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Post-silicon computing

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Could Pittsburgh be the nation's next "Strontium Valley"? The University of Pittsburgh is the lead institution on a $1.8 million grant from the National Science Foundation and the Nanoelectronics Research Initiative (NRI) of the Semiconductor Research Corporation (SRC) to bring a new kind of computer out of the lab and into the real world. The goal of the group, led by Jeremy Levy, a professor of physics and astronomy in Pitt's School of Arts and Sciences, is no less than transforming the way computing is done.

The four-year grant, titled "Scalable Sensing, Storage, and Computation With a Rewritable Oxide Nanoelectronics Platform," also involves researchers from the University of Wisconsin and Northwestern University. The program aims to create new high-tech industries and jobs in the United States.

"The search for a new semiconductor device that will provide the United States with a leadership position in the global era of nanoelectronics relies on making discoveries at these kinds of advanced universities," said Jeff Welser, director of the NRI for SRC.

From Etch-A-Sketch to Tiny Transistors

Levy and his team have invented a tiny Etch-A-Sketch that draws infinitesimally small "wires" on a surface, then erases them. The device works by switching an oxide crystal between insulating and conducting states. The interface between these two materials can be switched between an insulating and metallic state using a sharp conducting probe.

Electronic circuits can be "written" and "erased" at scales approaching the distance between atoms (two nanometers). The device, less than four nanometers wide, enables photonic interaction with objects as small as single molecules or quantum dots.

This research grant explicitly addresses key scientific and technological challenges that, if overcome, could lead turn the "Etch-A-Sketch®" into something real and useful—from being just a toy in a science lab to a possible replacement for conventional electronics made from silicon devices.

Beyond being just plain cool, this device could be the basis of an entirely new kind of transistor.

Transistors in a computer are the on/off switches that enable the efficient implementation of complex computational systems. And for the last half century, they've been getting smaller and smaller, according to (Intel founder Gordon) "Moore's law": The number of transistors that can be placed inexpensively on an integrated circuit doubles approximately every two years. At some point, though, this trend has to stop. Materials start acting "weird" when they are made too small. The useful properties of silicon, for example, are believed to break down at distances smaller than 10 nanometers.

"The question is, once you've pushed silicon to its limit, is there going to be another system to do computation?" asks Levy. That's really what we've been granted funding to explore. We're trying to break down the major barriers that are potential show-stoppers that would otherwise make it difficult to turn these new types of devices into real, useful things."

In 2008, Levy and colleagues reported in Science that they had made a transistor with elements that were five interatomic distances wide.

"These are really, really small transistors," Levy emphasizes. "We believe that they behave in a fundamentally different way from normal transistors."

To develop useful electronics, it is imperative to develop a scheme capable of creating and manipulating large numbers of devices. If it takes a minute to make a transistor, it would take a year to make a billion of them. This scaling is achieved through the use of large probe arrays.

Levy uses an atomic force microscope, a specialized instrument that moves a probe and along a surface, to create the transistors. Another method, used by Chad Mirkin at Northwestern University, has developed ways of producing millions of such tips on a single wafer. "The idea is to do parallel writing—to have all of these different tips working in parallel," says Levy. That way, manufacturing takes a few minutes instead of a year.

New Materials, New Ways of Sensing and Storage

How today's computers process information depends on a fixed architecture of ones and zeros—digital logic. Levy envisions using new materials that might not follow that same architecture. "We want the material to tell us the best way it can do computation, rather than trying to impose an old architecture that was really designed for another type of material," he says. "We want to listen to the material, and then map information processing onto what it's good at."

Professors Mark Rzchowski and Jack Ma at the University of Wisconsin will focus on this issue. The materials will be working with are part of a family known as "complex oxides". This class of materials shares many of the semiconducting properties of silicon, but have a wealth of other properties that make them interesting for computing, storage and sensing applications.

All computers require storage, but they store this information using very different architectures than the computer parts. In addition, an important function of electronics is that semiconductors can be used for sensing – which in this case really means sensing of light.

"We want to try to integrate all of these things together and have a platform that allows us to 'write' or 'erase' components capable of all of these functions," Levy says.

The principal material they wish to study is a sandwich of two such oxides: a thick layer of strontium titanate, with a thin (1.2 nanometer) layer of lanthanum aluminate. These materials will be grown in the laboratory of Professor Chang-Beom Eom at the University of Wisconsin.

Energy Efficiency

Another issue Levy is studying is the amount of power that is consumed by devices as they get smaller. With laptops, for example, clock speed—processor speed—used to be everything. But now, it's not touted as much. "Of course, that's because manufacturers can't make it go faster," Levy points out. "They could increase the clock speed, but it would melt the silicon."

Not only is making computing more energy efficient good for the environment, it's also practical. "What we're interested in doing is trying to see if we can create info processing much closer to the fundamental limits," Levy says. "We know we can make things small; the question is can we make them small and not heat up to the temperature of the sun?"

OnRamp to Success

The grant also includes an outreach component. A new "OnRamp" education program targets specific difficulties that students have in their subdiscipline while beginning their research careers. OnRamp tutorials are developed by beginning graduate students as they "learn the ropes" of doing research. Graduate students help develop research-based learning modules, which are shared with a broader research community—"putting a ramp there to smooth out the bumps in the road so that people can get moving with research faster," says Pitt professor of physics and astronomy Chandralekha Singh, who is leading this OnRamp program.

Such tools have been shown to help underrepresented groups.

In addition, both Pitt and Wisconsin continue to expand their high school outreach programs aimed at increasing the numbers of underrepresented groups in science and engineering disciplines.

More information: For more information on Levy's research, visit www.levylab.org

Provided by University of Pittsburgh