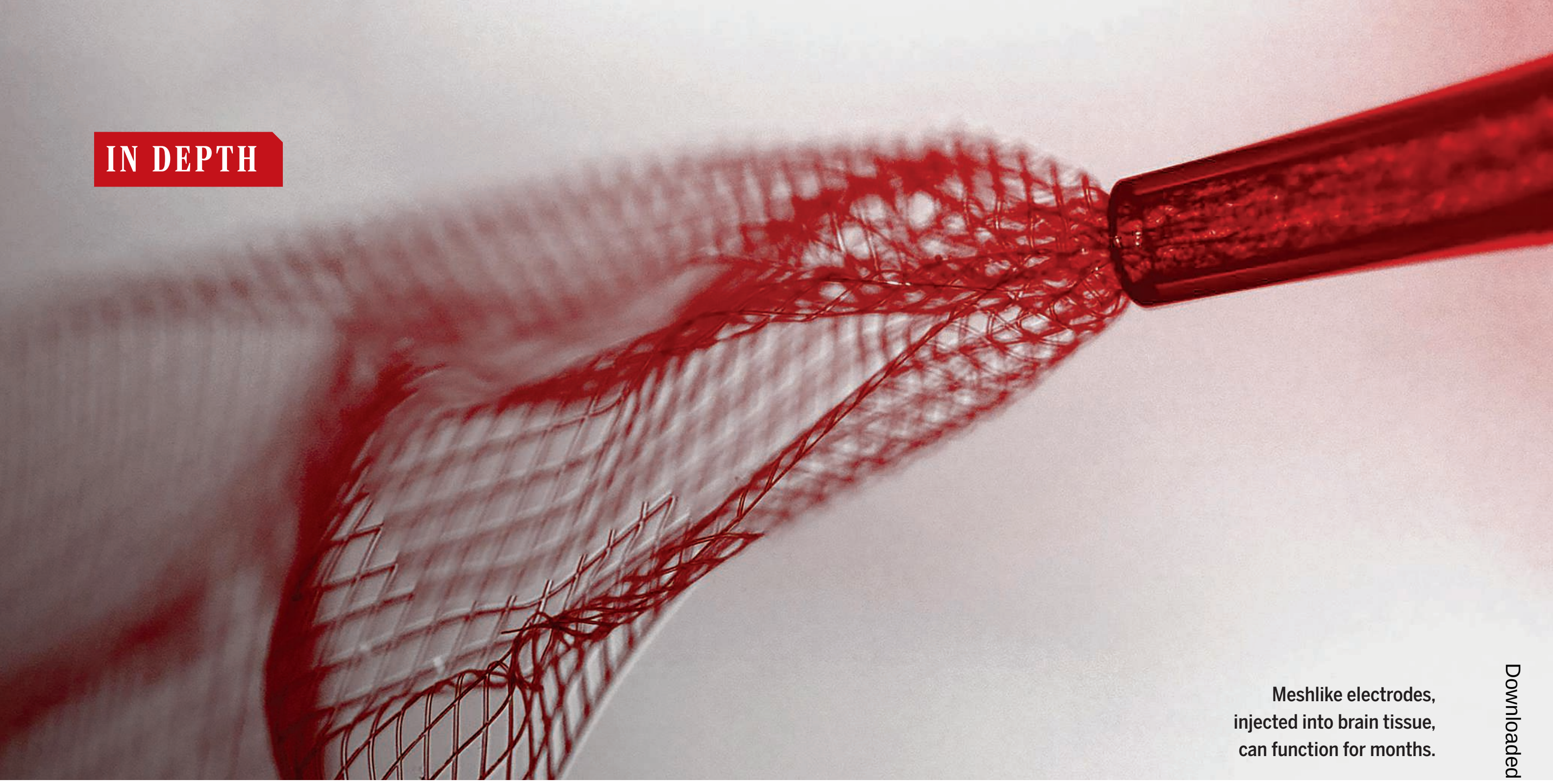


Meshlike electrodes, injected into brain tissue, can function for months.

