EE Times: Latest News

'Missing link' memristor created: Rewrite the textbooks?

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PORTLAND, Ore. — The long-sought after memristor--the "missing link" in electronic circuit theory--has been invented by Hewlett Packard Senior Fellow R. Stanley Williams at HP Labs (Palo Alto, Calif.) Memristors--the fourth passive component type after resistors, capacitors and inductors--were postulated in a seminal 1971 paper in the IEEE Transactions on Circuit Theory by professor Leon Chua at the University of California (Berkeley), but their first realization was just announced today by HP. According to Williams and Chua, now virtually every electronics textbook will have to be revised to include the memristor and the new paradigm it represents for electronic circuit theory.

"My situation was similar to that of the Russian chemist Dmitri Mendeleev who invented the periodic table in 1869," said Chua. "Mendeleev postulated that there were elements missing from the table, and now all those elements have been found. Likewise, Stanley Williams at HP Labs has now found the first example of the missing memristor circuit element."

When Chua wrote his seminal paper, he used mathematics to deduce the existence of a fourth circuit element type after resistors, capacitors and inductors, which he called a memristor, because it "remembers" changes in the current passing through it by changing its resistance. Now HP claims to have discovered the first instance of a memristor, which it created with a bi-level titanium dioxide thin-film that changes its resistance when current passes through it.

"This new circuit element solves many problems with circuitry today--since it improves in performance as you scale it down to smaller and smaller sizes," said Chua. "Memristors will enable very small nanoscale devices to be made without generating all the excess heat that scaling down transistors is causing today."

HP has already tested the material in its ultra-high-density crossbar switches, which use nanowires to pack a record 100 Gbits onto a single die--compared with 16 Gbits for the highest density flash memory chips extant.

"We have been looking for years for the best material to use in our ultra-dense nanowire crossbar switches, which can fit 100 billion crossbars into a square centimeter. What we have finally realized is that the ideal material is a memristor," said Williams, primary inventor of the memristor's titanium-dioxide-based material and founding director of HP's 12-year-old Information and Quantum Systems Lab, where his team perfected its formulation.

The hold-up over the last 37 years, according to professor Chua, has been a misconception that has pervaded electronic circuit theory. That misconception is that the fundamental relationship in passive circuitry is between voltage and charge. What the researchers contend is that the fundamental relationship is actually between changes-in-voltage, or flux, and charge. Such is the insight that enabled HP to invent the memristor, according to Chua and Williams.

"Electronic theorists have been using the wrong pair of variables all these years--voltage and charge. The missing part of electronic theory was that the fundamental pair of variables is flux and charge," said Chua. "The situation is analogous to what is called "Aristotle's Law of Motion, which was wrong, because he said that force must be proportional to velocity. That misled people for 2000 years until Newton came along and pointed out that Aristotle was using the wrong variables. Newton said that force is proportional to acceleration--the change in velocity. This is exactly the situation with electronic circuit theory today. All electronic textbooks have been teaching using the wrong variables--voltage and charge--explaining away inaccuracies as anomalies. What they should have been teaching is the relationship between changes in voltage, or flux, and charge."

HP invited Chua to speak about his theory a few years ago, but at that time the lab did not tell Chua that they were actively seeking the memristor. Only two weeks ago did Williams tell Chua that he had used the proper variables--flux and charge--to invent the world's first working memristor.

A memristor works by virtue of analog mode with our crossbar is a pretty good representation of a neural net."

Later in 2008, HP promises to begin releasing details of how its memristor material works with its already perfected nanoscale crossbar switch architecture in these various types of circuits.

"The memristor is not just a replacement technology for existing memory devices, but will be used to make a whole range of new types of devices that no one has ever thought of before," said Williams.

News - May 1, 2008

Missing Link of Electronics Discovered: "Memristor"

Memory plus resistor may add up to longer-lasting batteries and faster-booting computers

By JR Minkel

After nearly 40 years, researchers have discovered a new type of building block for electronic circuits. And there's at least a chance it will spare you from recharging your phone every other day. Scientists at Hewlett-Packard Laboratories in Palo Alto, Calif., report in *Nature* that a new nanometer-scale electric switch "remembers" whether it is on or off after its power is turned off. (A nanometer is one billionth of a meter.)

