Some Breakthroughs in Nanoelectronics in the Last Decade

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Abstract- Various research groups have contributed in taking electronics from the present micro level to a new nano level, which is needed for reducing the size of electronic devices and making them perform at a faster speed with an improved efficiency. The research groups have succeeded in making molecular level transistors, junction-less transistors, memory transistor (eliminating need for capacitor), trigate transistors (at Intel), faster graphene transistors (at IBM) and organic transistors (NOMFET). There are also attempts to invent technologies for fabrication of nanobased integrated circuits using concept of magnetic dots (at UCLA), nanowires (at Weizmann Institute), carbon nonotubes (at Stanford University). Researchers are working to print nanolevel circuits with inkjet printers using silver ink (at Pennsylvania) and on flexible plastics (at North Carolina State University) which may lead to flexible motherboards, mobiles and laptops. Attempts are also being made for designing nanolevel circuits with less power consumption and faster heat dissipation. Then research groups at West Lafayette and Motorola are working for better displays and monitors with sharper and intense output imaging using Nanowire and Carbon Nanotube technologies. Research groups have also succeeded in improving Random Access Memories MRAM (at University of Illinois, Chicago), MeRAM (at UCLA), NRAM (at Imec and Nantero) and hard disks (Race Track Memory with thousand times more storage capacity) at IBM. Researchers are also working on silicon nanophotonics and on spectrally purer laser for bringing speed in data transmission. These all research innovations and ideas are a leap forward by science and are worth being discussed for any future research in electronics.

Keywords:, 3D nanotube circuits, C60, flexible circuits, Graphene, magnetic quantum dots, MeRAM, NOMFET, NRAM, nanoglue, silicon nanophotonics, single molecular transistor, S-DFB laser, OLEDs, race track memory

INTRODUCTION

Researchers are using nanoelectronics to increase the capabilities of electronics devices, reduce their weight and power consumption. Some of the nano electronics areas, which are being explored in detail, can be introduced as follows.

A. REDUCTION IN SIZE: Smaller circuit means faster execution and data transmission. Various research groups are working to build nano level circuits. The researchers, for example, at university of Alberta [1] have constructed a single molecule transistor. A team of researchers led by Prof. Jean-Pierre Colinge at the Tyndall National Institute have reported the design and fabrication of the world's first junction less transistor in Nature [2]. Researchers at Center for Nanoscience and Nanotechnology, Tel Aviv University have reported [3] building a sophisticated memory transistor, with carbon C60 molecules, which is capable to both transfer and store energy, eliminating the need for a capacitor. Intel has developed [4] a fundamentally different technology to construct Tri-Gate transistor 3D transistors of size ~ 22 nm. IBM reported [5] the world's Fastest Graphene Transistor, which can be utilized to produce high performance devices and integrated circuits. Researchers at Georgia Institute of Technology have created graphene p-n junctions [6] by transferring films of the promising electronic material to substrates that have been patterned by compounds that are either strong electron donors or electron acceptors. CNRS and CEA researchers have developed a transistor [7] that can mimic the main functionalities of a synapse. This organic transistor, based on pentacene and gold nanoparticles and is known as a NOMFET (Nanoparticle Organic Memory Field-Effect Transistor), has opened the way to new generations of neuro-inspired computers. The researchers in Munich laboratories of Infineon Technologies AG (FSE/NYSE: IFX), in an efforts to create smaller and more powerful structures for integrated circuits, have constructed the world's smallest nanotube transistor, with a channel length of only 18 nm [8].

