John Rogers

Solving cardiac problems through electronic–tissue integration

Delegates at the Biotechnology and Medical Device Symposium on Wednesday morning were treated to a fascinating insight into the latest developments and future concepts in the field of bio-integrated electronics and their applicability to clinical cardiology.

John Rogers (Rogers Research Group, University of Illinois at Urbana-Champaign, USA), who gave the presentation, has conducted a huge degree of research into areas such as the fundamental and applied aspects of nano and molecular scale fabrication, as well as materials and patterning techniques for unusual electronic and photonic devices. His particular emphasis is on bio-integrated and bio-inspired systems. So far, he has published over 300 papers, and is named as an inventor on over 80 patents and patent applications, of which over 50 are licensed or in active use.

The Rogers Research Group, which includes students and post-doc researchers in a wide range of fields and from all over the world, employs highly multidisciplinary approaches to focus on soft materials for flexible 'macroelectronic' circuits, nanophotonic structures, microfluidic devices, and microelectromechanical systems.

Beginning his talk, Professor Rogers explained that his presentation would represent a "dramatic shift from the material in the other presentations" given so far that day. He continued: "I am a device guy, material scientist and engineer, and what we're trying to do is develop new classes of electronics that we're referring to as bio-integrated electronics, as we think this kind of technology can be useful in areas like clinical cardiology."

Offering a history of the development of electronics so far, Professor Rogers stated that the overall processor size has not change, but that the number of transistors, historically, included on those processors has doubled every approximately 18 months. This is because transistors have been getting smaller and smaller and so it has been possible to pack more and more of them into each unit area. Consequently, the functionality that can be achieved increases.

Another key aspect of the changes in transistors, Professor Rogers said, is that they are operating at higher and higher frequencies and at lower and lower voltages, becoming more and more power efficient, resulting in a trend that is an "amazing evolution of electronics and transformers".

He added: "Ninety nine per cent of the folks working in electronics are trying to figure out ways to maintain this elegant pathway over time." This, he said, can carry on for about another 10 years before the natural limits of the technologies employed are reached.

"This is not the problem we are trying to address, we're looking at electronics from a slightly different perspective," Professor Rogers continued. That perspective is based on the realisation that all electronics of the type that are involved in the aforementioned pathway are built on, basically, single crystalline wafers, or frisbees of material that are rigid and hard.

Explaining the difficulties with maintaining this approach, Professor Rogers said: "To constrain electronics to this kind of substrate really rules out a lot of those uses that might be interesting if you want to bring solutions to bear to problems in biology or cardiology because the geometries and properties of the supporting substrate are totally different from those of the soft tissue in the body.

"If you could remove that engineering design constraint...you would open up new areas for electronics." One of the key aspects of this, he said, is to be able to bring electronics into intimate contact with tissues, on the outside surface of the body, for example, or the tissues of the brain or heart.

Seeking to explain how this can be achieved, Professor Rogers continued: "It turns out there are a few fairly simple concepts in mechanics that allow you to bridge that gap [between the transistor and the tissues] and build classes of silicon electronic devices that have physical properties matched to important tissues of the body."

Primarily, he said, it depends on the mechanics and the geometry of the materials in question. So if 1 mm-thick slices of silicon are sliced it into incredibly thin sheets, the consequence of that is the sheets become 'floppy', based on the concept that a plate's bending stiffness is determined by the cube root of stiffness divided by density.

Furthermore, anything that is very, very thin becomes, essentially, sticky, Professor Rogers said, and it can be bonded to an underlying substrate. This results in cantilevered substances that are bonded simply through contact.

As these plates also become very fragile, multilayer stacks are used, each 20 nanometers thick. The question then becomes how to organise this multilayer stack to create a bio-integrated circuit, Professor Rogers said, showing a stack onto which had been printed an array. "Each one of these is about 250 microns in size and about 200 nanometers in thickness," he added. "The printed array stays on because of the previously mentioned stickiness of the material."

Turning to the application of these technologies in cardiology and how they can be scaled up, Professor Rogers highlighted a device that convtained a variety of multipad sensors designed to map the electrophysiology of the heart. It consisted of 288 electro pads, each one of which connects to a transistor and a low volt amplifier, with the whole device encased in a sheet of plastic.

He said: "So you can take that kind of device and laminate it up to the heart. The muscle surface of the heart provides enough adhesion that it can comfortably make contact with the heart and interface to the tissue without any adhesive scratches or other complications."

The device and others like them, he said, allow high-speed mapping, so that clinicians are able to see the rate change and electrophysiological activity of the heart. In an arrhythmic heart, it offers fascinating data, he continued, to provide real time, high resolution mapping.

Professor Rogers went on to say that the technology is moving forward very rapidly, citing a non-cardiac application that allows physiologists to understand the electrophysiology of seizures. Pointing to the future evolution of the technologies, he said that it will be able to allow the curvature of the heart to be probed to give a full mapping capability, which "is an interesting thing to think about".

The key to all of these technologies, he added, is that it needs to be as thin as possible to ensure the kind of conformal wrapping that is essential to its functionality. Amongst a series of example, he looked at cases where a single sheet would not work. For these situations, a thin sheet can be cut into a mesh, giving an kind-of open, web format that can conform to surfaces.

For the surgeon, he said that it can be manipulated so that there is an ultra thin mesh, known as a sacrificial substrate, that dissolves away to leave a thin film containing the device. "This offers a system that is fully integrated with the heart," Professor Rogers said in closing.

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