HP Labs Proves Existence of New Basic Element for Electronic Circuits
Media Coverage Report
(As of April 30, 2008 at 12:00pm PT)

Summary

Coverage of the Memristor announcement has been strong , with 12 stories monitored so far in outlets including: The New York Times, Wall Street Journal, CNET, Bloomberg, EE Times, Crunch Gear, New Scientist, InfoWorld, and PopSci.com. The stories are positive and clearly outline our key messages and position Stan as a thought leader.

Headlines of note include:

- NY Times, HP Unveils New Memory Technology
- WSJ, H-P Thinks New 'Memristor' Could Have Big Impact on Data Storage
- Bloomberg, Hewlett-Packard Finds New Computer Memory Technology
- CNET, HP Makes Memory From a Once Theoretical Circuit
- PopSci.com, HP Discovers Potential "God Particle" of Electronics

In addition to those stories, the team has also conducted briefings with Kevin Bullis of the Technology Review, Michelle Kessler of USA Today, Cade Metz of the Register and Agam Shah at IDG. We expect coverage from those outlets as well as an AP story by Jordan Robertson to hit later today.

Full coverage is attached. We will send an additional recap EOD today. Please let us know if there are follow up questions.

Thank you,
Ryan

Coverage Index

HP makes memory from a once theoretical circuit
CNET, By Michael Kanellos, 4/30/08

'Missing link' memristor created: Rewrite the text books?
EE Times, By R. Colin Johnson, 4/30/08
(Also appears on InformationWeek.com)

Found: the missing circuit element
NatureNews, By Michael Hopkin, 4/30/08

HP Discovers Potential "God Particle" of Electronics
PopSci.com, By Sean Captain, 4/30/08

HP Creates Atomic Memory
CrunchGear, By John Biggs, 4/30/08

Engineers find 'missing link' of electronics
New Scientist, By Paul Marks, 4/30/08

Down With The Transistor
Science News, By Davide Castelvecchi, 4/30/08

H-P Proves Theoretical Circuits, Theoretically (HPQ)
24/7 Wall St., By Jon C. Ogg, 4/30/08

HP "Memristors" Promise Memory Revolution
Electronista, 4/30/2008

Full Text

H.P. Unveils New Memory Technology
New York Times, By John Markoff, 4/30/08

A team of Hewlett-Packard scientists reported Wednesday in the science journal Nature that they have designed a simple circuit element they believe will enable tiny powerful computers that could imitate biological functions.

The device, called a memristor, could make it possible to build extremely dense computer memory chips that use far less power than today's DRAM memory chips, which are rapidly reaching the limit in how much smaller they can be made.

The memristor, an electrical resistor with memory properties, may also make it possible to fashion advanced logic circuits, like a class of reprogrammable chips known as field programmable gate arrays, that are today widely used for rapid prototyping of new circuits and for custom-made chips that need to be manufactured quickly.

Potentially even more tantalizing is the memristors' ability to store and retrieve a vast array of intermediate values, not just the binary 1s and 0s as conventional chips do. This makes them

function like biological synapses, which would be ideal for many artificial intelligence applications ranging from machine vision to understanding speech.

The H.P. researchers said that the discovery of the memory properties in tiny, extremely thin spots of titanium dioxide, came from a frustrating, decade-long hunt for a new class of organic molecules to serve as nano-sized switches. Researchers in both industry and academia have hoped they would be able to fashion switches as small as the size of a single molecule to someday replace transistors once the semiconductor industry's shrinking of electronic circuits made with photolithographic techniques reached a technological limit.

Independent researchers said that it seemed likely that the memristor might relatively quickly be applied in computer memories, but that other applications might be more challenging. Typically, technology advances are not adopted unless they offer dramatic cost or performance advantages over the technologies they are replacing.

"Whether it will be useful for other large scale applications is unclear at this point," said Wolfgang Porod, director for the Center of Nano Science and Technology at the University of Notre Dame.

The material offers a new approach that is radically different than another type of solid state storage called "phase-change memory" that is now being pursued by I.B.M., Intel and other companies. In a phase-change memory heat is used to shift a glassy material from an amorphous to a crystalline state and back again. The switching speed of these systems is both slower and requires more power, according to the H.P. scientists.

The memristor technology should be fairly quickly commercialized, said R. Stanley Williams, director of the quantum science research group at H.P. "This is on a fast track," he said.

The memristor was predicted in 1971 by a Berkeley electrical engineer, Leon Chua. There have been hints of an unexplained behavior in the literature for some time, Mr. Chua said in a phone interview on Tuesday.

However, he noted that he had not worked on his idea for several decades and that he was taken by surprise when he was contacted by the H.P. researchers several months ago. The advance clearly points the way to a prediction made in 1959 by the physicist, Richard Feynman, that "there's plenty of room at the bottom," referring to the possibility of building atomic-scale systems.

"I can see all kinds of new technologies and I'm thrilled," he said.

The original theoretical work done by Mr. Chua was laid out in a 1971 paper titled "Memristor — The Missing Circuit Element." The paper argued that basic electronic theory required that in addition to the three basic circuit elements — resistors, capacitors, and inductors — a fourth element should exist.

The H.P. research team titled their paper, "The Missing Memristor Found."

The H.P. team has successfully created working circuits based on memristors that are as small as 15 nanometers (the diameter of an atom is roughly about a tenth of a nanometer.) Ultimately, it will be possible to make memristors as small as about four nanometers, Mr. Williams said. In

contrast the smallest components in today's semiconductors are 45 nanometers, and the industry currently does not see away to shrink those devices below about 20 nanometers.