B. IMPROVEMENT IN FABRICATION OF CIRCUITS: There are attempts to improve the technology used in the fabrication of circuits for the electronic devices. Researchers at University of California, Los Angeles (UCLA) and Intel Corporation have created advanced 'magnetic quantum dots', a futuristic semiconductor technology that will pave the way for the next generation of electrical and information technology systems [9]. A team led by Prof. Ernesto Joselevich of the Weizmann Institute's Materials and Interfaces Department [10] have successfully created self-integrating nanowires whose position, length and direction can be fully controlled. They then succeeded in creating a transistor from each nanowire on the surface, producing hundreds of such transistors simultaneously. The nanowires were also used to create a more complex electronic component – a functioning logic circuit called an Address Decoder, an essential constituent of computers. A team of Stanford engineers have built [11] a basic computer using carbon nanotubes that runs faster and uses lesser energy than those made from silicon chips. The researchers, at Stanford [12] designed a chip with the most advanced computing and storage elements, made of carbon nanotubes to date, by devising a way to root out the stubborn complication of nanotubes that cause short circuits. Five members of the team (Wei, Patil, Lin, Wong and Mitra) immediately followed up the VMR paper at IEDM with another presentation [13] describing the first multilayer carbon nanotube three-dimensional integrated circuit. Like multilevel parking garages, three-dimensional circuits allow for packing of more units – in this case, transistors – into a confined area. A team of researchers, led by Professor Cherie Kagan, from the University of Pennsylvania, showed [14] that nanoscale particles, or nanocrystals, of the semiconductor cadmium selenide can be "printed" or "coated" on flexible plastics high-performance electronics. Researchers from Georgia Tech, the University of Tokyo and Microsoft Research have developed a novel method to rapidly and cheaply make electrical circuits by printing them with commodity inkjet printers and off-the-shelf materials [15]. Dr. Yong Zhu and his coworkers in North Carolina State University have developed highly conductive and elastic conductors made from silver nanowires, which can be used to develop stretchable electronic devices [16]. Scientists at the Lockheed Martin Space System Advanced Technology Center (ATC) in Palo Alto developed a revolutionary nanotechnology copper-based electrical interconnect material, or solder that can be processed around 200 °C. Once fully optimized, the CuantumFuse™ solder material is expected to produce joints with up to 10 times the electrical and thermal conductivity compared to tin-based materials currently in use [17].

C. INCREASING THE SPEED OF DATA TRANSMISSION: Researchers are integrating silicon nanophotonics components into CMOS integrated circuits and are producing new lasers that help produce the light with much tighter frequency control than previously achieved. This may allow much higher data rates for information transmission over fiber optics. IBM (NYSE: IBM) announced a major advance [18] in the ability to use light instead of electrical signals to transmit information for future computing. The breakthrough technology – called "silicon nanophotonics" – allows the integration of different optical components side-by-side with electrical circuits on a single silicon chip using, for the first time, sub-100nm semiconductor technology. The researchers [19] recently achieved unprecedented spectral purity as a direct consequence of the incorporation of a nano scale corrugation within the multilayered structure of the laser. The purer the tone, the more information it can carry.

D. REDUCTION IN POWER CONSUMPTION: UC Berkeley researchers reported [20] to have exploited the special properties of the rare, heavy metal tantalum magnets, as an alternative to transistors because they require far less energy for switching. A team of interdisciplinary researchers at Rensselaer Polytechnic Institute [21] has developed a new method of boosting the heat transfer rate across two different materials with a "nanoglue", which is useful for cooling computer chips and lighting-emitting diode (LED) devices, collecting solar power, harvesting waste heat, and other applications.

E. BUILDING BETTER DISPLAYS: We can improve the display screens on electronic devices in terms of their reduced power consumption, decreased weight and thickness. West Lafayette ind. – Engineers created the first "active matrix" display [22] using a new class of transparent transistors made of "nanowires" and circuits - a step toward realizing applications such as e-paper, flexible color monitors and "heads-up" displays in car windshields. The applied research arm of Motorola Inc. developed [23] a working 5-inch color video display prototype based on proprietary Carbon Nanotube (CNT) technology – a breakthrough technique that will create large, flat panel displays with superior quality, longer lifetimes and lower costs than current offerings.

