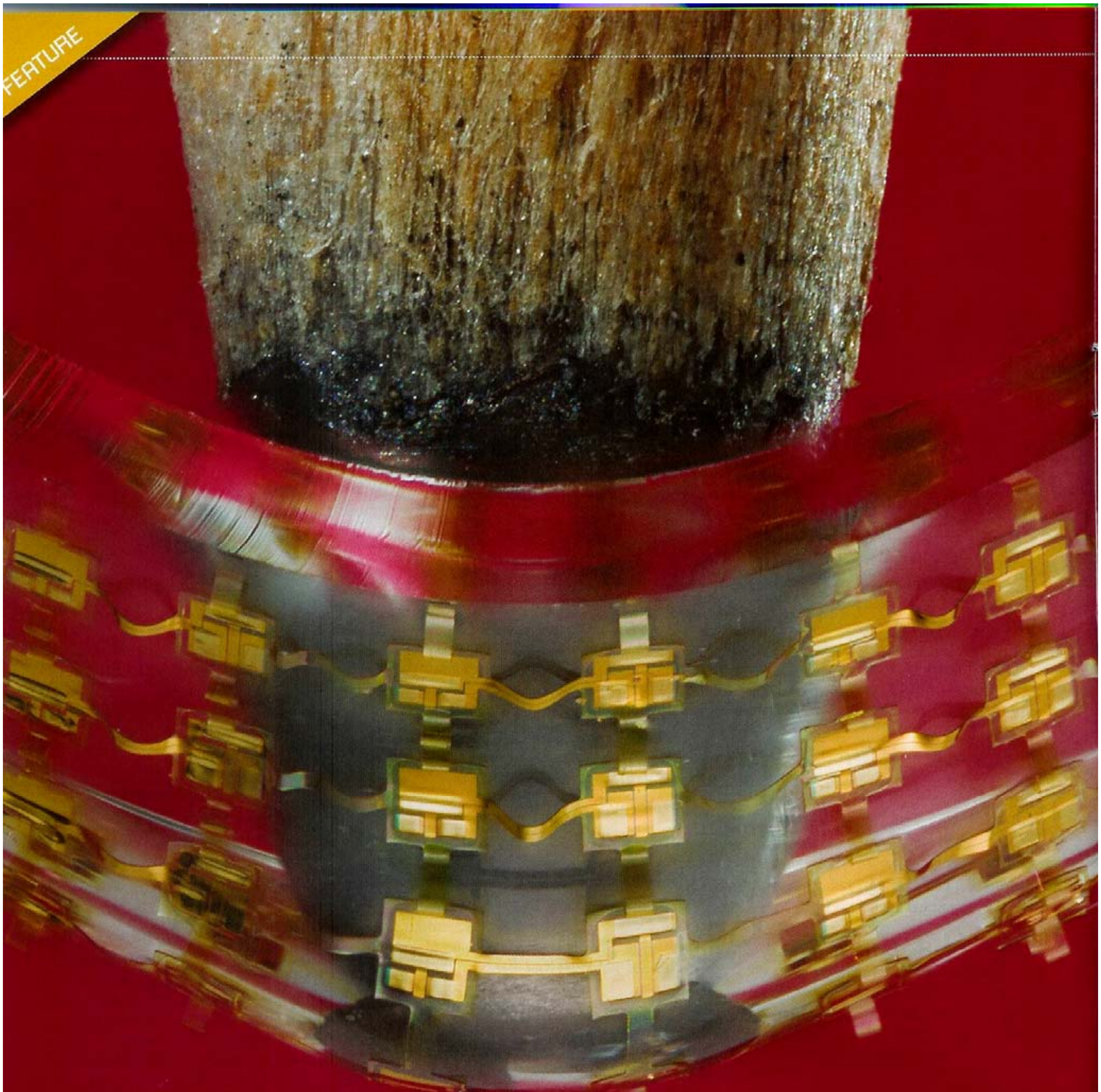


Bendy chips

Flexible, stretchable circuits will see electronics fit all sorts of shapes and sizes

MORE THAN HALF A CENTURY HAS PASSED SINCE THE FIRST MICROCHIPS WERE CREATED. IN THAT TIME WE HAVE SEEN A REVOLUTION IN ELECTRONICS DEVICES – AS MORE AND MORE COMPONENTS WERE SQUEEZED ONTO TINY CHIPS, TELEPHONES, COMPUTERS AND GADGETS GOT SMALLER AND SMALLER.

