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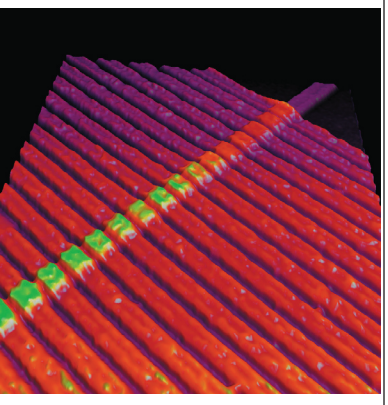
INTELLIGENCE
THE FUTURE OF COMPUTING



*An atomic force microscope image of a 17 memristor circuit. Memristors are expected to enhance neural nets and other technologies. **H-P**.*

WHAT'S NEXT IN CIRCUITS: TRANSISTOR REPLACEMENTS

Memristors from Hewlett-Packard - IBM, Intel Back Phase Change

The future of chip technology is poised to head off in at least two major new directions. Recent discoveries and refinements are moving the memristor into a place where it is often cited as the "next" transistor. Most recently, in an article published in *Nature*, **Hewlett-Packard** Laboratories researchers demonstrate that memristors, a fourth basic element in integrated circuits (capacitor, inductor, and resistor), are capable of performing logic as well as memory functions.

But other technologies, some based on new and novel materials, form a competing strategy known as phase change. As "An Emergent Change of Phase for Electronics," in *Science* notes: "Correlated electrons in transition metal oxides can form a variety of electronic phases. The phase change between these various states gives rise to novel device functions, including sensing, signal conversion, and nonvolatile memory, and is now at the frontier of research on 'emergent research device materials.' Those oxide devices may have an advantage over conventional semiconductor devices for added functionality and future downsizing to the nanoscale." And, the first phase change memory chip products are now appearing on the market, from companies such as **Samsung**. Both of

continued on 2

Editorial Insights and Implications: Why the iPad Will Foment Changes in Computing

The iPad's Transitions: Ubiquity; Lean Back; Touch. Speech, Video?

As I held an **Apple** iPad in my hand for the first time, this month, I realized that this light weight device has the potential to foment some changes in the future of computing and communications. And, I'm not the only one who foresees big and disruptive changes as a result of this electronic device becoming a mass market item and spawning other similar mass market devices. Several members of the press, media and computing community have already given their prognostications about what the iPad will bring. The new iPad also has its shortcomings, which, unless corrected, may inhibit its influence in the market.

Much of the discussion about the iPad has centered on what I think of as relatively short horizon business issues. E.g., will the iPad replace the Kindle and what effect will that have on **Amazon**? Will tablets replace netbooks? Laptops? Etc. But the real meat issues of what I believe the iPad holds in store

continued on 8

these approaches offer exciting new paths to the future of computing and communications devices.

The memristor (a contraction of 'memory-resistor') and devices based on memristors were first predicted to exist in 1971, by Leon Chua of the U of California, Berkeley. But it was not until 2008, when researchers, led by Stan Williams at H-P Labs, showed that memristors could exist beyond theory and began creating them. Williams, et al, lay out the significance of their latest work in their *Nature* paper:

"The authors of the International Technology Roadmap for Semiconductors—the industry consensus set of goals established for advancing silicon integrated circuit technology—have challenged the computing research community to find new physical state variables (other than charge or voltage), new devices, and new architectures that offer memory and logic functions beyond those available with standard transistors.

"Recently, ultra-dense resistive memory arrays built from various two-terminal semiconductor or insulator thin film devices have been demonstrated. Among these, bipolar voltage-actuated switches have been identified as physical realizations of 'memristors' or memristive devices, combining the electrical properties of a memory element and a resistor. Such devices… are characterized by one or more state variables that define the resistance of the switch depending upon its voltage history. Here we show that this family of nonlinear dynamical memory devices can also be used for logic operations.