F. BETTER MEMORY UNITS - RAM AND HARD DISKS: Researchers are developing a type of memory chip with a projected density of one terabyte of memory per square inch or greater. A team of researchers at University of Illinois at Chicago [24] has demonstrated that nanometer-sized permalloy rings, shaped into tiny rectangles, can store and access data almost instantly. The finding brings closer by one step the commercial reality of a promising form of memory called MRAM. The team of researchers at UCLA's Henry Samueli School of Engineering and Applied Science has also developed an improved memory [25], which they call MeRAM for magneto electric random access memory, which uses electric voltage instead of a flowing electric current. MeRAM is an ultra-fast, high-capacity class of computer memory and has a great potential to be used in future memory chips for almost all electronic applications. Team of researchers at IBM [26] developed what they dubbed as "racetrack" memory, which combines the high performance and reliability of flash drives with the low cost and high capacity of the hard disk drive. Imec, a world-leading research institution in nanoelectronics and Nantero, Inc., a nanotechnology company [27] will develop the carbon-nanotube-based memory, which can be a high-density next-generation memory NRAM with a size under 20nm. The detailed review of these remarkable research works is as follows.

DISCUSSION

REDUCTION IN SIZE: Smaller circuit means faster execution and data transmission. Various research groups are working to build nano level circuits. There are research groups which are working for the miniaturization of transistors. It is possible to "put the power of all of today's present computers in the palm of hand" and it is all due to nanoelectronics. The efforts of these groups can be summarized as below:

Building a Single molecule transistor Researchers at the University of Alberta [1] constructed an electronic circuitry on a molecular scale, a breakthrough that will remove the limitations of conventional transistor technology and will pave the way for smaller, faster, cheaper microelectronic devices. The team shows that a single molecule can be controllably charged, with all the surrounding molecules remaining neutral, causing it to act as a basic transistor. Transistors control the flow of current in most electronic devices and are combined to form integrated circuits used to make the microprocessors and memory chips that drive everything from computers and cell phones to household appliances. But where conventional transistors might use a million electrons to switch a current, the team was able to control the current through a hydrocarbon molecule using a single atom. The transistor, has three terminals - an 'in,' and 'out,' and a control outlet. Although, the transistor developed by the team has a control, but it's very sluggish and slow right now. It takes the order of a minutes to change conditions that make current go or not. Therefore, so for any computer technology, this thing is today impractical. But it is not hopeless. There are many hurdles, but there are not any we see as insurmountable.

In fact, the research team has already cleared what appeared to be insurmountable obstacle in manipulating molecules measuring one one-billionth of a metre in size. It is very hard to connect wires to a molecule. This is trying to bring three watermelons together all to touch something the size of a poppy seed. You could not do it - you could make two watermelons touch a poppy seed, and even that would be kind of difficult, holding that poppy seed in place. But then to bring in the third watermelon is impossible - you cannot have all three touching such a small object. To solve this problem, the "transistor" molecule was placed on a silicon surface that has been exposed to hydrogen gas, so that each silicon atom was capped with a hydrogen atom. By removing the hydrogen cap from single silicon atom, that silicon atom can be made to conduct a charge while the surrounding atoms remaining neutral. The tip of a powerful scanning tunneling microscope serves as the on/off switch.

Practical nanoscale transistors may be decades away but the potential to create smaller, faster, more efficient electronic devices with minimal energy and material requirements is a powerful incentive to pursue this line of research. The group is studying switching, routing, and signal processing using nanostructure devices that operate on principles different from scaled conventional transistors, including devices incorporating layers of organic molecules and reduced metal oxides.

Tyndall breakthrough to revolutionize microchip manufacturing; the world's first junction less nanowire transistor

A team of researchers led Prof. Jean-Pierre Colinge at the Tyndall National Institute have reported [2] in Nature Nanotechnology the design and fabrication of the world’s first junction-less transistor, that can revolutionize microchip manufacturing. It significantly reduces power consumption and greatly simplifies the fabrication process of silicon chips.

