sensors so they have this tactile sensing that the robots need, but with biodegradable materials.'

The group claims its bioplastics are non-toxic and will be better for the environment as they use less energy and water resources to manufacture. Developing similar materials for electronic components could one day make entire machines biodegradable.

The team is using a 'mix and match' approach to developing so-called 'smart materials', combining different nanomaterials to generate products with new properties. 'What we are doing apart from making these new composite materials – smart materials – we're also using them to change the properties of other materials, other existing materials like paper or cotton or different foams; from synthetic foams like polyurethane or forms of cotton.

‘So like this, in all these existing materials we are giving new properties that these materials don’t have so we can open up their application range.’ Dr Athanassia Athanassiou, who leads the Smart Materials Group at ITT, told Reuters: ‘We are infusing any material with nanotechnology.’

Biodegradable polymer films

Iowa State’s research team is experimenting with a blend of programmable biodegradable and transient insulating polymer films. It found success in controlling the rate of transiency through the addition of materials. The addition of gelatin to the mix, can slow the dissolution, while the addition of sucrose worked to speed up the rate of transiency. Using these special polymers, the team was able to build and test an antenna that was capable of sending data and then completely dissolving when a trigger was activated.

Reconfigurable Electronics: Disappearing Carbon Circuits on Graphene

Using carbon atoms deposited on graphene with a focused electron beam process, Fedorov and collaborators have demonstrated a technique for creating dynamic patterns on graphene surfaces. The patterns could be used to make reconfigurable electronic circuits, which evolve over a period of hours before ultimately disappearing into a new electronic state of the graphene.

“We will now be able to draw electronic circuits that evolve over time,” said Andrei Fedorov, a professor in the George W. Woodruff School of Mechanical Engineering at Georgia Tech.

“You could design a circuit that operates one way now, but after waiting a day for the carbon to diffuse over the graphene surface, you would no longer have an electronic device. Today the device would do one thing; tomorrow it would do something entirely different.”

The change usually occurs over tens of hours, and ultimately converts positively-charged (p-doped) surface regions to surfaces with a uniformly negative charge (n-doped) while forming an intermediate p-n junction domain in the cours“

There are multiple ways to modulate the dynamic state, through changing the temperature because that controls the diffusion rate of carbon, by directing the atomic flow, or by changing the carbon phase,” Fedorov said. “The carbon deposited through the focused electron beam induced deposition (FEBID) process is linked to graphene very loosely through van der Waals interactions, so it is mobile.”e of this evolution.

“The electronic structures continuously change over time,” Fedorov explained. “That gives you a reconfigurable device, especially since our carbon deposition is done not using bulk films, but rather an electron beam that is used to draw where you want a negatively-doped domain to exist.”

Beyond allowing fabrication of disappearing circuits, the technology could be used as a form of timed release in which the dissipation of the carbon patterns could control other processes, such as the release of biomolecules.

Fedorov and his collaborators have so far shown only the ability to create simple patterns of charged domains in the graphene. Their next step will be to use their p-n junctions to create devices that would operate for specific periods of time.

Reported in the journal Nanoscale, the research was primarily supported by the U.S. Department of Energy Office of Science, and involved collaboration with researchers from the Air Force

Research Laboratory (AFRL), supported by the Air Force Office of Scientific Research.

Vanishing Electronics that Self Destructs in response to heat exposure

Researchers led by aerospace engineering professor Scott R. White and John A. Rogers, have developed a new type of “transient” electronic device that self-destructs in response to heat exposure instead of being exposed to water.

The technology involves first printing magnesium circuits on thin, flexible materials. The devices are coated with wax which contains Microscopic droplets of a weak acid. When exposed to heat, the wax melts and releases the acid, which completely dissolves the device. The researchers were also remotely able to trigger self-destruction by embedding a radio-frequency receiver and inductive heating coil in device. In response to a radio signal, the coil heats up and melt the wax, leading to the destruction of the device.

The team is also exploring the potential for other triggers, such as ultraviolet light and mechanical stress. The team’s work was supported by the National Science Foundation and DARPA.

DARPA’s Vanishing Programmable Resources (VAPR) program

DARPA’s Vanishing Programmable Resources (VAPR) program is investigating the development of special electronics that are rugged and functional as conventional electronics, but also capable of self-destruction on command or in response to environmental conditions, such as temperature. This shall prevent classified technology being leaked, reverse engineered or be used to develop countermeasures, if it fell in the hands of the enemy.

The main distinction between transient materials and conventional degradable materials is that unlike degradable materials, transient materials maintain their full characteristics and functionality until transiency is prescribed; and the dissolution rate is very often designed to be very fast. Military would benefit more with faster response to the trigger rather than waiting to slowly dissolve in the open environment or in the human body.

Sophisticated electronics are increasingly pervasive on the battlefield for a range of applications that include remote sensing and communications. However, it is nearly impossible to track and recover every device, resulting in their unintended accumulation in the environment, potential recovery and use by unauthorized individuals, and compromise of intellectual property and technological advantage.

The Vanishing Programmable Resources (VAPR) program seeks electronic systems capable of physically disappearing in a controlled, triggerable manner. These transient electronics should have performance comparable to commercial-off-the-shelf electronics, but with limited device persistence that can be programmed, adjusted in real-time, triggered, and/or be sensitive to the deployment environment.

VAPR aims to enable transient electronics as a deployable technology. To achieve this goal, researchers are pursuing new concepts and capabilities to enable the materials, components, integration and manufacturing that could together realize this new class of electronics.

Transient electronics may enable a number of revolutionary military capabilities including degradable environmental sensors or medical devices for diagnosis, treatment and health monitoring in the field.

Large-area distributed networks of sensors that can decompose in the natural environment (eco-resorbable) could provide critical data for a specified duration, but no longer. Alternatively, devices that resorb into the body may aid in continuous health monitoring and treatment in the field.

References and Resources also include

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