Researchers believe that the memristor, or memory resistor, might become a useful tool for constructing nonvolatile computer memory, which is not lost when the power goes off, or for keeping the computer industry on pace to satisfy Moore's law, the exponential growth in processing power every 18 months.

You may dimly recall circuit diagrams from your middle school science class; those little boxes with a battery on one end and a lightbulb on the other. Ring any bells? To an electrical engineer, the battery is a capacitor—a device for storing electric charge—and the lightbulb is a resistor—an obstacle to electric current. Until now, engineers have had only one other basic element to work with—the inductor, which turns current into a magnetic field.

In 1971 researcher Leon Chua of the University of California, Berkeley, noticed a gap in that list. Circuit elements express relationships between pairs of the four electromagnetic quantities of charge, current, voltage and magnetic flux. Missing was a link between charge and flux. Chua dubbed this missing link the memristor and created a crude example to demonstrate its key property: it becomes more or less resistive (less or more conductive) depending on the amount of charge that had flowed through it.

Physicist Stanley Williams of HP Labs says that after a colleague brought Chua's work to his attention, he saw that it would explain a variety of odd behaviors in electronic devices that his group and other nanotech researchers had built over the years. His "brain jolt" came, he says, when he realized that "to make a pure memristor you have to build it so as to isolate this memory function."

So he and his colleagues inserted a layer of titanium dioxide (TiO2) as thin as three nanometers between a pair of platinum layers [*see image above*]. Part of the TiO2 layer contained a sprinkling of positively charged divots (vacancies) where oxygen atoms would have normally been. They applied an alternating current to the electrode closer to these divots, causing it to swing between a positive and negative charge.

When positively charged, the electrode pushed the charged vacancies and spread them throughout the TiO_2, boosting the current flowing to the second electrode. When the voltage reversed, it slashed the current a million-fold, the group reports. When the researchers turned the current off, the vacancies stopped moving, which left the memristor in either its high- or low-resistant state. "Our physics model tells us that the memristive state should last for years," Williams says.

Chua says he didn't expect anyone to make a memristor in his lifetime. "It's amazing," he says. "I had just completely forgotten it." He says the HP memristor has an advantage over other potential nonvolatile memory technologies because the basic manufacturing tools are already in place.

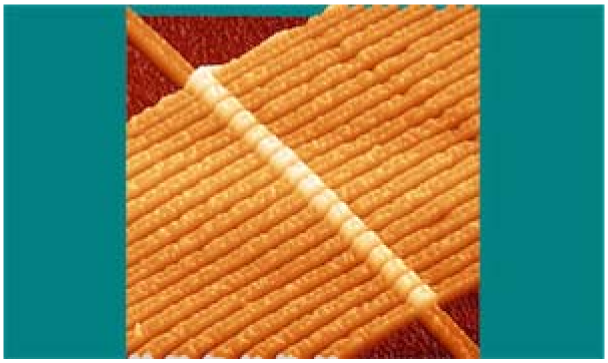
Williams adds that memristors could be used to speed up microprocessors by synchronizing circuits that tend to drift in frequency relative to one another or by doing the work of many transistors at once.

Whether industry will adopt it remains to be seen. In an editorial accompanying the paper, nanotech researchers James Tour and Tao He of Rice University in Houston note that "even to consider an alternative to the transistor is anathema to many device engineers, and the memristor concept will have a steep slope to climb towards acceptance."

But the memristor concept is a promising one, they wrote, adding: "It is often the simple ideas that stand the test of time."

Scientists Create First Memristor: Missing Fourth Electronic Circuit Element

By Bryan Gardiner April 30, 2008 | 12:03:41 PMCategories: Research



Researchers at HP Labs have built the first working prototypes of an important new electronic component that may lead to instant-on PCs as well as analog computers that process information the way the human brain does.