Because the idea of a memristor was invented almost 40 years ago by Mr. Chua, it is in the public domain, however the H.P. scientists have applied for patents covering their successful implementation of a working version of the device.

One of the most exciting aspects of the new devices is that they may consume dramatically less power compared with today's microprocessors and memory devices, which must be continually refreshed electrically to maintain their state. In contrast, circuits made from memristors will require power only to switch and will hold their state for at least several years once they have been set in a particular state. Moreover, they can be made in the same kinds of semiconductor factories that the chip industry now uses without specialized equipment.

The most significant limitation that the H.P. researchers said the new technology faces is that the memristors function about 10 times more slowly than today's DRAM memory cells.

The discovery was made when the H.P. researchers and a cooperating team of scientists at U.C.L.A. got widely different results in a technical experiment involving organic materials. Ultimately the H.P. team was able to prove that the dramatic changes in resistance they were seeing were coming from a contaminant, and not from the organic molecules.

"I'll take serendipity, but it took us a long time to figure this out," Mr. Williams said.

The researchers were eventually able to determine that the change in resistance came from the movement of oxygen atoms in the material in response to an electrical charge. Moreover, the changes were so significant that it was simple to detect the state of the device even at near-atomic scale.

After beginning to explore the properties of titanium dioxide, Mr. Williams said his group was at first baffled by the effect and were unable to produce it reliably. However, through experimentation they gained a solid theoretical understanding of the phenomenon. Currently they are building the devices from a sandwich of a pure layer of titanium dioxide and a second layer of the same material doped with a proprietary material.

http://www.nytimes.com/2008/05/01/technology/01hp-Web.html?hp

H-P Thinks New 'Memristor' Could Have Big Impact on Data Storage
Wall Street Journal, By Don Clark, 4/30/08

Researchers at Hewlett-Packard Co. say they've built a new element of electronic circuitry that had previously existed only in theory.

The company says the new component, known as the memory resistor, or "memristor," could have a big impact on the way data are stored in computers. Among other things, the development could help future memory chips store information for long periods without electrical current, eliminate the slow process of booting up computers and also sharply reduce power consumption, the company says.

The notion of a memristor was postulated in 1971 by Leon Chua, an electrical engineering professor at the University of California at Berkeley. A working prototype was developed by a team of scientists the tech giant's H-P Labs unit, who are disclosing their work in a paper being published Wednesday in the journal Nature.

H-P's development comes at a time when many companies are racing to find technologies to succeed a kind of chip known as flash memory, which is widely used to store data in products such as digital cameras and music players. Existing flash-memory technology is expected to lose its usefulness within the decade, as companies keep shrinking the dimensions of chip circuitry to store more data.

Assuming memristors can be manufactured efficiently and combined with other kinds of circuitry, the technology could store data in a smaller and more energy-efficient form than flash memory or other technologies, said R. Stanley Williams, H-P's lead researcher on the project and an expert in the field known as nanotechnology. In addition, while flash chips lose their data after a year or so, a memristor has an unusual ability to permanently recall the amount of electrical charge that flows through it, he said.

The researchers constructed a prototype by placing a microscopic film of titanium dioxide between two electrodes and applying a charge. "The memristor remembers because what's happening is you actually change the atomic structure of the memristor as charge flows through it," Mr. Williams said. "That's different from any other device."

But memristors will join a number of promising new memory technologies, some of which companies have worked on for years. For example, a joint venture called Numonyx that was recently formed by Intel Corp. and STMicroelectronics NV is betting on a technology called phase-change memory.

Edward Doller, chief technology officer of Numonyx, described the H-P paper as an interesting explanation of the behavior of some materials, but questioned whether it could have as broad an impact as technology his company is pursuing. "It doesn't really sound like a blazing new discovery in my mind," he said.

Mr. Chua, though, is enthusiastic about H-P's work. He had originally broached the idea of memristors by using a series of equations showing that in addition to the three known circuitry elements -- the capacitor, resistor and inductor -- there had to be another one with the property of memory. He once developed a prototype, but it was battery-powered and too large to be practical.

"I'm really excited, not so much because of the commercial applications now, but because to me, it's really a paradigm shift," Mr. Chua said. "It will wake up a lot of people."

Mr. Williams said H-P plans to work with chipmakers to get memristors into computers and hand-held devices. Wolfgang Porod, an engineering professor at the University of Notre Dame who's been briefed on the memristor paper, predicts it may take a decade before electronics companies figure out how to incorporate the technology.

"At this point, we see only a glimmer that a new kind of device like this may open new applications," Mr. Porod said.

http://online.wsj.com/article/SB120957501562556695.html?mod=googlenews_wsj

Hewlett-Packard Finds New Computer Memory Technology

Bloomberg, By Connie Guglielmo, 4/30/08

Hewlett-Packard Co. said its researchers proved the existence of a circuit that could let computers process information and store memory in a similar manner to the human brain.

Hewlett-Packard spent the past year and a half searching for proof of the concept -- called a memory resistor, or memristor -- which was first theorized 37 years ago. HP Labs researchers published their findings in today's edition of Nature, Palo Alto, California-based Hewlett-Packard said.

The discovery could lead to the development of memory chips that are smaller, consume less power and are less costly to make than the flash memory and dynamic random access memory chips used today, said R. Stanley Williams, who directs quantum science research at HP Labs. Such products may take five years to arrive.

