Electronic Tattoos

Electronic sensors are used to gather all sorts of information. Perhaps you've seen some fitness monitors that look like arm bands, chest bands, or watches. There are brain monitors, some look like a swim cap with wires coming out. Mindball (a game using your brain waves) just has a single band you put around your head. Now imagine an electronic sensor that is wireless, flexible, and as inconspicuous as a temporary tattoo!

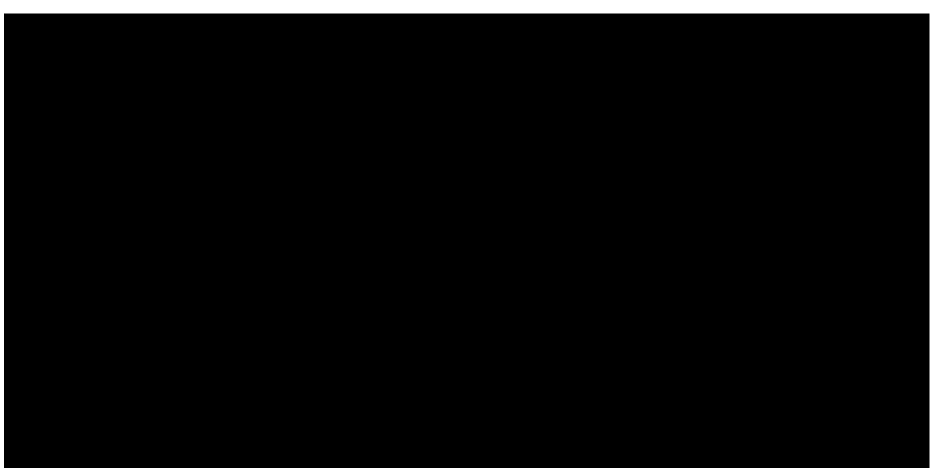
(a) (b) (c)

(d) (e) (f) (g)

(a) A wireless electronic sensor tattoo: front, back, and being scrunched. Images courtesy of the Rogers' Research Group (b) Heart rate monitor, chest and wrist band and (c) X-ray of heart rate monitors image credits Wiki Commons. (d) and (e) Person wearing electrodes to measure electrical brain activity along the scalp (electroencephalography, EEG), image credits Wiki Commons. (f) A picture of the mindball game, image credits Wiki Commons. (g) electronic tattoo applied to the forehead to measure electrical activity along the scalp. Image courtesy the Rogers' Research Group.

The innovation

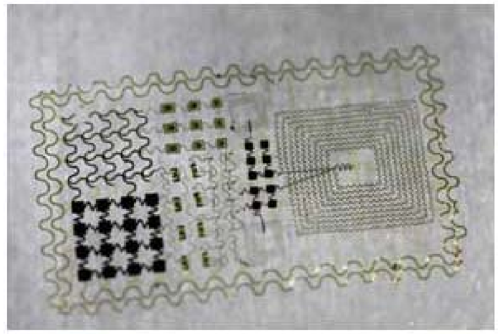
Small circuits have been around for a long time, and so have bendable materials, but never have the two been joined together so well. These small flexible electronic circuits are thinner than a human hair and have the same bendable, stretchable, and compressible properties as human skin! They were designed this way by the Rogers' Research Group at the University of Illinois in Urbana-Champaign. To watch a three minute video on this, click the link.



These cool tattoos, known officially as epidermal electronic systems (EES), stay on just by the adhesion forces between the atoms of the tattoo and the atoms of the skin. These attractive adhesion forces are also responsible for things like bugs and lizards walking on walls and ceilings. In the future, some adhesive substance (like on band-aids) may be added depending on what the electronic tattoo is being used for.

Electronic tattoos have all the same requirements as those of any electronic circuit. They require a closed loop for an electric current to exist, and a power source. The power source in the tattoo circuits shown is an inductor, which can be activated by a nearby wireless source. Rogers' Research Group also demonstrated serpentine solar cells as a power source. Imagine solar powered, wireless electronic tattoos! Future uses that would require continuous monitoring would require batteries, which is being worked on.

(a)



(b)

(a) various small inductors. Image credit Wiki commons.
(b) Tattoo circuit. The wireless power source, an inductor, is the winding square object on the right side of the circuit.
Image courtesy of the Rogers' Research Group .

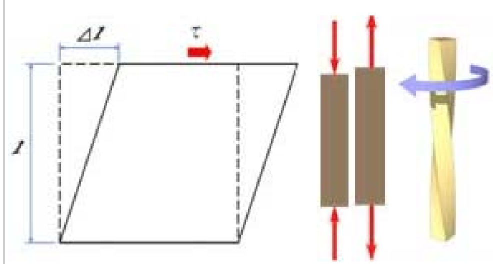
There are other requirements too – structural ones. Most electronics are built on rigid surfaces like a silicon chip. Skin is different than a rigid surface. It can be stretched, compressed, twisted, move up and down. Think about building on land prone to strong earthquakes. Imagine the building's bottom being pulled one way and then the next, perhaps twisted, and pushed up and down. What kind of structure and material could withstand all these forces?