The new component is called a memristor, or memory resistor. Up until today, the circuit element had only been described in a series of mathematical equations written by Leon Chua, who in 1971 was an engineering student studying non-linear circuits. Chua knew the circuit element should exist -- he even accurately outlined its properties and how it would work. Unfortunately, neither he nor the rest of the engineering community could come up with a physical manifestation that matched his mathematical expression.

Thirty-seven years later, a group of scientists from HP Labs has finally built real working memristors, thus adding a fourth basic circuit element to electrical circuit theory, one that will join the three better-known ones: the capacitor, resistor and the inductor.

Researchers believe the discovery will pave the way for instant-on PCs, more energy-efficient computers, and new analog computers that can process and associate information in a manner similar to that of the human brain.

According to R. Stanley Williams, one of four researchers at HP Labs' Information and Quantum Systems Lab who made the discovery, the most interesting characteristic of a memristor device is that it remembers the amount of charge that flows through it.

Indeed, Chua's original idea was that the resistance of a memristor would depend upon how much charge has gone through the device. In other words, you can flow the charge in one direction and the resistance will increase. If you push the charge in the opposite direction it will decrease. Put simply, the resistance of the devices at any point in time is a function of history of the device –- or how much charge went through it either forwards or backwards. That simple idea, now that it has been proven, will have profound effect on computing and computer science.

"Part of what's going to come out of this is something none of us can imagine yet," says Williams. "But what we can imagine in and of itself is actually pretty cool."

For one thing, Williams says these memristors can be used as either digital switches or to build a new breed of analog devices.

For the former, Williams says scientists can now think about fabricating a new type of non-volatile random access memory (RAM) – or memory chips that don't forget what power state they were in when a computer is shut off.

That's the big problem with DRAM today, he says. "When you turn the power off on your PC, the DRAM forgets what was there. So the next time you turn the power on you've got to sit there and wait while all of this stuff that you need to run your computer is loaded into the DRAM from the hard disk."

With non-volatile RAM, that process would be instantaneous and your PC would be in the same state as when you turned it off.

Scientists also envision building other types of circuits in which the memristor would be used as an analog device.

Indeed, Leon himself noted the similarity between his own predictions of the properties for a memristor and what was then known about synapses in the brain. One of his suggestions was that you could perhaps do some type of neuronal computing using memristors. HP Labs thinks that's actually a very good idea.

"Building an analog computer in which you don't use 1s and 0s and instead use essentially all shades of gray in between is one of the things we're already working on," says Williams. These computers could do the types of things that digital computers aren't very good at –- like making decisions, determining that one thing is larger than another, or even learning.

While a lot of researchers are currently trying to write a computer code that simulates brain function on a standard machine, they have to use huge machines with enormous processing power to simulate only tiny portions of the brain.

Williams and his team say they can now take a different approach: "Instead of writing a computer program to simulate a brain or simulate some brain function, we're actually looking to build some hardware based upon memristors that emulates brain-like functions," says Williams.

Such hardware could be used to improve things like facial recognition technology, and enable an appliance to essentially learn from experience, he says. In principle, this should also be thousands or millions of times more efficient than running a program on a digital computer.

The results of HP Labs teams findings will be published in a paper in today's edition of *Nature*. As far as when we might see memristors actually being used in actual commercial devices, Williams says the limitations are more business oriented than technological.

Ultimately, the problem is going to be related to the time and effort involved in designing a memristor circuit, he says. "The money invested in circuit design is actually much larger than building fabs. In fact, you can use any fab to make these things right now, but somebody also has to design the circuits and there's currently no memristor model. The key is going to be getting the necessary tools out into the community and finding a niche application for memristors. How long this will take is more of a business decision than a technological one."

Image: An atomic force microscope image of a simple circuit with 17 memristors lined up in a row. Each memristor has a bottom wire that contacts one side of the device and a top wire that contacts the opposite side. The devices act as 'memory resistors', with the resistance of each device depending on the amount of charge that has moved through each one. The wires in this image are 50 nm wide, or about 150 atoms in total width. Image courtesy of J. J. Yang, HP Labs.