``There's no new exotic materials and there's no extraordinarily complex structure like you've got in flash, which means the manufacturing expense will be lower," Williams said in an interview. ``Someone has to design the circuit and that's a nontrivial issue because today's circuit designs have evolved over decades and there's billions of dollars invested in them."

Hewlett-Packard, the world's largest personal-computer maker, fell 96 cents to $46.88 at 2:23 p.m. in New York Stock Exchange composite trading. The shares have declined 5.2 percent this year before today.

Origin of Idea

Leon Chua, an engineer at the University of California at Berkeley, came up with the concept of the memristor in the 1970s. He believed it was a fundamental circuit element with properties that couldn't be duplicated by any combination of the circuit's other three main pieces: the resistor, capacitor and inductor.

Hewlett-Packard researchers built a model that proved the validity of the mathematics behind Chua's research, Williams said. Memristors may lead to the development of memory chips that continue to retain information even after they lose power, something that today's DRAM chips can't do, Williams said. A memristor-based computer also wouldn't require booting up, something that wastes time and energy, he said.

The technology may help create systems for facial recognition and security that remember data and recognize patterns the same way the human brain does, Hewlett-Packard said.

HP Labs has built test chips and hopes to begin sharing its research with partners within the next few months. The first products to incorporate memristors will likely be memory chips for handheld devices, Williams said.

HP makes memory from a once theoretical circuit
CNET, By Michael Kanellos, 4/30/08

It's the tale of the lost circuit.

Thirty-seven years ago, Leon Chua, a professor at the University of California at Berkeley, mathematically theorized that scientific symmetry demands that there should be a fourth fundamental circuit. Engineers were already familiar with resistors (which resist the flow of electricity), capacitors (which store electricity), and inductors (which resist changes to the flow of electrical current), which can be combined to build more complex devices. The fourth circuit, which Chua called a "memristor" for memory resistor, would register how much current had passed.

"He looked at fundamental circuit equations and noticed there was a hole," said Stan Williams, who heads up the Information and Quantum Systems lab at HP Labs, "There should be a device that remembers how much current flowed through a device."

An atomic force microscope image of a circuit with 17 memristors in a row. The memristor consists of two titanium dioxide layers connected to wires. When a current is applied to one, the resistance of the other changes. That change can be registered as data.

Williams and other scientists at Hewlett-Packard are publishing a paper in Nature on Wednesday demonstrating that that these things actually exist. HP has a few discrete memristors as well as a silicon chip embedded with memristors. It's a first, according to HP.

If memristors can be commercialized, it could lead to very dense, energy-efficient memory chips. Scientists have made devices that function like memristors, but it took a good number of transistors and several capacitors, Williams said. Memristor chips would function like flash memory and retain data even after a computer is turned off, but require less silicon, consume less energy, and require fewer transistors.

A memristor effectively stores information because the level of its electrical resistance changes when current is applied. A typical resistor provides a stable level of resistance. By contrast, a memristor can have a high level of resistance, which can be interpreted as a computer as a "1" in data terms, and a low level can be interpreted as a "0." Thus, data can be recorded and rewritten by controlling current. In a sense, a memristor is a variable resistor that, through its resistance, reflects its own history, Williams said.

Varying resistance is the same principle at work with phase change memory. The difference in phase change memory, which will come to market later this year, is that changes in resistance are accomplished through a substantial amount of heating. A bit on a CD-like substrate is heated rapidly a few hundred degrees and then cooled. Depending on how rapidly the bit cools, the material becomes crystalline or amorphous. The different states--crystalline and amorphous--exhibit different states of resistance.

"We can get it (resistance changes) with less energy," Williams said. "It is a large amount of resistance change with a small amount of memory."

The secret sauce in HP's memristors is two layers of titanium oxide, a crystalline material consisting of one titanium atom and two oxygens, sandwiched between two metal wires. The bottom layer consists of standard, consistent titanium dioxide. The upper layer is missing a few oxygens--less than 1 percent--which creates voids. When a current is applied (via the wire) to the upper layer, the vacancies are pushed into the lower level of titanium dioxide. That changes the resistance of the lower level. Subsequent bursts of current can then reverse it.

"All we have to do is push around a very small number of vacancies in a crystalline material," Williams said. "We can switch it very fast, faster than we can measure."

Pushing the voids into the consistent layer of titanium dioxide does not change its characteristics otherwise. He likens it to bubbles in beer. "You can have bubbles in it, but it's still beer," he said.

Memristors in green. The wires in this image are 50 nanometers wide, which comes to about 150 atoms.

Memory and storage are the new frontier for chip designers. The explosion of data will require new ways to retrieve and store it. Cloud computing? It's a big hard drive, if you think about it. Numonyx, the Intel and STMicroelectronics joint venture, is leading the effort to commercialize phase change memory. IBM is working on ways to store data through magnetic charges on a wire. Seagate Technology, Hitachi, Zettacore, Grandis, and others are working on different memory and storage concepts.

HP has largely exited the chip business, but it has increased efforts to license the intellectual property inside its labs. The company, for instance, will likely try to commercialize the crossbar latch technology, which allows molecular grids to perform calculations. (Williams also works on that.)

While memristors can be made on silicon chips, memristor devices will require engineers to learn a new circuit design discipline.

"The technology is in good shape. The big barrier is not whether you can make it," Williams said. "It is the effort to design new circuits."

http://www.news.com/8301-10784_3-9932054-7.html?tag=nefd.lede

'Missing link' memristor created: Rewrite the text books?