But, despite their ever-shrinking size, microchips retain one small problem – if you bend them they break. This single factor limits their use in a range of potentially limitless applications from second skins to biomedical implants.

Elaine Mulcahy spoke to John Rogers about a new type of chip that can bend around corners and stretch like an elastic band, which could change the way we think about and use electronics.

"Lightweight, foldable and stretchable electronics with performance that matches traditional, rigid semiconductor wafers would enable many new applications," Rogers says.

"Some examples include wearable, or even implantable, health monitoring systems, smart surgical gloves with integrated electronics and futuristic electronic eye cameras with human-scale field of vision. The possibilities are enormous."

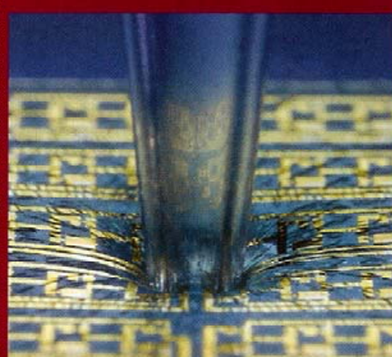
Professor Rogers holds the Flory-Founder Chair in Engineering, as a Professor in the Department of Materials Science and Engineering at the University of Illinois at Urbana-Champaign where they have been developing a new generation of such flexible, stretchable electronics.

Circuits printed onto plastic or foil with varying degrees of flexibility have been developed before. However, evidence suggests their flexibility has come at the cost of performance and they lag behind conventional chips in their functionality. Also, they do not offer the type of stretchability that would be required for integration on a complex curvilinear surface, such as an organ in the human body.

Using new techniques for printing n- and p-doped silicon nanoribbons onto ultrathin sheets of plastic, Rogers and his colleagues have built a new type of integrated circuit technology with similar performance characteristics and components to conventional chips but with the added benefit of being reversibly foldable and stretchable.

Bendable chips

To make the ultrathin, foldable circuits, Rogers and his colleagues printed n- and p-doped silicon nanoribbons onto a thin sheet of plastic, which was in turn glued to a fixed, inflexible substrate. The nanoribbons were organised and the chips fabricated to yield fully integrated Si-CMOS circuits, equivalent to the type of circuit used to manufacture about 99 per cent of all electronic devices. Once the circuits had been created, the underlying substrate layer was dissolved leaving only the circuit stamped onto the thin, flexible plastic sheet.



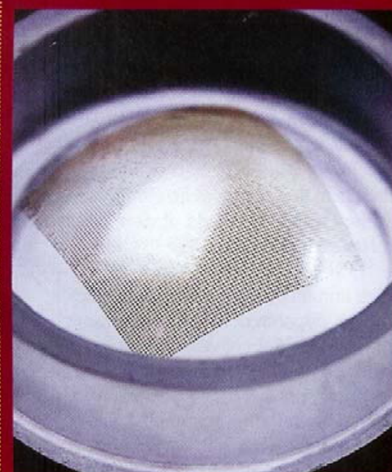
The technique was first described in Science in April this year.

"The ultrathin circuits exhibit extreme levels of bendability, without compromising the electronic properties," Rogers says.

"There are two reasons for this. Firstly, there's the basic mechanics. The entire thickness is just 1.5 microns. That includes the plastic substrate, metallization, silicon, dielectrics – everything. A circuit that thin is naturally bendable, just by the mechanics.

"A second and more subtle feature of our chips, is our ability to place the most fragile parts of the circuit into the "neutral mechanical plane". That is the part of the chip that experiences zero strain during bending or twisting.

"By placing the fragile components into these low-strain pockets, they are protected from external forces caused by bending and work just as well as those on a solid, inflexible wafer."