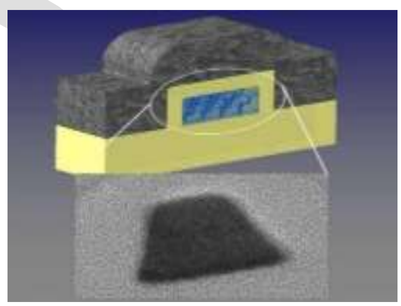

Fig.1. Junction less nanowire transistor successfully fabricated and tested at Tyndall National

The transistor is the fundamental building block in all electronic devices. Since the early seventies the number of transistors in a silicon chip has grown from a few hundred to over two billion transistors on a single chip today. The exponential increase in demand for feature packed electronic devices is driving the semiconductor industry to produce chips that need to be smaller, more energy efficient and more cost effective than ever before. As a consequence transistors are becoming so small that conventional transistor architectures, used since the seventies, can no longer be used. Current technologies require fabrication processes that are both complex and costly. All existing transistors are based on junctions. A junction is formed when two pieces of silicon with different polarities are placed side by side. Controlling the junction allows the current in the device to be turned on and off and it is the precise fabrication of this junction that determines the characteristics and quality of the transistor and is a major factor in the cost of production. Tyndall National Institutes ground breaking junction-less transistor does not require a junction. The current flows in a very thin Junction-less silicon nanowire and the flow of current is perfectly controlled by a `wedding ring` structure that electrically squeezes the silicon wire in the same way that you might stop the flow of water in a hose by squeezing it. These structures are easy to fabricate even on a miniature scale which leads to the major breakthrough in potential cost reduction. The Tyndall junction-less devices have near ideal electrical properties and behave like the most perfect transistors. Moreover, they have the potential of operating faster and using less energy than the conventional transistors used in today’s microprocessors. The credit for fabricating the junction-less transistor, which resembles in a way the first ideal transistor structure, proposed in 1925, goes to the skill and expertise of researchers who were able to fabricate silicon nanowire with a diameter of a few dozen atoms using electron-beam writing techniques.

Carbon-Based Transistors Ramp Up Speed and Memory for Mobile Devices

Mobile devices like smart phones and tablets are the computing devices of the post-personal-computer (Post-PC) era, and are hailed as the hardware of the future. However, their present-day incarnations have some flaws. These devices, which are small and battery operated, are quickly closing the gap with their laptop or desktop ancestors in terms of computing power and storage capacity — but they are lacking in RAM, the run-time memory reserves that computers need to operate various programs. Because current RAM technology is power-hungry and physically large, it doesn't function well in mobile devices. That's where laptops and PC's retain the edge. Low RAM memory limits the number of applications that can be run at one time and quickly consumes battery power. The idea of a sophisticated transistor, which can do the job of both the transistor and the capacitor, was a technological dream — until now. Elad Mentovich and his supervisor Dr. Shachar Richter of Department of Chemistry and Center for Nanoscience and Nanotechnology, Tel Aviv University have reported [3] a creative solution to these well-known problems. As silicon technology gets smaller, creating a large and powerful memory grows harder. They have successfully built a sophisticated memory transistor with carbon molecules called C60, that can both transfer and store energy, eliminating the need for a capacitor. This molecular memory transistor, which is as small as one nanometer, stores and disseminates information at high speed — and it is ready to be produced at existing high-tech fabrication facilities. The basis of the technology has been published in the journal Advanced Materials and Applied Physics Letters. Year 2012 was the first in which big technology companies sold more tablets and smartphones than laptops and notebooks combined. The memory of smartphones and tablets will approach the level of a laptop with this new technology. It will be possible to run applications simultaneously, and because it is low voltage, power consumption will fall and battery life will be longer. The next step is to find a fabrication facility with the necessary materials to manufacture the transistors. The benefit of this product is that with the right equipment, which is standard in high-tech facilities and breakthroughs on how to put the transistors together, these molecular memories can be manufactured anywhere. Therefore, the distance to implementation is not far.