EE Times, By R. Colin Johnson, 4/30/08

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 text books 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."

The virtues of hysteresis

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 hysteresis, whereby its rate of change accelerates as it moves from one state to the other--"on" to "off," or vice versa. Hysteresis has been explained away by current circuit theory as an anomaly, according to Chua and Williams, whereas its existence is, in fact, a fundamental property of passive circuitry.

"Hysteresis is a tell-tale manifestation of the fourth circuit element--the memristor," said Chua. "And Stan Williams is very smart to have realized that if you cannot explain something properly, then there must be a better explanation."

For instance, electrical engineers have known that titanium dioxide changes its resistance in the presence of oxygen--this is the principle behind titanium dioxide oxygen sensors--but they could not explain why.

"They traced its curve, and knew it contained hysteresis, but because they could not explain it, they could only design the simplest of devices using it--sensors," said Chua. "But now that it has been explained, they will be able to design all types of new circuitry using it. This is a wonderful development."

Chua predicts that electrical engineers will soon begin discovering all types of new materials that manifest the hysteresis relationship between flux and charge. He predicts that this new era of electronics will be able to solve the problems with scaling--such as using too much power and generating too much heat--that are currently plaguing progress in circuit design.

"The memristor is our salvation, because it works better and better as you make it smaller and smaller," said Chua. "The era of nanoscale electronics will be enabled by the memristor. This is not just an invention, it is a basic scientific discovery. It has always been there--we just had to face these nanoscale problems to realize its importance."

The memristor behaves like a non-linear resistor with memory--a small, compact and highly energy-efficient means of creating a memory device. But Chua and Williams claim it is also a new type of circuit element that should enable the creation of new devices never before imagined.

The world's first memristor invented at HP Labs by Williams and his research team is based on a two-layer sandwich of titanium dioxide films. As a memory element, it works by changing the atomic structure of the films--by coupling the motion of atoms in the material with the movement of electrons through the material. The bottom layer of HP's material uses a symmetrical lattice of titanium atoms and oxygen atoms, which makes it a good insulator. But the top layer has had oxygen vacancies introduced as a dopant, which makes it into a good conductor--the more vacancies, the more conductive. HP's secret sauce for creating these oxygen vacancies in titanium dioxide involves using sputter deposition that begins with an excess of oxygen, then cuts back on the oxygen flow to create the layer with vacancies.

By placing the crossbar of nanowires above and below the sandwiched layers, charge can be passed through the material. "The way I discovered the material for our memristor was by studying how titanium dioxide oxygen sensors work--that got me thinking about moving oxygen vacancies around in the material to create a memristor," said Williams. "By running current through the device, we can push oxygen vacancies from the layer that has them into the layer that does not, thereby changing its resistance by a factor of 1000 or even more, thus switching the memristor 'on,' then by reversing the current we can move the vacancies back into the first layer, thereby switching the memristor 'off'."

New era of devices

New era of devices As Chua predicted, Williams is already thinking about creating new types of devices with HP's crossbar architecture beyond a simple memory device. "If we push current through it hard and fast, it acts like a digital device, but if we run current through it gently and slowly it acts as an analog device," said Williams. "We are already designing new types of circuits in both the digital and analog domains using our crossbar architecture. In the analog domain, we want to build memristor-based devices that operate in a manner similar to how the synapse works in the brain--neuron-like analog computational elements that could perform control functions where decisions must be made involving comparisons as to whether something is larger or smaller than something else. We are not building a neural network yet, but we think that using the memristor in its 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.

http://eetimes.com/news/latest/showArticle.jhtml;jsessionid=OW0DJKEP4R0UIQSNDLSCKHA?articleID=207403521

Found: the missing circuit element
NatureNews, By Michael Hopkin, 4/30/08

High-school physics students grappling with the delights of capacitors, inductors and resistors will be groaning into their exercise books. Electronics experts in California have finally succeeded in proving the existence of a fourth fundamental unit of electronic circuits: the 'memristor'.

The existence of the memristor, short for 'memory resistor', was first suggested in 1971, but only now have researchers succeeded in creating a real, working example. They hope that the new components could revolutionize computing, promising an end to frustrating waits for your computer to boot up.

"A memristor is essentially a resistor with memory," explains Stan Williams of HP Labs in Palo Alto, California, who reports the memristor's creation in this week's Nature 1. "The actual resistance of the memristor changes depending on the amount of voltage and the time for which that voltage has been applied to the device."

That means that a computer created from memristive circuits can 'remember' what has happened to it previously, and freeze that memory when the circuit is turned off. This quality could allow computers to turn off and on again in an instant, as all the components could revert to their last state instantly, rather than having to 'boot up'.

Size problems

Williams and his colleagues created a memristor while experimenting with very tiny circuits. They sandwiched a nanoscopic film of a semiconductor (titanium dioxide) between two slivers of metal (platinum). Those are standard materials; the trick is to make the component just 5 nanometres wide — about 10,000 times thinner than a human hair.

It's only at the nanoscale that the behaviour of memristors begins to be detectable, Williams says. Any larger and they behave just like ordinary resistors, where resistance is equal to the voltage divided by the current. Electronics were originally developed at a scale far too large to see these effects and only recently have researchers been able to work at that scale.

That's probably one reason why the idea has smouldered on the shelf for 37 years, suggests Leon Chua, the electrical engineer at the University of California, Berkeley, who first postulated the existence of memristors in a 1971 paper2.