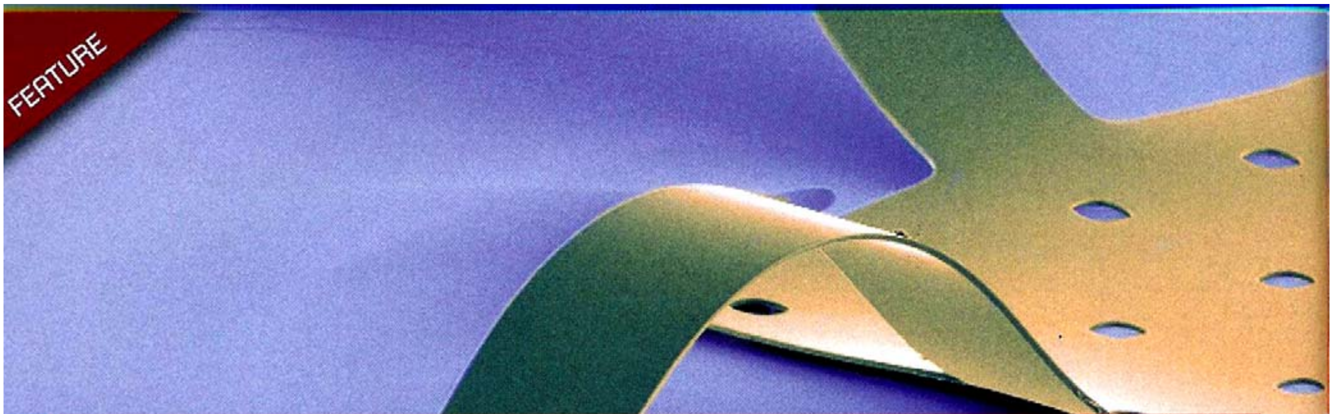
Stretch and flex

Such foldable, bendable chips marked a significant step forward in the design up flexible circuitry. However, while good at bending like a sheet of paper, they were not stretchable, like a rubber band.

In order to overcome this limitation, Rogers and his colleagues came up with a simple solution. Immediately after releasing the thin circuit sheet from the inflexible substrate, they bonded it to a prestretched piece of rubber. Allowing the rubber to snap back to its original state cause the formation of small waves, or mechanical buckling, in the circuit sheet.

"Circuits in this geometry offer fully reversible, stretchability without substantial strains in the circuit materials themselves. The physics is similar to the workings of an accordion bellows," Rogers explains.

This type of circuit technology developed by Rogers and his team offer new possibilities for integrating electronics with biological systems, medical prostheses and monitoring devices, lightweight packaging and a range of various other applications.→



> THE STRATEGIES WE HAVE DEVELOPED ARE IMPORTANT NOT ONLY FOR THE SI-CMOS CIRCUITS THAT THEY ENABLE BUT ALSO FOR THEIR STRAIGHTFORWARD SCALABILITY TO MUCH MORE HIGHLY INTEGRATED SYSTEMS WITH OTHER DIVERSE CLASSES OF ELECTRONIC MATERIALS WHOSE INTRINSIC BRITTLE, FRAGILE MECHANICAL PROPERTIES WOULD OTHERWISE PRECLUDE THEIR USE IN SUCH APPLICATIONS.

Eye camera

Already, the team has explored and developed the use of their stretchable circuits in the design of an electronic eye camera with a wide field of view, published in Nature in August.

"The human eye is an extremely efficient system, capable of taking a panoramic image of the field of view. We cannot only see what is straight in front of us, we can also see what is left and right of our direct field of vision. They accomplish this performance even with very simple, single component imaging lenses, by using hemispherical detector arrays (i.e. the retina)," Rogers says.

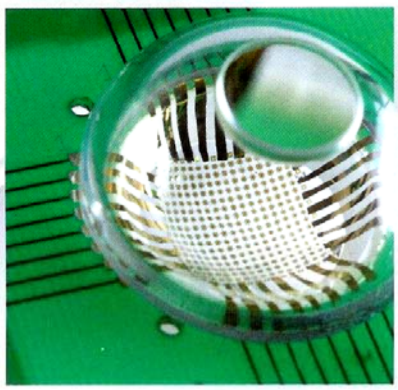
"In contrast, cameras on the market today use planar detector arrays and comparatively more complex optics that add cost, weight and size to the system. Even in these cases, for wider fields of view, distortions, poor focusing and aberrations can occur in the image at the edges.

"Tackling this problem by attempting to create a camera that more closely mimics the working of a natural eye presented a good test for a practical application of our approaches to stretchable electronics."

Eyes are hollow spheres. Along the inside wall of the back of the eyeball lies a layer of detector cells, the retina, which process information from the light that passes through the lens near the front of the eye.