If you study structures and the properties of materials you learn about the plasticity of the material and how well they can return to their original shape by a restoring force. The structure could feel a variety of forces. A shear stress is the force of one layer of the structure being pushed or pulled over another layer. A compression (push together) or tension (pull apart) force could act on the structure. A torsional force (twisting) could also exist. Scientists consider the strain on the object (how much it is deformed compared to its original dimensions). An elastic material possesses properties that pull the object back to its original dimensions (a restoring force). It's easy to think of materials that go back to their original shape, a bit harder to find some that have the same properties as skin, but imagine designing a circuit like this! How would you create the structure of conducting wires?

If you make a silicon chip thin enough (or anything thin enough) it becomes bendable. The silicon layers used in these tattoos are about 300 nm or 0.3 microns. They are a bit bendable. These "tattoo" circuits are composed of layers of metals, polymers, and silicon with a total thickness of about 5 microns (0.000005 meters)! This is much thinner than head hair, which is between 50 and 180 microns. Now, consider taking those properties of a building in an earthquake zone and you may think of building a wavy looking serpentine circuit like the one below. These integrated circuits embed active and passive devices that are in an open mesh design that forms a "web" of electronics. The circuit is embedded in an elastomer material, similar to the silicone that is used in caulking and sealants around windows and bathtubs. The elastomer used has a restoring force and behavior similar to skin. This design is able to withstand the effects of stretching, compressing, and twisting!

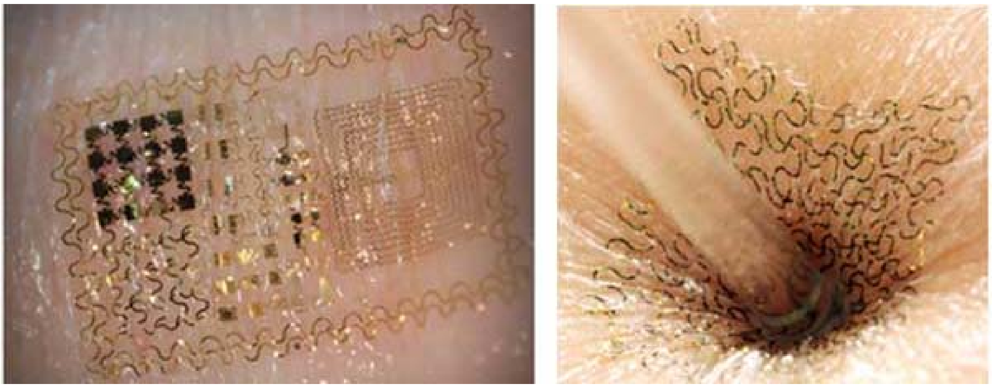
Rogers' Research Group has demonstrated sensors to monitor physiological quantities and the ability for these sensors to act as an interface between humans and technology. For example, commanding a video game wirelessly through an electronic tattoo that detects your brain activity.

Crash testing a building model on a shake table.
Image credit: Wiki Commons



(a) (b) (c) (d)

(a) shear stress force, (b) compression force and (c) tension force (d) Twisting or torsional force. Image credits wiki commons.



The circuits' filamentary serpentine shape allows them to bend, twist, scrunch and stretch while maintaining functionality. Electronics mounted directly to the skin, with no need for wires, conductive gel, or pins. They bend, stretch and deform with the same mechanical properties of skin, granting the wearer comfort and freedom of movement. Approximate dimensions of tattoo circuit 2.1 cm x 1.3 cm x 5 microns. Images courtesy of the Rogers' Research Group .

Future research and applications

There are many applications in health care, wellness, and fitness. These tattoos can gather electrophysiological information which connects electrical activity to physiological functions such as brain activity, heart rate, respiration, and so on. The sensor, when mounted on the throat for example, can utilize data collected in conjunction with pattern recognition software that can work as an interface to technology and assist those with larynx disorders. Premature babies often need to be monitored for appropriate breathing and heart rate. A wireless tattoo would make it that much easier to ensure the baby's safety rather than hardwiring the infant. These tattoos may also aid with physical rehabilitation not just as monitors, but also as a device to stimulate muscle contractions without restraining motion.

The Rogers' Research Group plans to incorporate energy storage capacity (batteries) into these epidermal electronic systems (EES). Even more challenging, they plan to advance these circuits so that the distinction between skin and circuit is even harder to detect. They hope to include microfluidic channels for drug delivery, and perhaps even a temporary circulatory system! The idea is to combine electronics with active microfluidic networks. Over the past ten years there have been many advances on stretchy microfluidic systems with sophisticated devices, but not for the epidermis (skin) and there seems no reason not to include electronics. A future application of this could be for treatment of burns. It could be useful to have an epidermal system that goes directly on the wound site to provide monitoring and drug delivery, in a closed-feedback loop.

References, resources, and links

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