MATERIALS RESEARCH

Bioelectronics herald the rise of the cyborg

Flexible plastic electronics can be wedded to brain tissue to monitor neural chatter

By **Robert F. Service**, *in Boston and Cambridge, Massachusetts*

The wires emerging from the heads of the small black mice—strain C57BL6—are a tip-off. If you're a sci-fi aficionado, you know that this is how cyborgs get their start. Charles Lieber, a chemist at Harvard University, and his colleagues have injected the brains of the mice with tiny, meshlike electronic probes—flexible and invisible to the immune system—that can eavesdrop on neurons for months at a time. Standard electrodes can't match that longevity, nor can they match another feat that Lieber reported at a meeting of the Materials Research Society here in Boston last week: simultaneously recording neural chatter in the eye alongside two other visual processing centers in the brain.

Lieber's result, together with other advances on display at the meeting, heralds a new era in bioelectronics, when electronics integrated seamlessly into nervous tissue could lead to innovative treatments in humans for everything from blindness and paralysis to brain diseases such as Parkinson's and Alzheimer's. For now, the researchers are working mostly in animals, and are primarily just listening to neural activity to understand the brain. But because the electrodes can carry inputs as well as outputs, the day when Lieber will not just monitor his mice, but also control them, is not far off. The boundary between living organisms and the outside world is dissolving, says David Martin, a bioelectronics expert at the University of Delaware in Newark. "You have to ask: Where does life end and engineering begin?"

Researchers have measured neural activity across three visual processing regions in the brains of mice.

PHOTOS: LIEBER GROUP, HARVARD UNIVERSITY

For decades, neuroscientists have inserted thin, metallic probes into the brains of mice and other animals to investigate the basic operation of neural circuitry, and those electrodes are growing ever more capable. Last month, for example, an international team of researchers reported the creation of ultrathin metallic probes capable of simultaneously tracking neural activity from hundreds of different spots along each probe. Clinicians already use related metallic probes in a therapy called deep brain stimulation, in which neurons are triggered to tamp down the muscular tremors associated with Parkinson's and other diseases.

But even thin metal spears can damage nerve tissue when inserted in the brain, Lieber says. And in the subsequent weeks to months, immune cells typically attack these rigid foreign objects, creating an inflammatory response and scar tissue that isolates the probes and renders them less effective over time.

So Lieber and others are crafting biofriendly alternatives. His group, for example, devised meshlike electrodes made from ultrathin gold wires wrapped in biofriendly organic polymers—plastics that have the suppleness of cells. The resulting electrodes are flexible enough to be suspended in a watery fluid, sucked into a syringe, and injected

deep in animal brain tissue. There, the mesh enfolds neurons and can read out or stimulate the activity of single cells or small cell groups for up to a year in mice.

At the meeting, Lieber and his colleagues reported injecting 16-channel mesh electrodes onto the retina of a mouse and into two other visual processing centers: the lateral geniculate nucleus and the primary visual cortex. The team then monitored the firing of neurons in all three regions as the animal viewed a series of moving images. It's the first time neuroscientists have been able to track all three levels of visual circuitry at work in live animals, Lieber says. "This is quite ground-breaking," says Ivan Minev, a bioelectronics expert at the Technical University of Dresden in Germany, who attended Lieber's talk. "It's a platform that can be deployed in many places."

Next, Lieber says he hopes to use the meshes to study learning, memory formation, and the loss of memory associated with aging and diseases—first in animals, and eventually in humans. As a first step toward evaluating the safety of the meshes, he has applied to an institutional review board for permission to implant them in the brains of patients with severe epilepsy who will later have surgery to remove those parts of their brains to treat the disease.

Lieber's meshes could be just the beginning. Whereas his electrodes record the activity of whatever neurons happen to be nearby, chemist Zhenan Bao and neuroscientist Karl Deisseroth of Stanford University in Palo Alto, California, want to target specific types of neurons, among the dozens present in the brain. At the meeting, Bao reported that she and her colleagues had genetically engineered specific nerve cells in mice to express a protein called peroxidase on the outer surface of their cell membranes. After sacrificing the animals and isolating brain slices in culture, the researchers added the chemical building blocks for an electrically conducting polymer to the culture fluid. The peroxidase selectively triggered the formation of the polymer, leaving the engineered nerve cells wrapped in polymer while other neuron types stayed bare.