This hemispherical detector helps the eye to achieve its wide field of view and is extremely difficult to match using conventional, planar optoelectronics technologies.

"Technologies developed until now have only been useful on surfaces of rigid,



semiconductor wafers or glass plates and, in more recent work, flat plastic sheets and slabs of rubber. None are suitable for the eye-camera application contemplated here because of the mechanical strains needed to accomplish the hemispherical geometry are too large. They just would not be able to bend into shape without fracturing the circuit materials," Rogers says. "Fully stretchable electronics, on the other hand."

Using techniques similar to those described above for bendable circuits, Rogers and his colleagues have created an eye camera with a hemispherical detector system that mimics the human retina.

To create the eye, a thin, hemispherical elastomeric element was stretched into a flat 'drumhead' shape. Separately, a silicon wafer consisting of photo-detectors and diodes with metal interconnects was created. The circuit was then laid onto the pre-stretched elastomer before it was allowed to relax back into its initial, hemispherical shape, forcing the circuitry to also take on the hemispherical configuration. As it did this, the tiny interconnects between the electronic components adopted a slight bend, taking the strain off the electronics in the system.

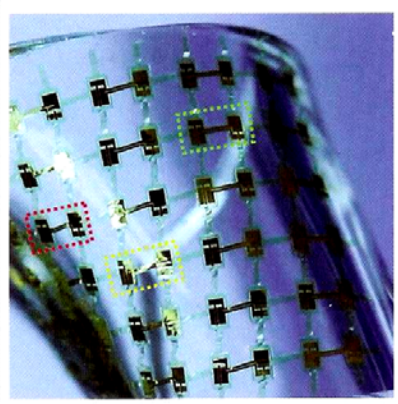
The circuit was then transferred to a hollow hemispherical glass lens substrate and the electronics were connected to an external recording device. A hemispherical glass cap containing an imaging lens was fixed to the top of the system to complete the eye.

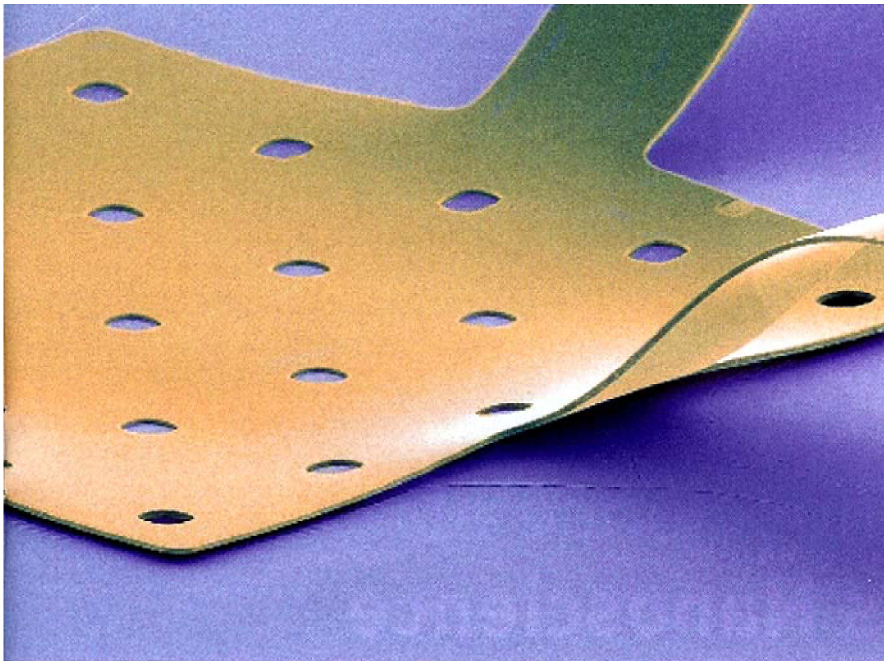
Images taken with the camera proved it did work and that the optical effects were consistent with expectation, as verified by modeling. As more pixels (electronic components) are added, the resolution could potentially match conventional cameras and offer enhanced features for biomedical and photographic imaging techniques.

"The ability to place electronic systems on unconventional, non-planar surfaces has application far beyond hemispherical camera or even other classes of bio-inspired device designs, to include biological monitoring devices, implants, prosthetics, and so on," Rogers says.

