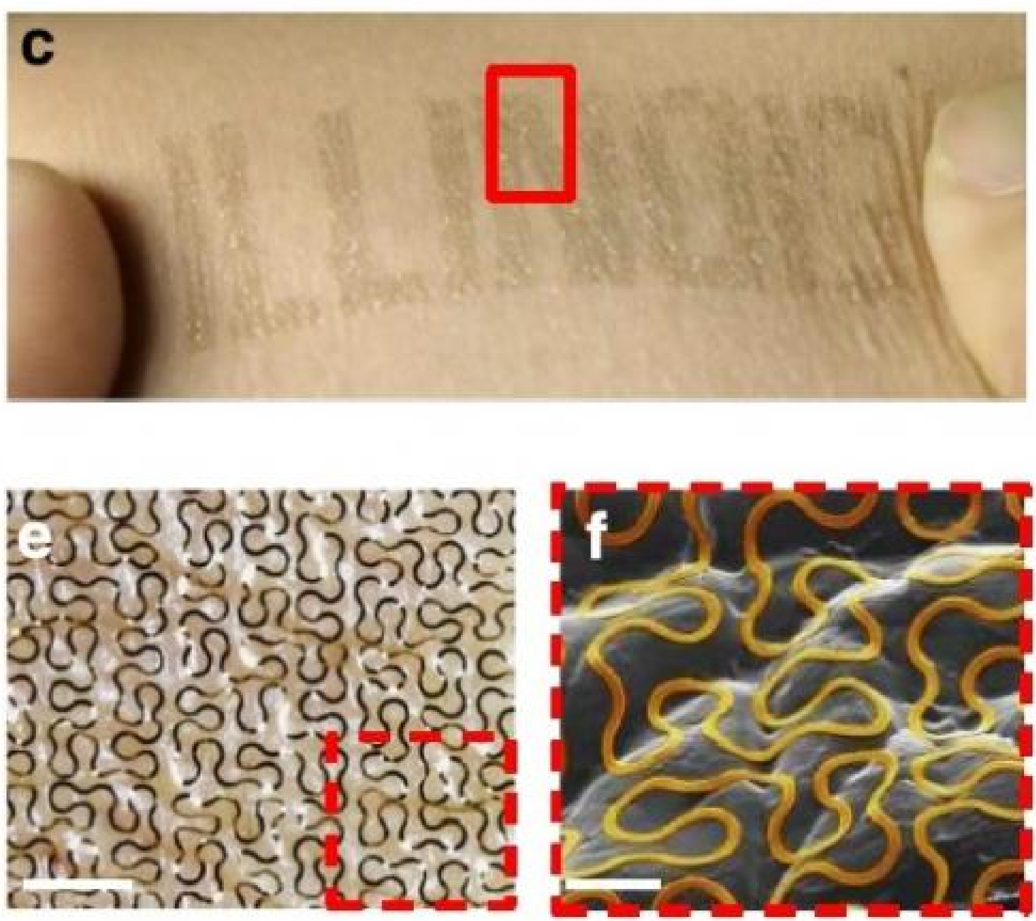
Fractal wire patterns enhance stretchability of electronic devices

February 18 2014, by Lisa Zyga



(Top) Image of metal wires with the Peano fractal pattern, with an overall geometry that spells out the characters in 'ILLINOIS', mounted on skin. Optical (lower left) and scanning electron (lower right) microscopy images of Peano-based wires on skin and a skin-replica (colorized metal wires), respectively, show how the wires conform to the substrate. Credit: Fan, et al. ©2014 Macmillan Publishers Limited

(Phys.org) —Fractals—patterns defined by their scale-invariance that makes them look the same on large scales as they do on small scales—are found in nature everywhere from snowflakes to broccoli to the beating of the heart. In a new study, researchers have demonstrated that metal wires patterned in various fractal motifs, when integrated into elastic materials, enable highly stretchable electronic devices. The fractal wire patterns could lead to a variety of new devices, such as biomedical sensors that can be attached to the skin and that have unique properties such as invisibility under magnetic resonance imaging (MRI).

