Technology Review
AN MIT ENTERPRISE

Nanowires Listen In on Neurons

Electrodes made of nanowires can measure the complex signals in a single brain cell.
By Katherine Bourzac

Creating a tool with unmatched sensitivity, Harvard University researchers have made silicon nanowires that can precisely measure multiple electric signals within a neuron. These ultrasmall silicon wires could help brain scientists understand the underpinnings of learning and memory. They could also be used in neural prosthetics, providing electrodes far more sensitive than those currently used.

The research group, led by Charles Lieber, professor of chemistry at Harvard University, has developed techniques for synthesizing large arrays of silicon nanowires, which act as transistors, amplifying very small electrical signals from as many as 50 places on a single neuron. In contrast, the most precise existing methods can pick up only one or two signals from a neuron. By detecting electrical activity in many places along a neuron, the researchers can watch how it processes and acts on incoming signals from other cells.

The nanowires are about the same size as the branches that neurons use to communicate with one another. William Ditto, professor of biomedical engineering at the University of Florida, says neurons probably send the same kinds of signals to the nanowires as they do to other neurons. As a result, the nanowires could provide a realistic view of a neuron's complex firing patterns.

Lieber and his coworkers make the silicon nanowires from silane gas in a vacuum furnace. Gold catalyst particles in the furnace determine the nanowires' diameters -- 20 nanometers for the neuron experiments. The nanowires are separated from one another and connected to electrical contacts made of nickel. The wires and their contacts are then mounted on a silicon chip that has been patterned with protein to promote neuron growth. Next, Lieber seeds a rat brain neuron on the chip and waits 7 to 10 days, while it grows. The neuron-friendly protein provides a path that directs a neuron's growth along the chip and ensures that it makes contact with the nanowires.

"The most interesting question is: How do cells in the brain actually communicate?" says Lieber. Electrical signals travel across neurons by means of an "action potential," a rapid swing in the cell's membrane voltage from negative to positive and back to negative within a few milliseconds. This voltage change doesn't occur throughout the whole cell at once, but rather spreads from a neuron's incoming branches, called dendrites, to the main body of the cell. Other branches, called axons, carry signals in the form of action potentials to other neurons' dendrites, as well as to muscle and other tissues.

Neurons receive many incoming electrical signals through their dendrites that aren't carried even as far as the cell body. Although tiny changes in electrical conductivity within cells are the basis of normal learning and memory -- and many brain pathologies -- neuroscientists still have not been able to observe these small changes with the existing tools.

Arrays of microfabricated metal electrodes can be used to monitor tissue slices, or can even be implanted into the brain. But the electrodes in these arrays are the same size as, or bigger than, single neurons. Lieber says the signals picked up by such electrodes are small because they represent average electrical activity over an entire cell or multiple cells.

Using Lieber's system, "you can sense inputs to a neuron on dendrites, and sense how it responds at the axon," says

Todd Pappas, director of sensory and molecular neuroengineering at the University of Texas Medical Branch. "This is a great leap forward."

Florida's Ditto says the nanowires will be an important tool for studying neural circuits -- the networks of communicating neurons -- in great detail. And understanding neural circuits could provide insight into learning and memory, as well as advancing computer science.

Lieber hopes the nanowires will find applications in medical devices. They might be used to "build an interface to the brain that's much more sophisticated" than current ones, which rely on large electrodes, he says. Such devices might help control epilepsy or pain, or, like cochlear implants for hearing, substitute for damaged sensory nerves.

Lieber's group is also developing the nanowires to make even more sophisticated connections with neurons. The area where two neurons meet, a synapse, is characterized not just by electrical signaling but also by chemical signaling. In fact, the transfer of chemicals known as neurotransmitters at synapses is what allows the transmission of electrical signals from one neuron to another. Lieber has already demonstrated that his nanowires can act as sensitive chemical sensors (see "Drugstore Cancer Tests"). His group is now working to make nanowires that can detect -- and someday possibly release -- neurotransmitters.

Zhong Lin Wang, director of the Center for Nanostructure Characterization at Georgia Tech, says Lieber's arrays of 50 nanowires are a remarkable achievement. "From a nanowire point of view, an array of 50 is a landmark," he says. Indeed, to attain this level, Lieber had to fine-tune his manufacturing process to end up with 90 percent functioning nanowires in each batch.

Wang views Lieber's nanowire work as a validation of nanotechnology's growing relevance. "It shows that work in the nanotechnology field can become revolutionary and important" in other fields, such as biology, he says.