QnAs with John A. Rogers

Nature is full of curves. So it is only natural that manmade devices meant to interact with nature emulate its elements of design. That is the line of reasoning behind the innovations of John Rogers, a member of the National Academy of Engineering and a professor of materials science at the University of Illinois, Urbana-Champaign. Rogers' innovations have inspired an array of approaches to render supple rigid surfaces found in electronic devices. From stretchable electronic sensors that can be slapped onto human skin like removable tattoos to digital cameras that mimic the retina to create pin-sharp images, Rogers has attempted to stretch the limits of engineering to bring creative solutions to common problems. In 2011, Rogers won the Lemelson-Massachusetts Institute of Technology prize, a $500,000 award for inventions that improve the world. Here, Rogers explains his bioinspired design to PNAS.

John A. Rogers.

PNAS: You have fabricated a skin patch that can monitor a number of functions in the human body. How did you get the idea to develop a stretchable sensor?

Rogers: Most efforts in the electronics industry seek to make transistors smaller and to pack them at ever higher densities into integrated circuits. That trend is known as Moore's law, which posits that the number of transistors that can be inexpensively placed in circuits doubles every 2 years. We decided to focus on a different problem, one that constrains the ways transistors can be used: They are built on the rigid and brittle surfaces of silicon wafers. Over the past few years, we have developed materials and manufacturing strategies that open up new engineering possibilities, without sacrificing the performance of transistors, in ways that enable circuits with the mechanical properties of a rubber band. We have used these approaches for electronic devices that can intimately integrate, almost like electronic Saran Wrap, with the human body, which is teeming with soft and stretchy surfaces both in internal organs, such as the heart and brain, and on the skin.

PNAS: How do you make a silicon-based device compatible with human tissues?

Rogers: The stiffness of a material is defined by its intrinsic mechanical properties and its geometry, particularly its thickness. Silicon wafers are about 0.5-mm thick, which, combined with silicon's elasticity, results in its extremely stiff and brittle nature. By reducing the thickness of the silicon to less than, say, 100 nm, you reduce the stiffness by a factor of 100 billion, thereby creating a flexible and floppy form of silicon. But human tissues are also stretchable; so an ideal device must be able not only to bend like paper but to stretch like latex. To make ultrathin silicon stretchable, we bond it in a wavy, undulating configuration to a thin, rubber membrane that acts as an elastic support. Like accordion bellows, the wave structures change to accommodate deformations induced by stretching. With these two design features–bendability and stretchability–we are able to engineer circuits with mechanics and shapes precisely matched to human tissues.

PNAS: What can your skin devices measure?

Rogers: Our epidermal electronic devices can be used for applications in hospitals and homes. We demonstrated that these skin-mounted circuits can measure electrical activity tied to the contraction of skeletal muscles, firing of brain cells, and beating of the heart. We also showed that the devices can be used in physical rehabilitation to stimulate the contraction of atrophied or injured muscles without constraining muscle movement. The devices eliminate bulky wiring, and are thus well-suited as non-invasive monitors of health in infants and as diagnostic tools to evaluate sleep patterns.

PNAS: Last year, your start-up company, mc10, announced a partnership with Reebok to make athletic apparel based on wearable electronics. What sorts of devices are you trying to bring to market?

Rogers: We are designing devices that integrate closely with the bodies of athletes to measure certain injury-related physiological properties as they are playing a sport. Such devices have the potential for near-term, widespread commercial use. We hope to launch a first product in mid-2012 for use in the subsequent sporting season.

PNAS: Your February 2011 paper in PNAS describes an "electronic-eye" camera that can be dynamically tuned. How is it different from conventional digital cameras?

Rogers: That is an application that also exploits the ability to stretch and deform semiconductor devices: in this case, arrays of silicon photodetectors. We create such arrays as part of digital imaging systems, which, unlike conventional cameras that constrain the photodetectors to planar layouts, can be dynamically tuned to alter the curvature of the surface on which the detectors are mounted. The human retina provides a hemispherical photodetector surface, which contributes to exceptional performance in terms of field of view, uniformity of illumination, and resolution, all with the use of very simple lenses. By contrast, manmade cameras use flat photodetector arrays, which require complex arrays of lenses to obtain high-quality images. The size, weight, and cost of professional-grade cameras can be unattractive because of the numbers and sizes of the lenses. By mounting the photodetectors on curvilinear surfaces that can be tuned for variable zoom, our electronic-eye cameras produce high-quality images at a far lower size, weight, and cost. We believe that such concepts could potentially allow professional-quality image capture with handheld cameras or cell phones. Such technologies can also be used in more specialized settings, such as night vision imagers, or ultracompact endoscopes.

PNAS: You have also ventured into the field of photovoltaic devices for solar cells.

Rogers: Cost is typically the limiting factor in the widespread use of solar cells for utility-scale power generation. Through a variety of design concepts and material growth techniques, we have tried to reduce the cost of high-efficiency, compound semiconductor-based solar cells, which are often formed on wafers of gallium arsenide. In particular, we have fashioned ways to grow layered stacks of such materials in formats that can be released and separated from the underlying wafer to yield millions of tiny, thin solar cells. Sparse, interconnected arrays of thousands of these cells, coupled with miniaturized focusing optics, allow us to capture sunlight in simple and low-cost ways, with exceptional efficiencies for power conversion. These innovations are being jointly commercialized by Siemens and North Carolina-based Semprius, Inc.

PNAS: How do you decide what projects to pursue? Do you start with an application in mind?

Rogers: In some instances, the application drives our science. In others, we start with a basic research question and see where it leads us. We try to select scientific topics where insights could lead to technologies with broad value to society.

Prashant Nair, *Science Writer*