"Incorporated within an appropriate circuit, memristive switches can thus perform 'stateful' logic operations for which the same devices serve simultaneously as gates (logic) and latches (memory) that use resistance instead of voltage or charge as the physical state variable."

And: "the memristive switches both store logic values and perform logic operations. The same nanoscale switches can be dynamically defined to be either logic gates or memory latches, so memristive IMP [i.e., 'material implication,' a logic function] can be embedded within a nanoscale crossbar array to perform logic using the memory cells themselves."

What this may mean in the future was summed up in a list by Tom Foremski at *ZDNet.com*:
• "The memristor can store data like DRAM or Flash but it doesn't require any energy to maintain the data storage.

• Memristor chips can be laid down in layer upon layer upon layer, creating three-dimensional structures that can store and process data.

• Memristors are easy to make and completely compatible with today's CMOS chip making processes.

• Memristors can be scaled to very small geometries without losing their properties.

• The memristor can also perform logic, it can act as a microprocessor!"

H-P's Williams told *The New York Times*: ""Not only do we think that in three years we can be better than the competitors, the memristor technology really has the capacity to continue scaling for a very long time, and that's really a big deal."

The H-P memristors, however, still require connections with silicon-based components and, as the H-P Labs *Nature* paper concludes: "Applications of this technology will most likely require substantial parallel operations in order to amortise any silicon-based driving circuitry. The devices themselves are capable of fast (nanoseconds) and low-energy (picojoules) switching, but further research will be required at the device, circuit and architecture levels to determine the practical utility of this approach."

The article: "An Emergent Change of Phase for Electronics," by Hidenori Takagi (U of Tokyo & RIKEN Advanced Science Institute) and Harold Y. Hwang (U of Tokyo), was published

in a special issue of *Science* covering "Materials for Electronics." Takagi and Hwang conclude: "Because of the presence of a rich variety of competing electronic phases, devices based on correlated transition metal oxides emerge as a rich playground for development. They have in principle advantages in device scaling because correlated oxides have essentially metallic electron densities, even in their insulating phases. This should help ensure a sufficient number of carriers in a nanoscale device to avoid the limits of density fluctuations, which are becoming increasingly important in conventional semiconductor devices.

…"The basic issues to be resolved include the impurity and interfacial states formed in correlated insulators and metals, in which many-body effects may require qualitatively distinct physics. …we do not yet know down to what length-scale electronic phases and their transitions can be reasonably defined. Recent work using scanning tunneling microscopy indicates the presence of strong phase variations over a few nanometers. This is enticing in showing that a pathway to ultra-small correlated oxide devices based on phase changes exists."

IBM, Intel and other companies are convinced that phase change is a technology that can see current applications in new kinds of chips.

In a "Perspective" paper in that same *Science* issue, two IBM researchers, Thomas N. Theis and Paul M. Solomon, declare: "It's Time to Reinvent the Transistor!" They begin: "Have you noticed that computers have stopped getting faster? Microprocessor clock frequencies plateaued around 2005, a stunning break after a decades-long run of ever-compounding improvements in computing speed." The result: …"unsupportable increases in power dissipation and heat generation. The transistor is rapidly approaching its ultimate physical limits."

Another article in the section on materials, "Oxide Interfaces—An Opportunity for Electronics," by J. Mannhart (U of Augsburg, (Germany) and D. G. Schlom (Cornell) further plumbs the environment for creating oxide interfaces for devices in the future: "Extraordinary electron systems can be generated at well-defined interfaces between complex oxides."

NEWS & NOTES

FOLLOW-UPS: NEWS ROUND-UP: Again this past month, several of the stories previously reported on in **INTELLIGENCE** have seen recent developments. A summary of some of these events and reports follows:

• **BROADBAND**: The US FCC (Federal Communications Commission) lost a court case, on a 'net neutrality' principle, to the cable company **Comcast**. Despite that decision, Julius Genachowski, FCC chair, said that the FCC would continue with its plans for a national broadband initiative that it made public last month. *The Washington Post* reported that: "the FCC will begin the long process of creating regulations out of its national broadband plan, starting with a half-dozen policy inquiries and proposed rules.