Six years after reading Chua's 1971 work, Williams and his team managed to make the tiny device. The scale of the project was not the only challenge. The mathematics underlying the principle were not simple, says Williams. "The original prediction and the papers in which the prediction appeared were very heavy mathematically, so it required a very significant investment in order to read those papers," he says.

Chua, somewhat modestly, disagrees, and thinks the idea may have struggled to find its feet simply because it is so weird. "It's not really that difficult — it is more that it is sort of heretical. Nobody would believe this was the case because it sounds unnatural in some sense."

Volatile discovery

Chua says that he is pleased that his theory has finally been proved. "I was very excited — I never thought I would live to see this happen."

Now that his calculations have been vindicated, he thinks that memristors will be a big deal. They should be crucial in developing 'non-volatile' memory — the type that doesn't decay when the power is switched off.

Most computers use 'volatile memory' to perform their running functions, because this offers faster access to data than the non-volatile memory used to store data on hard disks and flash devices such as iPods. Building computers with memristors might allow a full switch to non-volatile memory, doing away with power-sapping 'running memory' and allowing devices to consume far less power when operating. "Someday I imagine that you won't have to charge your cellphone or your laptop so often," says Chua.

But what of the poor high-school students who now have more to learn in their electronics classes? "I believe this is going to be in textbooks in the near future," Chua says. He says that the rounding out of his theory and creation of an actual memristor should make the concept easier to grasp than it was when he first proposed it. Struggling students might be more, shall we say, resistant to progress.

http://www.nature.com/news/2008/080430/full/news.2008.789.html

HP Discovers Potential "God Particle" of Electronics
PopSci.com, By Sean Captain, 4/30/08

Silicon Valley is mostly a world of practical technology—applying principles from pure science to create handy gadgets. But today, Hewlett Packard announced a new electrical component born of theoretical physics. The device, a nanoscale component called a "memristor," requires no power to retain data, which it can store more densely than a hard drive and access about as fast as a computer's RAM memory—potentially allowing it to replace both components in the future.

Memristors can function in either a digital mode, in which a memory cell is "on" or "off," or in analog mode, in which each cell holds some value in between. These values grow every time the cell receives an electrical signal, mimicking the way neurons in the brain build stronger memories the more they are stimulated.

The memristor was theorized in the early seventies by an electrical engineer name Leon Chua, but it took decades before anyone could prove it exists. The process was similar to particle physics, in which mathematicians first propose a particle and then experimenters eventually find it—or don't. (The hottest current example is the search for the theoretical Higgs boson, aka the "god particle.") Chua's mythical electrical component didn't show up until recently when HP researchers were studying the electrical properties of nanoscale materials and came upon a few that acted suspiciously like the memristor. After some refinements, they invented exactly what Chua theorized.

First PCs

It's a long path between proving something in the lab and selling it at Best Buy. Stan Williams, who leads the HP research team, expects memristors to first show up in the next few years as "cache" that sits between a hard drive and the DRAM memory in PCs. The hard drive could load key data, like the instructions to start up Windows, into the memristor cache, which can dump it into the DRAM far faster than transferring it straight from the hard drive—resulting in lightening-fast boot-ups and quick opening of large files.

But Williams has bigger plans to eventually replace both the hard drive and the RAM with one memory system that eliminates the need to store data on a relatively slow hard drive and then laboriously load it into fast DRAM before the PC can use it. He thinks a memristor can hold scads more data than a hard drive and access about as fast as DRAM. “You expand out both ways and try to eat the heart out of both the DRAM and the hard disk,” said Williams.

Then Androids?

Williams also wants to eat into the CPU. He says that many processes requiring fuzzy logic, like recognizing a face, are very hard to work out with that yes/no logic of a digital computer. But for an analog computer—like, say, the brain—it’s a piece of cake. So Williams proposes a CPU with multiple processing cores: Some digital for the number crunching that today's computers do so well, and others using analog memristors. Take facial recognition. Someone’s face can change from day to day, and definitely from year to year. But it’s not a drastic change that a yes/no digital system is good at figuring out. It’s a mild difference with some degree of change along a continuum that Williams says is perfect for an analog computer.

Could Williams take it even further—creating not just a PC that thinks a little more like a human, but an electronic mind that thinks exactly like one? “We’re not claiming we’re going to build a brain anytime in the next decade,” he says. But he’s not ruling it out for later on.

How it Works

The unlikely invention of the memristor took about 40 years. It started in the early 1970s when electrical engineer Leon Chua was looking at the interplay of electrical forces in the basic elements of circuits: resistors, capacitors and inductors. The same math that explained those three elements indicated that there should be a fourth, which he named the memristor (short for “memory resistor”) in a 1971 paper. A memristor would change its level of electrical resistance if charge were applied and retain or “remember” that resistance until another charge were applied. Like the Higgs boson “god particle,” the memristor made perfect sense on paper, but no one had ever seen one.

Not until the late 1990s, when researchers at Hewlett Packard Labs were studying the electrical properties of different nanotech materials and found several that looked pretty similar to Chua’s hypothetical memristor. Suspecting that Chua’s mythical circuit was real, HP researchers set out to invent one.

What they wound up with was deceptively simple: two layers of a semiconductor, titanium dioxide, sandwiched between electrodes. The bottom layer contains the standard material, which is virtually useless for conducting electricity. The top layer is missing a few oxygen atoms, creating positively charged “bubbles” that make it a conductor.