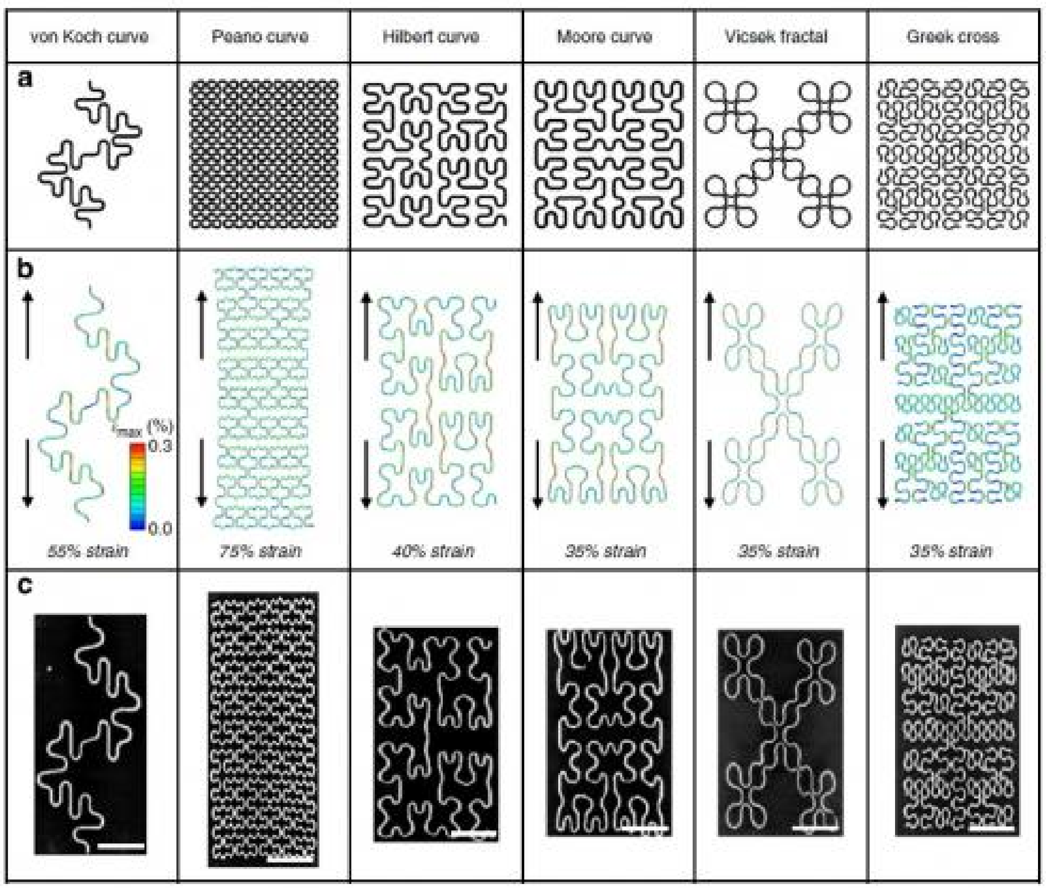
The researchers, Jonathan A. Fan, et al., from institutions in the US, China, Korea, and Singapore, have published a paper on the benefits of fractal wire patterns for stretchable electronics in a recent issue of *Nature Communications*.

In general, a main challenge in designing stretchable electronics is maintaining good electronic functionality while enabling stretching of up to twice the normal device size. Some of the most successful approaches to achieving both of these goals involve combining two separate components: a hard component that provides high conductivity and a soft component that provides mechanical stretchability.

The dual-component nature of these devices raises the question of how hard and soft materials can be ideally integrated.

The results of the new study show that fractal patterns offer a promising approach to hard-soft materials integration, and suggest that fractal patterns can influence the mechanical properties of 2D materials. In the new devices, the hard metal wires are engineered into fractal designs and then bonded to soft elastomers.

"We have established an approach, with general utility, for configuring hard materials with soft ones, in ways that have immediate relevance in all areas of stretchable electronics," coauthor John Rogers, Professor at the University of Illinois at Urbana-Champaign, told *Phys.org*. "The resulting properties also provide advanced capabilities in stretchable/conformal devices and sensors, not only electronic, but photonic, optoelectronic and photovoltaic as well."



(a) Fractal-inspired patterns for hard-soft materials integration, with (b) FEM images and (c) MicroXCT images. Credit: Fan, et al. ©2014 Macmillan Publishers Limited

In their experiments, the researchers investigated several different fractal patterns, including Peano, Greek cross, Vicsek, and others. They found that these fractal patterns offer key advantages over other patterns, such as periodic loops and serpentine shapes investigated in previous studies. With the Peano pattern, for example, the researchers showed that modifying the orientation of the pattern enhances the material's elastic strain in one or more selected directions, and allows the pattern to support different types of deformations. Previously explored wire patterns do not offer the ability to control the strain and deformation in these ways.

This control provided by fractal patterns could allow researchers to tailor stretchable electronics devices for different applications, depending on the type of stretching required. One potential application is "epidermal electronics," or skin-mounted sensors and actuators. A common example is electrodes, which measure electrophysiological processes in the brain, heart and muscle. To optimize the level of connectivity, the electrodes must conform to the skin, which has a stretchability of up to 20%. The researchers found that electrodes made with the Greek cross fractal pattern offer a high connectivity, stretchability, and robustness that enables them to compare favorably to conventional gel-based electrodes.

Fractal patterns could also have applications for radio-frequency devices, which could enable electrodes that are compatible with MRI scans. The researchers performed MRI experiments comparing electrodes made from three types of fractal patterns, two variants of serpentine (non-fractal) patterns, a pattern consisting of superimposed vertical and horizontal lines, and no pattern. While the serpentine patterns and unpatterned samples contained shadows that distorted the images, the fractal samples showed no shadows or distortion. The researchers attribute this difference to the highly interconnected closed loops of metal in the serpentine patterns; in contrast, the fractals do not contain closed loops, so they do not couple to RF radiation and are therefore invisible under MRI. The results suggest that fractal patterns offer a promising route to future MRI-compatible skin-mounted or implanted electrodes and other electronic devices.

In the future, the researchers plan to investigate further applications of fractals in electronics.

"We are now exploiting these same ideas to move from electrodes and test structures of silicon, to active materials for stretchable LEDs and solar cells, with a next goal of producing full functional systems in these types of layouts," Rogers said.

More information: Jonathan A. Fan. "Fractal design concepts for stretchable electronics." *Nature Communications*. DOI: 10.1038/ncomms4266