• **GOOGLE**: In addition to its purchase of **Agnilux**, replete with ex-**PA Semi** employees, fresh from underpaid stints at **Apple** (see above, **EDITORIAL**), **Google** made the news this month, in part, over attacks that took place on Google servers last year from China. Reporting in *The New York Times*, John Markoff noted: "a person with direct knowledge of the investigation now says that the losses included one of Google's crown jewels, a password system that controls access by millions of users worldwide to almost all of the company's Web services, including e-mail and business applications. The program, code named Gaia for the Greek goddess of the earth, was attacked in a lightning raid taking less than two days last December, the person said. Described publicly only once at a technical conference four years ago, the [Gaia] software is intended to enable users and employees to sign in with their password just once to operate a range of services."

• **WEBCAMGATE**: School officials of the Lower Merion, PA, school district claimed that they had only initiated surveillance on 42 occasions. Now it has been revealed that during those instances, thousands of pictures were taken of students by their laptop computer cameras, which were remotely activated to make photos by school officials. *Slashdot.org* reported that: "One of the key administrators involved has been answering all questions about the program by invoking the Fifth Amendment."

• **PRINTING CELLS**: *Reuters* reported this month: "Inspired by a standard office inkjet printer, researchers at Wake Forest U (Winston-Salem, NC) have rigged up a device that can spray skin cells directly onto burn victims, quickly protecting and healing their wounds as an alternative to skin grafts. Tests on mice showed the spray system, called bioprinting, could heal wounds quickly and safely."

TRAFFIC: Ericsson reported that, for the first time, mobile data traffic surpassed voice traffic, worldwide.

NETS & BOTS

GOING TO CHURCH: In the 1950s and '60s, artificial-intelligence researchers saw themselves as trying to uncover the rules of thought. But those rules turned out to be way more complicated than anyone had imagined. Since then, artificial-intelligence (AI) research has come to rely, instead, on probabilities — statistical patterns that computers can learn from large sets of training data.

The probabilistic approach has been responsible for most of the recent progress in artificial intelligence, such as voice recognition systems, or the system that recommends movies to **Netflix** subscribers. But Noah Goodman, an MIT research scientist whose department is Brain and Cognitive Sciences but whose lab is Computer Science and Artificial Intelligence, thinks that AI gave up too much when it gave up rules. By combining the old rule-based systems with insights from the new probabilistic systems, Goodman has found a way to model thought that could have broad implications for both AI and cognitive science.

As a research tool, Goodman has developed a computer programming language called Church (named after the great American logician Alonzo Church) that, like the early AI languages, includes rules of inference. But those rules are probabilistic. E.g., "Told that the cassowary is a bird, a program written in Church might conclude that cassowaries can probably fly. But if the program was then told that cassowaries can weigh almost 200 pounds, it might revise its initial probability estimate, concluding that, actually, cassowaries probably can't fly."

While Church programs work well on targeted tasks, they're currently too computationally intensive to serve as general-purpose mind simulators.

NETS & GRIDS

SEE: **Follow-ups, above: BROADBAND: FCC**.

NANO

NEW TRANSISTORS?: See PAGE ONE.

Editorial Insights and Implications: Why the iPad Will Foment Changes in Computing

(continued from 8)

lightness and dexterity of use of the iPad may well enable it to become just such a "take everywhere" device.

I'm not the only observer seeing an Apple video future. Late this month, *ComputerWorld* reported: "Ezra Gottheil [**Technology Business Research**] thinks that Apple is ready to make a major move into video, and based his bet on a series of clues in the company's upcoming hardware, as well as the $1 billion [Apple] data center in North Carolina that's now hiring personnel. …Gottheil: 'makes sense if Apple is going to push into video conferencing, video social network or video social gaming. Apple is the kind of company that could make that a big deal'"

The iPad will certainly be used, in both home and work environments, the way no computing device has in the past. Because it is so light, it is easy to pass around, to casually invite someone over to share what its contents display and provide.