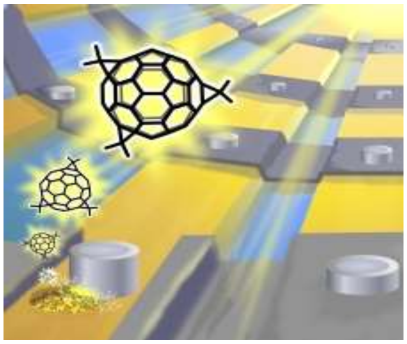

Fig.2. Carbon C60 molecules used to successfully fabricate sophisticated memory transistor

3D, 22 nm: New Technology Delivers an Unprecedented Combination of Performance and Power Efficiency

It is better to have smaller and more power efficient transistor. Intel reports [4] a fundamentally different technology to construct Tri-Gate transistor 3D transistors of size ~ 22 nm. Intel continues to predictably shrink its manufacturing technology in a series of "world firsts": 45 nm with high-k/metal gate in 2007; 32 nm in 2009; and now 22 nm with the world's first 3D transistor in a high volume logic process beginning in 2011.This technology will help to relentlessly pursue Moore's Law and to ensure the pace of the technological advancement. Transistor size and structure are at the very center of delivering the benefits of Moore's Law to the end user. With a smaller, 3D transistor, Intel will design even more powerful processors with incredible power efficiency. The new technology will enables innovative micro architectures, System on Chip (SoC) designs, and new products – from servers and PCs to smart phones, and innovative consumer products. Intel's 3D Tri-Gate transistor uses three gates wrapped around the silicon channel in a 3D structure, enabling an unprecedented combination of performance and energy efficiency. Intel designed the new transistor to provide unique ultra-low power benefits for use in handheld devices, like smart phones and tablets, while also delivering improved performance normally expected for high-end processors. The new transistors are so impressively efficient at low voltages that they allow the Intel® Atom™ processor design team to innovate new architectural approaches for 22 nm Intel® Atom™ micro architecture. Intel's future SoC products based on the 22 nm 3D Tri-Gate transistors will hit sub 1 mW idle power—for incredibly low-power SoCs.

IBM Scientists Demonstrate World's Fastest Graphene Transistor

Graphene is a single atom-thick layer of carbon atoms bonded in a hexagonal honeycomb-like arrangement. This two-dimensional form of carbon has unique electrical, optical, mechanical and thermal properties and its technological applications are being explored intensely. A key advantage of graphene lies in the very high speed, with which electrons propagate, which is required in high-speed and high-performance next generation transistors. IBM showed [5] that graphene can be utilized to produce high performance devices and integrated circuits. The high frequency operation was achieved using wafer-scale, epitaxially grown graphene, using processing technology compatible to that which is used in advanced silicon device fabrication.

Uniform and high-quality graphene wafers were synthesized by thermal decomposition of a silicon carbide (SiC) substrate. The graphene transistor itself utilized a metal top-gate architecture and a novel gate-insulator stack involving a polymer and a high dielectric constant oxide. The gate length was modest, 240 nanometers, leaving plenty of space for further optimization of its performance by scaling down the gate length. It is noteworthy that the frequency performance of the graphene device already exceeds the cut-off frequency of state-of-the-art silicon transistors of the same gate length (~ 40 GigaHertz). This performance was obtained from devices based on graphene obtained from natural graphite, and suggests that that still better performance can be obtained from graphene of different origins.

Field-Effect Transistors: Self-Assembled Monolayers Create P-N Junctions in Graphene Films

The electronic properties of graphene films are directly affected by the characteristics of the substrates on which they are grown or to which they are transferred. Researchers are taking advantage of this to create graphene p-n junctions– which is essential to fabricate devices – by transferring films of the promising electronic material to substrates that have been patterned by compounds that are either strong electron donors or electron acceptors. A low temperature, controllable and stable method has been developed to dope graphene films using self-assembled monolayers (SAM) that modify the interface of graphene and its support substrate. The team of researchers at the Georgia Institute of Technology [6] uses this concept to create graphene p-n junctions without damaging the lattice structure of the material or significantly reducing electron/hole mobility. The graphene was grown on a copper film using chemical vapor deposition (CVD), a process that allows synthesis of large-scale films and their transfer to desired substrates for device applications. The graphene films were transferred to silicon dioxide substrates that were functionalized with the self-assembled monolayers. Putting graphene on top of self-assembled monolayers uses the effect of electron donation or electron withdrawal from underneath the graphene to modify the material’s electronic properties.

