Injectable electronics fit right in

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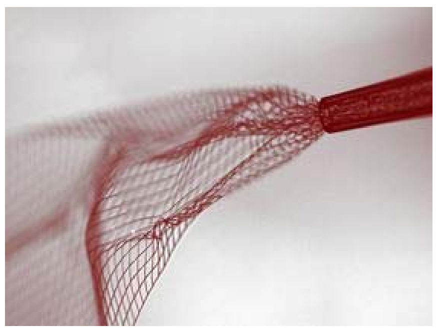
Flexible electronic devices that can be injected into cavities or living tissue through a needle and interpenetrate the space have been developed by a team of researchers at Harvard University [Liu et al., Nature Nanotechnology 10 (2015) 629, **http://dx.doi.org/10.1038/nnano.2015.115**].



Bright-field image showing the mesh electronics being injected through a sub-100 μm inner diameter glass needle into aqueous solution.

“[The] submicron thickness, large-area macroporous mesh electronics [are] roughly one million times more flexible than traditional flexible electronics,” says Charles M. Lieber, who led the project. “The ultra-flexible nature of the structures allows the electronics to be injected through needles without damage, while the macroporous mesh structure allows for three-dimensional interpenetration with tissue and man-made structures.”

The mesh electronics, which resemble chicken wire, are made up of semiconductor, metal, and polymer device elements such as electrochemical devices or Si nanowire field-effect transistors (FETs). The porous sheets roll up to fit through glass and metal needles with diameters as small as 100 μm. After injection into the targeted area, the mesh electronics, which can be up to 30 times wider than the needle diameter unfurl within an hour to fit the space available. The mesh electronics regain around 80% of their original configuration and retain their performance largely unaffected after the injection process.

Natural and artificial materials could be monitored and manipulated using such devices, suggest the researchers, who demonstrate the capabilities of the approach by injecting flexible electronic meshes into the brain tissue of live mice. Five weeks after injection, mouse brain samples showed few adverse effects. The mesh appears to integrate with the local tissue, with neural cells tightly embedded into it. The findings indicate that these injectable, flexible meshes could be ideal for monitoring neural activity or stimulating brain activity following injury.

The mesh electronics are particularly biocompatible, the researchers demonstrate, because their flexibility and micrometer-scale features are comparable to the properties of the surrounding tissue, precluding local damage and trauma.

“Our foldable mesh electronics can unfold and seamlessly integrate with biological tissue with little or no chronic damage and immunoreactivity,” says Lieber. “This provides transformative capabilities for implants and naturally allows for co-injection with regenerative medicine, such as stem cells.”

The approach is equally successful with artificial materials. The researchers injected a mesh containing Si nanowire piezoresistive strain sensors into polydimethylsiloxane (PDMS) and recorded the output during

deformation of the structure. Local strains can be monitored by the nanodevices and mapped onto optical images of the structure. Chemical or pH sensors could be injected into the cavities of engineered structures to monitor strain as materials deform or corrode.

"The beauty of this approach is that [virtually any kind of] electronics can be fabricated by conventional lithography technology and incorporated into the mesh, so it is very practical," says Lieber.

Ravi V. Bellamkonda of Georgia Institute of Technology and Emory School of Medicine believes that these flexible mesh electrodes and their delivery by simple injection are novel and innovative. "The fact that [the researchers] demonstrate successful *in vivo* recordings from these electrodes is heartening and it is encouraging to see that no tissue reaction to the implanted meshes that might impede with their recording function [was detected]," he told Nano Today.

Now, suggests Bellamkonda, the researchers need to demonstrate how long *in vivo* recordings can last and if the mesh electronics can be deployed safely without severing axons and micro-vessels in the process.

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