David Carr, media columnist of *The New York Times*, said on the "Charlie Rose" TV program that while he sat in bed with his wife, he didn't want to watch the movie she had on their TV. So, he took out his iPad, plugged in headphones, placed the iPad on his lap and watched a movie of his choice.

Other users have been charmed by the iPad as well. The iPad works, and works well, a testament to what has made Apple a powerhouse in computing, music playing, buying and storage, as well is mobile telephony. These successes are due to Apple and its leader, Steve Jobs, ability to focus and accomplish a near complete integration of hardware, systems and software.

Over the past two years, articles have appeared with regularity questioning whether this (e.g., **RIM** Blackberry, **Google** Anrdroid, **Microsoft**, et al) model is the iPhone killer. To date, no iPhone killer model of a mobile phone has yet appeared, much less moved to market domination. This is because other computer and communications companies have neither the desire, the focus nor the expertise to integrate their machines and the software they run. Apple works hard on such integration and it shows in their products like, Mac computers, iPod music systems, iPhones and now the iPad.

But, the iPad is by no means a "perfect" machine. Despite its light, one-and-one-half pound weight, the iPad is too heavy to hold in one hand for long periods of time. More importantly, the iPad is not a full computer, not even in the way netbooks are full computers. Though it can run hundreds of thousands of apps (applications), designed for it and for the iPhone, it cannot run many programs that people are used to running on computers, at home and at business.

Apple provides, at an inexpensive price, three important function programs: for word processing, spreadsheet creation and presentation creation, and these programs documents, etc., can be saved in standard, Microsoft, formats, like Word, Excel and PowerPoint. But, when using other apps, choices become more limited. Sometimes simple computing tasks, like saving a file, or going back on a process, are either unavailable or counter-intuitively provided.

The iPad display is beautiful, bright and clear, and is enhanced by the machine's overall design. And, if the newly revealed iPhone 4 prototype is any indication, future models of the iPad may well have both two cameras and a higher resolution screen: a 960 x 640 display.

I was particularly surprised that Apple chose to use screens for the iPad from standard Taiwan-based suppliers, but eschewed use of the amazing screens from **PixelQi**. That company's screens can do both epaper-style display, visible in sunlight, as well as the bright colorful displays that we've all come to expect from contemporary LCD screens.

Many were surprised that Apple did not choose standard chips, but, instead, chose to design and have fabricated its own chip as the basis for the iPad. Some observers speculate that the next version of the iPhone may also include a chip designed by Apple, like the iPad's A4 chip.

This chip capability came, in part, from Apple's 2008 acquisition of **PA Semi**. N.B., several founders of that company have since left Apple for start-up **Agnilux**. And, this month: "*peHUB* has

learned that Google recently acquired Agnilux, which previously held strategic investment talks with companies like **Cisco**, Microsoft and **Texas Instruments**."

Apple's penchant for smaller chip companies continued, *The New York Times* reported, when, last month, Apple purchased Austin, TX-based **Intrinsity**. "Tom R. Halfhill, an analyst with *Microprocessor Report*, said he believed the acquisition price was $121 million." Intrinsity's Hummingbird is said to be at the core of several features and functions of the iPad's A4 chip. Intrinsity has worked with **Samsung**, the company that manufactured the A4 chip for Apple. *Ars Technica* reports: the "A4 was fabbed on Samsung's 45nm SoC process" and has more detail about the A4 and Intrinsity (http://arstechnica.com/apple/news/2010/04/apple-purchase-of-intrinsity-confirmed.ars).

The press has this month been full of reviews of the iPad that range from raves lauding the new system, to itemized lists of why not to buy an iPad. More than 500,000 iPads had been sold near the end of this month and that's before the 3G iPad has even gone on sale. Also this month, Apple revealed its plans to developers for the iPad and the iPhone's next, 4.0 operating system and indicated that multitasking (the lack of which caused the most iPad complaints) will be available on the iPad starting next fall.