Running a positive charge through the electrode above this layer pushes some of the charged bubbles into the lower layer (where they stay, until another charge is applied), allowing it to conduct electricity and lowering the electrical resistance of the entire cell. A computer can read information in a memristor cell by measuring how much resistance it has.

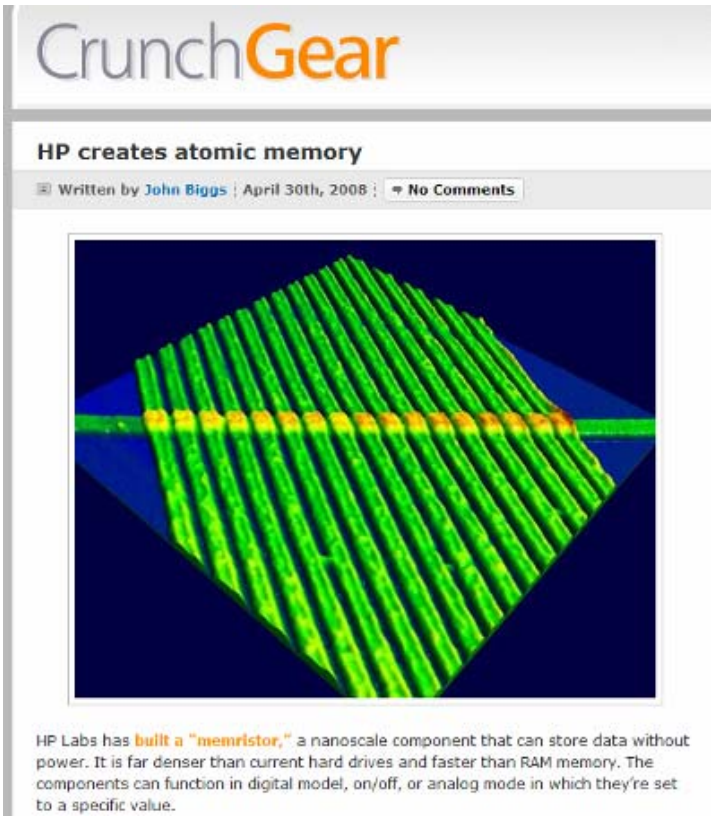
Hitting the cell with relatively big zaps switches it from high to low resistance levels that correspond to zero and one for digital data. Using less power can give it some resistance value in-between the extremes. And the results are cumulative. The more often you charge the cell, the

lower its resistance—in other words, the stronger its memory becomes. That matches the way neurons build stronger connections over time to make memories stronger (and explains why the more you practice something like piano, the better you get at doing it). Applying a negative charge to the top of the cell reverses the process—a lot of power switches a one to a zero in a digital system. Applying finer amounts of current causes a memory to fade.

HP's memristors are tiny, about 15 nanometers across. That allows them to store data about as densely as a hard drive—100 gigabits per square centimeter. But HP thinks it can get them far smaller—down to four or even two nanometers. Even at 4nm, a square centimeter of memristor can hold one terabit.

http://www.popsci.com/scitech/article/2008-04/hp-discovers-potential-god-particle-electronics

HP Creates Atomic Memory
CrunchGear, By John Biggs, 4/30/08



HP Labs has built a "memristor," a nanoscale component that can store data without power. It is far denser than current hard drives and faster than RAM memory. The components can function in digital model, on/off, or analog mode in which they're set to a specific value.

The unlikely invention of the memristor took about 40 years. It started in the early 1970s when electrical engineer Leon Chua was looking at the interplay of electrical forces in the basic elements of circuits: resistors, capacitors and inductors. The same math that explained those three elements indicated that there should be a fourth, which he named the memristor (short for "memory resistor") in a 1971 paper. A memristor would change its level of electrical resistance if

charge were applied and retain or “remember” that resistance until another charge were applied. Like the Higgs boson “god particle,” the memristor made perfect sense on paper, but no one had ever seen one.

Don’t expect these in your MacBook anytime this year. These things will take years to become usable in real applications.

http://www.crunchgear.com/2008/04/30/hp-creates-atomic-memory/

Engineers find 'missing link' of electronics
New Scientist, By Paul Marks, 4/30/08

Nanoscale circuits based on molecules used in sunscreen lotion have led to the discovery of the "missing link" of electronics engineering - a previously mythical device known as a "memristor".

First predicted in 1971, the memristor could help develop denser memory chips or even electronic circuits that mimic the synapses of the human brain, says Stan Williams who made the discovery with colleagues at Hewlett-Packard's lab in Palo Alto, California.

Since electronics was developed, engineers have made circuits using combinations of three basic elements - resistors, capacitors and inductors.

But in 1971, a young circuit designer called Leon Chua at the University of California, Berkeley, realised something was missing. He was toying with the non-linear mathematics that describes how the four variables in a circuit - voltage, current, charge and flux - behave in the three basic elements.

'Sheer genius'

The three building blocks each relate two of the four electronic properties of circuits, creating a chain linking charge to flux via voltage and current. But his calculations showed there should be a fourth device to directly link flux and charge.

"This was a stroke of absolute, sheer genius by Chua," says Williams. "He then worked through some complex mathematics and saw that such a device would have an unusual property: the ability to remember its past history."

Chua showed that his predicted device could remember the last voltage applied to it, and how long it had been applied. He dubbed the property "memristance" but the memristor was quietly forgotten because it was unclear how it could ever be built.

Sunblock circuits

But Williams' team has now done just that, using nanoscale circuits including molecules of the active ingredient of sunscreen - titanium dioxide.