Corkscrew twist

The eye camera has already inspired Rogers to investigate the potentials for even





greater stretchability in electronic design. He predicts electronic circuits capable of twisting into corkscrew shapes or stretching like an elastic band.

"We have already demonstrated in a range of circuit examples, a form of stretchable electronics that matches conventional chips in performance but can also accommodate nearly any type of mechanical deformation to high levels of strain," he says.

The technique was recently published in the Proceedings of the National Academy of Sciences.

To create these circuits, the researchers firstly fabricated the Si-CMOS circuits on ultrathin plastic substrates, as described above. Small regions between the individual components of the system were then removed to leave a segmented mesh with active electronic islands connected by thin metal bridges. The plastic substrate was then dissolved to leave only the patterned circuit sheet.

This sheet was then transferred to a pre-stretched plastic substrate, in much the same manner as the stretchable circuits described above. However, in this case, when the plastic was allowed to relax back into shape, rather than the wavy characteristic of the first stretchable circuits, the interconnecting lines between the electronic components on the new circuits were able to raise from the surface to form arched bridges between the components.

In this format, the system could be stretched or compressed to high levels of strain – up to 100 per cent in some cases – in any direction or combination of directions.

This design led to electronic properties that were largely independent of strain, even in extreme configurations such as a corkscrew twist or elastic stretched to twice its length.

"We have created new design rules for circuits that provide both excellent electrical performance and capacities to be elastically deformed in diverse configurations to high levels of strain. The same ideas can, in many cases, be used to advantage in other conventionally rigid, planar technologies such as photovoltaics, sensor networks, photonics, and so on," Rogers says.

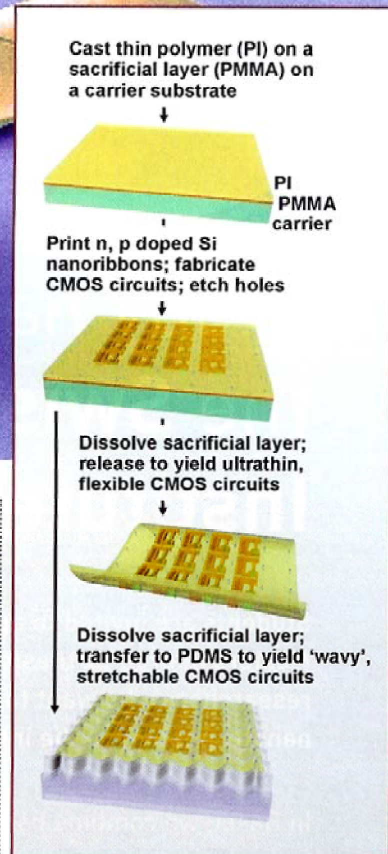
"The strategies we have developed are important not only for the Si-CMOS circuits that they enable but also for their straightforward scalability to much more highly integrated systems with other diverse classes of electronic materials whose intrinsic brittle, fragile mechanical properties would otherwise preclude their use in such applications."

Medical monitors

One potential application of such technology could be in the development of a sheet of electronics that could sit on the brain and monitor activity in patients at risk of epilepsy, for example. Another technology being considered is an electronic latex glove that would enable a surgeon to monitor the patient's vital signs during surgery.

Rogers says, "We are building lots of different things – stretchable solar 'skins' for integration with wide ranging classes of structures and surfaces, stretchable display systems, and so on.

Our main interest is in biomedical.We now have, in our collaborations with Professor Brian Litt at the University of Pennsylvania, working electrical monitors that wrap the



surface of the brain (successful demonstrations in rats) and pacing devices that wrap the heart (successful demonstrations in pigs). We are pushing into other similar types of possibilities, and increasing the sophistication and capabilities of the brain and heart systems."

So is this technology likely to mark a revolution in electronic design?

"We feel that the rigid, planar nature of existing technologies impose design constrains that limit application possibilities. Bringing the power of state-of-the-art electronics, sensors, displays, and photovoltaics to places where they couldn't go before should have considerable value. We have a seed effort, funded by a prominent venture capital firm in Boston, to explore market sizes associated with the most promising application possibilities. We also have many interactions with large companies who are interested in these types of systems," Rogers says.

The message: watch this space. ✪

All images courtesy of John Rogers, UIUC