Here is some of what I found to be the most cogent commentary on the iPad: • Tim O'Reilly (**O'Reilly Media**), in the *Times*: "If the iPhone didn't tell us that the 25-year reign of the mouse and windows user interface popularized by that original Macintosh was soon to be over, the iPad shouts it loud and clear. …But the iPad signals more than the end of the PC era. It signals that the App Store, the first real rival to the Web as today's dominant consumer application platform, isn't going to be limited to smartphones. It signals that App Store-based e-commerce may replace advertising as the favored model of startup entrepreneurs. It signals that cheap sensors are ushering in an era of user interface innovation."

• Steven Johnson (author of five books +: http://www.stevenberlinjohnson.com/) in *Wired*: "With the arrival of the tablet, we have crossed a critical threshold: Where text is concerned, we effectively have infinite computational resources, connectivity, and portability. For decades, futurists have dreamed of the "universal book": a handheld reading device that would give you instant access to every book in the Library of Congress. In the tablet era, it's no longer technology holding us back from realizing that vision; it's the copyright holders. Advances in technology will give us plenty of headroom with other kinds of data: streaming real-time video, conjuring virtual spaces, exploring real-world environments with geocoded data, modeling complex systems like weather."

• Kevin Kelly (www.kk.org/) in *Wired*: "Don't think of them as tablets. Think of them as windows that you carry. Two things distinguish them from always-on smartphones and lightweight laptops. First, these are mobile screens, meant to move. They are aware of where they are in space and time. Hold a window up in front of you and you see an alternative view of the scene. Maybe you see annotated layers or a view from long ago. If someone is speaking to you through the window, move the screen and it will sweep across the caller's room. This portable portal will peer into anything visible. You'll be able to see into movies, pictures, rooms, Web pages, places, and books seamlessly.

"Many people think of this sheet as a full-color, hi-res, super ebook reader, but this viewer will be about moving images as much as text. Not just watching video but making it. It will have a built-in camera and idiot-proof video-editing tools, and it will also serve as a portable movie screen, eventually enabled for 3-D. You'll "film" with the screen! It will remake both book publishing and Hollywood, because it creates a transmedia that conflates books and video. You get TV you read, books you watch, movies you touch."

Much of the attention given to the iPad has centered on its potential role to act as a "savior" for print media, especially books, newspapers and

magazine. The "Charlie Rose" television show (now seen on both **PBS** and **Bloomberg TV**) has featured several interviews and discussions this month about the iPad, including the program with *The Wall Street Journal*'s Walt Mossberg and the *Times*' David Carr, that I referred to, above.

Another of the "Charlie Rose" programs featured Ken Auletta, who had written a story about the iPad and publishers in *The New Yorker* this month. Auletta, in that article and on TV, noted that book publishers were thrilled when Apple's iPad offered them an alternative to dealing with Amazon. Amazon controls over 80% of all past ebook sales and was selling all ebooks at a fixed price of $9.99 each, and at a loss. Since Amazon's Kindle ebook reader cannot display color or multimedia, Auletta speculated to Rose that Amazon may have to update the Kindle in the future to compete with the iPad.

The ebook market appears to be entering a phase of important competition, with Amazon, Apple, **Barnes & Noble, Sony** and, soon, Google, and a host of others, marketing ebooks, ebook reading devices and ebook stores and services. Amazon currently has over 460,000 ebooks, while Apple has only 100,000. Google is expected to debut an ebook system this summer with perhaps as many as 12 million ebooks. To date, Amazon has been unwilling to reveal how many ebooks it has sold nor to share information about those sales with the ebook publishers. Auletta noted that book publishers are now concerned about what will happen to bookstores in the age of the ebook.