Such circuits are used to try and use small clumps of molecules to store the binary 0s and 1s of charge to work as computer memory.

However, these efforts have been dogged by bizarre electronic effects, says Williams, who has now worked out the reason. His titanium dioxide works as a memoristor - the mythical device has been found.

Chua, now close to retirement, is thrilled at the finding. "This seminal work presents the first example of the memristor I postulated in 1971," he told New Scientist. "We can now expect many new unconventional applications, including super-dense memories and brain-like computing chips."

Electronic synapse

The way memristors handle current and voltage is startlingly similar to the way synapses between brain cells do, says Chua. Both build up voltage to a threshold before firing and letting a current pass.

Williams agrees. "The memristor equations do a very good job of modelling the known behaviour of synapses," he says.

He is now working to find which materials make the best memristors, and why it has only been seen so far in nanoscale devices. Williams then wants to attempt to build memristor-based memories, which will store information as resistance values and therefore need no power to hold on to the data.

http://technology.newscientist.com/article/dn13812-engineers-find-missing-link-of-electronics.html?DCMP=ILC-hmts&nsref=news2_head_dn13812

Down With The Transistor

Science News, By Davide Castelvecchi, 4/30/08

After going unchallenged for decades, the transistor's supremacy could come to an end. Researchers have demonstrated a new type of electronic component that could replace transistors as the building blocks of computer chips, and lead to faster, more powerful and less energy-thirsty computers.

Stanley Williams and his collaborators at HP Labs in Palo Alto, Calif., have created a surprisingly simple new device called a memristor. The device is a piece of an electric circuit with baggage: Its history determines its electrical resistance. Depending on the voltage that was recently applied to it, a memristor will switch from acting as an insulator ("off") to acting as a conductor ("on") and back.

This on-off capability offers engineers a way to build circuits that manipulate and store information. "All of a sudden, you have a new tool in your toolbox," Williams says. The most immediate advantage of memristors, Williams adds, is that they could be packed into chips up to 100 times more densely than transistors.

For decades, progress in electronics has relied on shrinking the features of computer chips, roughly doubling the number of transistors per chip every two years — a trend that has become known as Moore's law, after Intel cofounder Gordon Moore.

But engineers' ability to shrink transistor-based electronics is rapidly approaching physical limits, and Moore's law is expected to hit a hard wall in about 10 years. The memristor offers "an alternate way to continue progress," says Leon Chua, an electrical engineer at the University of California, Berkeley who first proposed the memristor concept in 1971.

Memristors could be shrunk to smaller sizes because they exploit the very physics that makes shrinking transistors hard. Transistors are built out of semiconducting materials. These semiconductors' electronic properties are finely tuned by adding small amounts of impurities called dopants. But voltages make dopant atoms move within a transistor. At nanometer scales, this effect is strong enough to change the semiconductor's properties and degrade performance, something that electrical engineers have so far seen as a nuisance.

Williams' team built the memristor by sandwiching a thin film of titanium dioxide between two platinum layers. Normally, titanium dioxide is an insulator. But applying a voltage between the platinum layers exerts a force on the film's oxygen atoms, pushing the atoms toward one side. As the atoms move, they leave behind gaps in the titanium dioxide's crystal structure. Such gaps create an imbalance in the crystal's distribution of electric charge, simulating the presence of positive ions. The gaps act like the dopants in a semiconductor, and move in the opposite direction as the oxygen atoms do.

Such gap doping turns titanium dioxide into a good conductor, so the memristor switches to "on." But if the voltage is reversed, the oxygen atoms go back to their places, turning the memristor back to "off," the researchers describe in the May 1 Nature.

In the past, researchers including Williams had simulated the behavior of a memristor using combinations of transistors, but this is the first "pure memristor," he says. He and his collaborators also showed last year that memristor-based devices can act like transistors and be used to process information.

Memristors also can store bits of data, representing a "1" in the on state and a "0" in the off state. And the data is not lost when the device is shut down, similar to the non-hard drive memory that's become ubiquitous in flash drives, cell phones and mp3 players. Williams says that his lab has already built prototypes of memristor-based computer memory that is tens of times more dense than current flash memory or even than state-of-the-art ordinary RAM.

Moreover, he says, inserting memristors into chips would not require substantial changes to current chip production methods, and so mass production should be feasible.

Chua says that while demonstrating memristors, the researchers' experiments also showed the limits of ordinary transistors, due to the migration of dopants. "They not only built a device. They showed that, as you get smaller and smaller, transistors are going to stop working."

http://www.sciencenews.org/view/generic/id/31637/title/Down_with_the_transistor

H-P Proves Theoretical Circuits, Theoretically

24/7 Wall St., By Jon C. Ogg, 4/30/08

Hewlett-Packard (NYSE: HPQ) has announced that researchers from its own research facility in HP Labs have proven the existence of the theoretical "fourth fundamental circuit element" in electrical engineering.

H-P said that this advancement could make it possible "to develop computer systems that have memories that do not forget, do not need to be booted up, consume far less power and associate information in a manner similar to that of the human brain."

Nature has the full report. More data can be found at H-P's dedicated site.

Keep in mind that this is a mathematical model, not a working prototype. It called it a physical example of a "memristor," the blend of "memory resistor."

Interestingly enough, it was just in the late-1990's when we were all using this new thing called Pentium when we were reading about micro-computing and multi-core processors being mainstream. In the early 1990's and late 1980's the promise was more desktop power than most supercomputers of the time, when many thought they'd never need a computer. They've supposedly been theorizing this since 1971.