Creating n-type and p-type doping in graphene – which has no natural bandgap – has led to development of several approaches. Earlier scientists substituted nitrogen atoms for some of the carbon atoms in the graphene lattice, compounds were applied to the surface of the graphene, and the edges of graphene nano-ribbons were modified. However, most of these techniques have disadvantages, including disruption of the lattice – which reduces electron mobility – and long-term stability issues. Any time graphene is put into contact with a substrate of any kind, the material has an inherent tendency to change its electrical properties. However in this study, this was done in a controlled way and was used to make the material predominately n-type or p-type. This could create a doping effect without introducing defects that disrupt the material’s attractive electron mobility. Using conventional lithography techniques, the researchers created patterns from different silane materials on a dielectric substrate, usually silicon oxide. The materials are chosen because they are either strong electron donors or electron acceptors. When a thin film of graphene is placed over the patterns, the underlying materials create charged sections in the graphene that correspond to the patterning. The researchers were able to dope the graphene into both n-type and p-type materials through an electron donation or withdrawal effect from the monolayer which does not lead to the substitutional defects observed in many of the other doping processes. The graphene structure itself is still pristine as it comes to us in the transfer process. The monolayers are bonded to the dielectric substrate and are thermally stable up to 200 degrees Celsius with the graphene film over them. The team used 3-Aminopropyltriethoxysilane (APTES) and perfluorooctyltriethoxysilane (PFES) for patterning. In principle, however, there are many other commercially-available materials that can also create the patterns. The researchers used their technique to fabricate graphene p-n junctions, which was verified by the creation of field-effect transistors (FET). Characteristic I-V curves indicated the presence of two separate Dirac points, which indicated an energy separation of neutrality points between the p and n regions in the graphene. The real goal is to find ways to make graphene at lower temperatures and in ways that allow us to integrate it with other devices, either silicon CMOS or other materials that do not tolerate the high temperatures required for the initial growth. Therefore, this study shows us that graphene can be used as a useful electronic or opto-electronic material at low temperatures and in patterned forms.

An organic transistor paves the way for new generations of neuro-inspired computers

CNRS and CEA researchers have developed a transistor [7] that can mimic the main functionalities of a synapse. This organic transistor, based on pentacene and gold nanoparticles and known as a NOMFET (Nanoparticle Organic Memory Field-Effect Transistor), has opened the way to new generations of neuro-inspired computers, capable of responding in a manner similar to the nervous system. The development of new information processing strategies consists in mimicking the way biological systems such as neuron networks operate, to produce electronic circuits with new features. In the nervous system, a synapse is the junction between two neurons, enabling the transmission of electric messages from one neuron to another and the adaptation of the message as a function of the nature of the incoming signal (plasticity). For example, if the synapse receives very closely packed pulses of incoming signals, it will transmit a more intense action potential. Conversely, if the pulses are spaced farther apart, the action potential will be weaker. It is this plasticity that the researchers have succeeding in mimicking with the NOMFET. A transistor, the basic building block of an electronic circuit, can be used as a simple switch - it can then transmit, or not, a signal - or instead offer numerous functionalities (amplification, modulation, encoding, etc.). The innovation of the NOMFET resides in the original combination of an organic transistor and gold nanoparticles. These encapsulated nanoparticles, fixed in the channel of the transistor and coated with pentacene, have a memory effect that allows them to mimic the way a synapse works during the transmission of action potentials between two neurons. This property therefore makes the electronic component capable of evolving as a function of the system in which it is placed. Its performance is comparable to the seven CMOS transistors (at least) that have been needed until now to mimic this plasticity. The devices produced have been optimized to nanometric sizes in order to be able to integrate them on a large scale. Neuro-inspired computers produced using this technology, are capable of functions comparable to those of the human brain. Unlike silicon computers, widely used in high performance computing, neuro-inspired computers can resolve much more complex problems, such as visual recognition.