During a talk at the meeting, Jia Liu, a postdoc in Bao's group, said he is now working to connect these polymer-wrapped cells to mesh electrodes, which could allow the cells to communicate with the outside world. "That's the future," says Bozhi Tian, a bioelectronics expert at the University of Chicago in Illinois. Bao's strategy isn't likely to translate to humans any time soon, given its reliance on growing genetically engineered neurons. But at least for mice, it brings the cyborg era one step closer. ■

ORBITAL DEBRIS

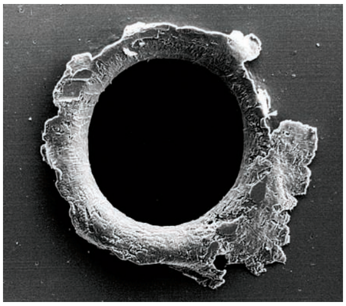
NASA sensor to study space junk the size of dust

Data could help satellitemakers avoid deadly microdebris

By **Ilima Loomis**

The film *Gravity* dramatized the risks of space junk. But although flyaway wrenches and broken-off rocket parts like those that hurtled toward audiences may pose the deadliest threat to spacecraft, most orbital debris is much smaller—think flecks of paint and the splinters of shattered satellites. Now, NASA hopes to learn more about the dust-size microdebris orbiting Earth with the Space Debris Sensor (SDS), set to ride a SpaceX cargo rocket next week to the International Space Station (ISS).

The U.S. Air Force already uses ground-based radars to keep track of about 23,000 objects larger than a baseball, so that satellite operators can avoid collisions by maneuvering out of the way. But the SDS will study objects smaller than a millimeter. They are likely to be far more abundant—and at high speeds they can still cause real damage, says Brian Weeden of the Secure World Foundation, a nonprofit focused on space sustainability, in Washington, D.C. "If a satellite is in orbit for 10 or 15 years, those little abrasions can have an impact by degrading sensors or degrading materials," he says.



Microdebris bored a 0.5-millimeter pit in the Solar Maximum Mission satellite.

NASA previously studied microdebris by inspecting space shuttles that returned to Earth pockmarked with tiny impacts on windows and other surfaces. "A detailed ground inspection could estimate what sizes the objects were that impacted it, but there's limited information you can get out of that," says Joseph Hamilton, an orbital debris scientist and the SDS principal investigator at Johnson Space Center in Houston, Texas.

The new sensor, to be attached to the ISS, will offer a better handle on the microdebris population. The 1-square-meter detector contains a mesh of fine wires backed by two layers of thin sensors. Debris striking the SDS will sever a number of these wires that correlate to the particle's size. By detecting where the wires were damaged and how quickly the particle penetrates the layers, the sensors can track particle speeds and trajectories. A back plate will measure the intensity of the impact, helping scientists estimate the object's density.

With these data, scientists can determine the particles' orbits, which provide clues to their origins. An elliptical orbit, for instance, suggests that a particle is a natural micrometeoroid, whereas a circular orbit implies that it probably sloughed off of a satellite. From their microdebris census, scientists can extrapolate to objects larger than 1 millimeter and smaller than 10 centimeters, improving population estimates. These objects can cause more significant damage to spacecraft, but are still too small to be tracked by radar, Hamilton says.

The SDS is considered a technology demonstration. If it succeeds, future missions could study microdebris at altitudes of 700 to 1000 kilometers, twice as high as the ISS, a region more congested with satellites and space junk, where even less is known. The findings could help satellite designers develop better shielding, and improved models of the microdebris population could help them find orbits less plagued by space dust.

Some companies hope to find a market for data on space junk. Astroscale, a private satellite services company based in Singapore, developed a 22-kilogram microsatellite called IDEA OSG 1 that was to study debris at altitudes between 600 and 800 kilometers, collecting data that the company hoped to sell or share with government agencies or private organizations. On 28 November, IDEA OSG 1 was one of many satellites launched on a Russian Soyuz rocket that failed to reach its target orbit and is presumed lost. Astroscale did not respond to requests for comment about the Russian rocket failure. ■

Ilima Loomis is a journalist on Maui in Hawaii.

PHOTO: NASA

Science

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