Theory and science fiction have a way of converging into modern technology... if you are patient enough. All that matters here is this differential: Will this be HAL? or will it be Milla Jovovich?

http://www.247wallst.com/2008/04/h-p-proves-theo.html

HP "Memristors" Promise Memory Revolution
Electronista, 4/30/08

HP's Quantum Systems Labs today said it has proved the existence of a technology that could permanently alter the design approach of computers. Called a memory resistor, or a "memristor," the technology discovered by R. Stanley Williams differs from traditional resistors and other circuits by inherently storing the history of the information it receives. The unique property would let a computer effectively avoid a start-up process: as memory would always store its most recent state, computers could be instantly ready for use.

The breakthrough would also reduce power consumption by saving the need to reload data and could also lead to human-like learning processes, HP adds. As a computer could always trace the history of information across the entire system, it could better process information such as face detection or adapt to the user based on long-term experience.

Although memristors are currently an established theory, the development isn't expected to translate to a shipping product in the immediate future. However, the company already explains that memristor-based storage could replace typical volatile RAM in a computer or find its way into consumer electronics where instant response or adaptive behavior will be useful.

http://www.electronista.com/articles/08/04/30/hp.memristors/

Return to top

HP Labs

http://www.hpl.hp.com/news/2008/apr-jun/memristor.html

Demystifying the memristor:
Proof of fourth basic circuit element could transform computing

By Jamie Beckett, April 2008

Researchers at HP Labs have solved a decades-old mystery by proving the existence of a fourth basic element in integrated circuits that could make it possible to develop computers that turn on and off like an electric light.

The memristor — short for memory resistor - could make it possible to develop far more energy-efficient computing systems with memories that retain information even after the power is off, so there's no wait for the system to boot up after turning the computer on. It may even be possible to create systems with some of the pattern-matching abilities of the human brain.

A mathematical model and a physical example that prove the memristor's existence appear in a paper published in the April 30 issue of the journal Nature.

"To find something new and yet so fundamental in the very mature field of electrical engineering is a big surprise," said R. Stanley Williams, an HP Senior Fellow and director of the Information and Quantum Systems Lab (IQSL).

* Fundamental circuit element

The memristor first appeared in a 1971 paper published by Professor Leon Chua, a distinguished faculty member in the Electrical Engineering and Computer Sciences Department of the University of California Berkeley.

Chua described and named the memristor, arguing that it should be included along with the resistor, capacitor and inductor as the fourth fundamental circuit element. The memristor has properties that cannot be duplicated by any combination of the other three elements.

Although researchers had observed instances of memristance for more than 50 years, the proof of its existence remained elusive - in part because memristance is much more noticeable in nanoscale devices. The crucial issue for memristance is that the device' atoms need to change location when voltage is applied, and that happens much more easily at the nanoscale.

Proving memristor in the lab

Williams and co-authors Dmitri B. Strukov, Gregory S. Snider and Duncan R. Stewart were able to formulate a physics-based model of a memristor and build nanoscale devices in their lab that demonstrate all of the necessary operating characteristics to prove that the memristor was real.

"This is an amazing development," Chua says. "It took someone like Stan Williams with a multi-disciplinary background and deep insights to conceive of such a tiny memristor only a few atoms in thickness."

Williams has a background in physical chemistry. Strukov is a theoretical physicist, Snider is a computer architect and Stewart is an experimental physicist.

Possible replacement for D-RAM

By providing a mathematical model for the physics of a memristor, the team makes possible for engineers to develop integrated circuit designs that take advantage of its ability to retain information.

"This opens up a whole new door in thinking about how chips could be designed and operated," Williams says.

Engineers could, for example, develop a new kind of computer memory that would supplement and eventually replace today's commonly used dynamic random access memory (D-RAM). Computers using conventional D-RAM lack the ability to retain information once they are turned off. When power is restored to a D-RAM-based computer, a slow, energy-consuming "boot-up" process is necessary to retrieve data stored on a magnetic disk required to run the system.

Memristor-based computers wouldn't require that process, using less power and possibly increasing system resiliency and reliability. Chua believes the memristor could have applications for computing, cell phones, video games - anything that requires a lot of memory without a lot of battery-power drain.

Brain-like systems?

As for the human brain-like characteristics, memristor technology could one day lead to computer systems that can remember and associate patterns in a way similar to how people do.

This could be used to substantially improve facial recognition technology or to provide more complex biometric recognition systems that could more effectively restrict access to personal information.

These same pattern-matching capabilities could enable appliances that learn from experience and computers that can make decisions.

Nanoscale electronics experience

In the memristor work, the researchers built on their extensive experience - Williams founded the precursor lab to IQSL in 1995 - in building and studying nanoscale electronics and architectures.

One goal of this work has been to move computing beyond the physical and fiscal limits of conventional silicon chips. For decades, increases in chip performance have come about largely by putting more and more transistors on a circuit. Higher densities, however, increase the problems of heat generation and defects and affect the basic physics of the devices.

"Instead of increasing the number of transistors on a circuit, we could create a hybrid circuit with fewer transistors but the addition of memristors - and more functionality," Williams says. Alternately, memristor technologies could enable more energy-efficient high-density circuits.

In 2007, the team developed an architecture for such a hybrid chip using conventional CMOS technology and nanoscale switching devices.

"What we now know," Williams says, "is that these switches have a name - memristor."

The memristor could lead to far more energy-efficient computers with some of the pattern-matching abilities of the human brain.