Infineon develops 18nm Channel Length Nanotube Transistor

The researchers in Munich laboratories of Infineon Technologies AG (FSE/NYSE: IFX), in an efforts to create smaller and more powerful structures for integrated circuits, have constructed the world's smallest nanotube transistor, with a channel length of only 18 nm [8]. The most advanced transistors currently in production are almost four times this size. The researchers build nano transistor by growing carbon nanotubes, each one measuring only 0.7 to 1.1 nm in diameter, in a controlled process. A single human hair is around 100,000 times thicker by comparison. The carbon nanotubes can carry electrical current virtually without friction on their surface as a result of "ballistic" electron transport and can therefore handle conduction 1000 times more than copper wire. This characteristic properties of carbon nanotubes make them the ideal material for many applications in microelectronic. Also they can be both conducting and semiconducting. Infineon is one of the pioneers in developing carbon nanotubes and was the first semiconductor company to demonstrate how the tubes can be grown at precisely defined locations and how transistors for switching larger currents can be constructed. The nanotube transistor just unveiled can deliver currents in excess of 15 µA at a supply voltage of only 0.4 V (0.7 V is currently the norm). A current density of some 10 times above that of silicon, today's standard material, has been observed. On the basis of the test results, Infineon researchers are confident that they can go on miniaturizing transistors at the same rate as previously. Even supply voltages as low as 0.35 V, which are according to the ITRS currently not expected before the year 2018, will be realized with carbon nanotubes used as the material.

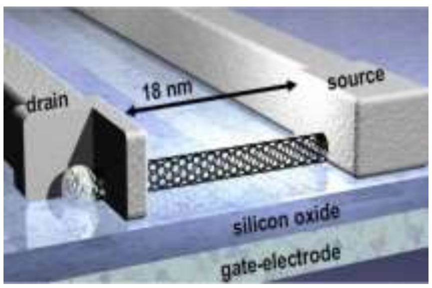

Fig.3. 18nm channel length smallest nanotube transistor developed at Infineon

IMPROVEMENT IN FABRICATION OF CIRCUITS: There are also attempts to improve the technology used in the fabrication of circuits for the electronic devices. Research works in this direction, worth mentioning are as follows;

Novel material paves the way for next-generation information technology

Professor Jin Zou and Dr Yong Wang from the Faculty of Engineering, Architecture and Information Technology have collaborated with the University of California, Los Angeles (UCLA) and Intel Corporation to create advanced 'magnetic quantum dots', a futuristic semiconductor technology that paves the way for the next generation of electrical and information technology systems. The breakthrough research was published in prestigious scientific journal Nature Materials [9]. The magnetic quantum dots simultaneously utilise both 'charge' and 'spin' – two types of outputs generated by electrons. Magnetic quantum dot technology is expected to underpin future communications and resolve power consumption and variability issues in today's microelectronics industry by providing computers and other devices with extraordinary electrical and magnetic properties. Developing quantum dots which are able to harness both outputs will help to significantly reduce the size of electrical devices and reduce power dissipation inherent in electrical systems, because the collective spins in spintronics devices are expected to consume less energy than current charge-based technology. The novel technology was proven even in experiments at relatively high temperature, which was not previously thought possible. This research is expected to lead to greater efficiency and stability for electrical systems and information technology, which provide essential infrastructure for every sector.

