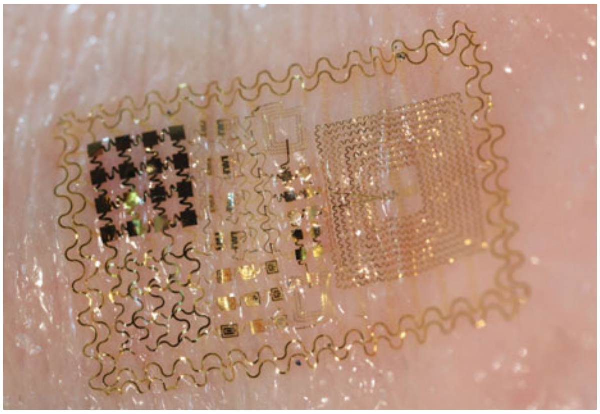
Bio Focus

Filamentary serpentine layout enables epidermal electronic "smart skin"

"Narrow, wavy, and thin"—that's how John Rogers of the University of Illinois at Urbana-Champaign describes the new "epidermal electronics" that he and his co-workers have developed for both monitoring electrical signals from the heart, brain, and muscles, and for stimulating muscles by supplying electrical signals. As reported in the August 12 issue of *Science* (DOI: 10.1126/science.1206157; p. 838), they have fabricated elastomeric patches containing open, spiderweb layouts of electrical circuits that have elastic modulus and bending properties very close to that of human skin. This will make them easy to wear and potentially useful, for example, in sleep studies, neonatal care, and rehabilitation applications.

The key to the flexibility and stretchability of the design is the "wavy" nature of the electronic circuits. This is known more technically as a "filamentary serpentine" layout, which consists of components with many large loops instead of shorter, linear circuit paths.

"If you look at the designs that best match the properties of skin in our work, they involve the *entire circuit* consisting of this filamentary serpentine shape," Rogers said. "So not only the interconnect wires but the devices themselves—the silicon itself, including transistors and the other device components—have this serpentine geometry." Quantitative mechanics modeling was used to determine the optimal thickness of the filaments and the loop geometry for the best skin matching.



The electronics are 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. *Photo courtesy:* John Rogers.

The result is an elastomeric patch less than 7 μm thick containing an antenna light-emitting diode, a wireless power coil, radio-frequency coils and diodes, a temperature sensor, and electroencephalogram, electrocardiogram, and electromyogram sensors to monitor the brain, heart, and muscle signals, respectively. The circuit is attached to the skin by van der Waals forces only, so no adhesive is needed; the van der Waals forces are sufficient to maintain conformal contact with the skin, withstanding normal body movements over periods of hours without cracking or delamination. The researchers have also experimented with commercially available temporary transfer tattoos that could conceal the circuitry and provide greater adhesion if necessary.

This technology is an outgrowth of the macroscale stretchable electronics that Rogers's group and others have been investigating. Earlier versions were just too thick (a few mm to 1 cm), with elastic moduli a few orders of magnitude too high to match human skin.

"We've extended some of those design concepts that we and others have been exploring in stretchable electronics to an extreme, in terms of design, filamentary shape, thinness, and modulus-matched substrate to enable this epidermal format," Rogers said. "We view it as a different class of technology for that reason, but it has historical origins in flexible and, more recently, stretchable forms of electronics."

Tim Palucka

Nano Focus

Millimeter-long GaN nanowires grow horizontally on sapphire substrate

Most nanowires are grown standing up, rising vertically from a substrate to reach heights in the range of tens of micrometers. They typically require post-fabrication processing to form aligned arrays of nanowires suitable for use in an electronic or optical device. Attempts to grow nanowires horizontally on a surface have had some success, but the resulting nanowires were still in the micrometer-length range, with limited control over their crystallographic orientation. Now, researchers at the Weizmann Institute of Science in Israel, led by Ernesto Joselevich, have reported in the August 19 issue of *Science* (DOI: 10.1126/science.1208455; p. 1003) the development of a process for producing *millimeter-long* GaN nanowires by guided growth on various crystallographic planes of a sapphire surface. The process allows the researchers to grow "very long and perfectly aligned horizontal nanowires with exquisite control of their crystallographic orientation," according to Joselevich.

The research team, which included graduate student David Tsivion, postdoctoral fellow Mark Schvartzman, and staff scientists Ronit Popovitz-Biro and Palle von Huth, used chemical vapor deposition of GaN on eight different sapphire planes seeded with Ni catalysts to achieve these results.

Analysis of the nanowires produced on these various planes revealed that those formed on surface steps and grooves were better aligned than those formed on a smooth plane. For instance, on a well-cut, smooth sapphire *c*-plane,

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