Thinking about this issue, it seems to me that bookstores will have to follow an analogous path that books have taken in transforming into ebooks. Book publishers are now rushing to develop new, and refurbish existing books, into ebook editions that feature color, animations, web linking and a variety of other einnovations. Bookstores might well have to molt into ebookstores, offering screens as well as shelves, in order to make their way in the future. Authors are changing, too: check out Ander Monson's new book, *Vanishing Point*, and the web site he connects to its print edition: http://otherelectricities.com/vp/

With newspaper and magazines, the role of the iPad is not quite as clear as with books. In the rush to be free on the Internet, newspapers and magazines, depending on an advertising-supported business model that was ransacked by the Recession in 2008, provided much of their content free on the net. Recently they have seen the appearance of the iPad as a hope that it will provide publishers with a platform for them to, once again charge for their content.

As a result, and encouraged by Apple (Steve Jobs made a rare recent trip to New York City to discuss the iPad with *The New York Times, The Wall Street Journal* and *Time* magazine), many magazines have made special 'apps' for their magazines on the iPad. As publisher **Axel Springer**'s Chair, Mathias Döpfner, told Charlie Rose: If everything on the net has to be free, that's "web communism" and he went on to describe three or four business models for net content: free, pay-per-click, subscription and advertising supported, as well as combinations.

Also interviewed by Rose was Alan Rusbridger, the Editor of UK-based *The Guardian*, though with 37 million looking at that newspaper's web version (www.guardian.co.uk/) every month, it may be more based in cyberspace than real space. Rusbridger loves the iPad, saying its ease of use, great display and book-based size allow it to carry on some 400 years of "book" history. He believes the iPad and its brethren advance us toward a new media age: "There's a lot to be frightened of, but there's an awful lot to like about this media revolution."

N.B., as I go to press (29 April), Apple's purchase of San Jose, CA-based **Siri** was announced. *The Register* cites *Business Insider* for a sale price of $150 million, and has a video demo of the Siri speech recognition-driven (from **Nuance**) web search app for Apple's iPhone, that Siri now gives away free. (http://www.theregister.co.uk/2010/04/29/apple_siri/ & http://siri.com/)

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Editorial Insights and Implications: Why the iPad Will Foment Changes in Computing

continued from 1

are more far reaching. E.g., I see the iPad responsible for several fundamental transitions in the ways we communicate and the ways in which we use computational power. E.g., for many functions one uses the iPad sitting back, not leaning forward, as one does when using a computer. This move, from close up to arm's length, signals a transformation in the way computing and communication devices will have to be designed and created in the future.

Another iPad transition is the way you use it. The iPad moves users away from using a mouse to a haptic, touch-based user interface. This move changes more than a quarter-century of computing practice. As with other iPad changes, it is not that the iPad is making use of touch as something brand new. Touch and motions have been in many devices (e.g., **Nintendo**'s Wii game machine, etc.,) for some time. What the iPad does, in the instance of using touch, is to recontextualize this interface and make it seem natural and fully integrated with both the iPad hardware and its software.

And, this touch transition, eventually, will lead to a far more profound change: the move away from using a mouse and keyboard to interact with a "computer," toward an interface that will simply and naturally combines both touch and speech recognition.

The transitions I've already cited could, perhaps, in combination, enable, I hope, the full integration of video communications into many people's everyday communications. You can tell I'm hedging my prediction here. That's because I've touted "the next coming of video" in these pages far too often over the years. But I can dream.

My dreams could become reality if future versions of the iPad contain two cameras, one for shooting pictures and video and the other, on the other side of the device, for iChat/video conferencing. There have been rumors, and photos of iPad frames, that seem to indicate that the, or a next iPad model will have at least one, if not two cameras. The iPhone already has one camera, and the recent version of the next, 4.0 iPhone sports just such a two camera set-up. With Apple's iChat, pervasive video communications may finally be on the horizon.

iPad and iPhone models equipped with this two camera configuration, I believe, would hasten what I see as another of the iPad's transitional potentials: ubiquity. So far, though perhaps billions have computers, and even laptops, until smart phones, especially the iPhone, came to market, there was no computing device that users would take virtually everywhere with them. The

continued on 4