Guided Growth of Nanowires Leads to Self-Integrated Circuits

Researchers working with tiny components in nanoelectronics face a challenge similar to that of parents of small children: teaching them to manage on their own. The nano-components are so small that arranging them with external tools is impossible. The only solution is to create conditions in which they can be "trusted" to assemble themselves. Much effort has gone into facilitating the self-assembly of semiconductors, the basic building blocks of electronics, but until recently, success has been limited. Scientists had developed methods for growing semiconductor nanowires vertically on a surface, but the resultant structures were short and disorganized. After growing, such nanowires need to be "harvested" and aligned horizontally. Since such placement is random, scientists need to determine their location and only then integrate them into electric circuits. A team led by Prof. Ernesto Joselevich of the Weizmann Institute's Materials and Interfaces Department has managed to overcome these limitations and have, for the first time, successfully created self-integrating nanowires whose position, length and direction can be fully controlled. The achievement, reported in the Proceedings of the National Academy of Sciences (PNAS), USA, [10] is based on a method developed by Prof. Joselevich two years ago for growing nanowires horizontally in an orderly manner. First, the scientists prepared a surface with tiny, atom-sized grooves and then added to the middle of the grooves catalyst particles that served as nuclei for the growth of nanowires. This setup defined the position, length and direction of the nanowires. They then succeeded in creating a transistor from each nanowire on the surface, producing hundreds of such transistors simultaneously. The nanowires were also used to create a more complex electronic component – a functioning logic circuit called an Address Decoder, an essential constituent of computers. The method makes it possible, for the first time, to determine the arrangement of the nanowires in advance to suit the desired electronic circuit. The ability to efficiently produce circuits from self-integrating semiconductors opens the door to a variety of technological applications, including the development of improved LED devices, lasers and solar cells.

Stanford engineers build basic computer using carbon nanotubes

A team of Stanford engineers have, a semiconductor material reported in an article [11] published on the cover of the journal Nature, to have built a basic computer using carbon nanotubes (CNTs) which are long chains of carbon atoms extremely efficient at conducting and controlling electricity. CNTs has the potential for a new generation of electronic devices that run faster, while using lesser energy, than those made from silicon chips.. They are so thin – thousands of CNTs could fit side by side in a human hair – and it takes very little energy to switch them off. In theory, this combination of efficient conductivity and low-power switching make carbon nanotubes excellent candidates to serve as electronic transistors. Firstly, the challenge was to grow CNTs in straight lines, as with billions of nanotubes on a chip, even a tiny degree of misaligned tubes causes errors. Secondly, depending on how the CNTs grow, a fraction of these carbon nanotubes end up behaving like metallic wires that always conduct electricity, instead of acting like semiconductors that can be switched off. Since mass production is the eventual goal, researchers had to find ways to deal with misaligned and/or metallic CNTs without having to hunt for them like needles in a haystack. There has to be some way to design circuits without having to look for imperfections or even know where they were.

The authors describe a two-pronged approach called "imperfection-immune design." The researchers switched off all the good CNTs and pumped the semiconductor circuit full of electricity. Therefore the electricity got concentrated in the metallic nanotubes, which grew so hot that they burned up and literally vaporized into tiny puffs of carbon dioxide. This sophisticated technique eliminated the metallic CNTs in the circuit. However, bypassing the misaligned nanotubes requires even greater subtlety. The Stanford researchers created a powerful algorithm that maps out a circuit layout that is guaranteed to work no matter whether or where CNTs might be askew. This 'imperfections-immune design' [technique] makes this discovery truly exemplary. The Stanford team used this imperfection-immune design to assemble a basic computer with 178 transistors, a limit imposed by the fact that they used the university's chip-making facilities rather than an industrial fabrication process. Their CNT computer performed tasks such as counting and number sorting. It runs a basic operating system that allows it to swap between these processes. In a demonstration of its potential, the researchers also showed that the CNT computer runs MIPS, a commercial instruction set developed in the early 1980s by then Stanford engineering professor and now university President John Hennessy.

New Stanford techniques make carbon-based integrated circuits more practical: 3-D nanotube circuits

The researchers, at Stanford built a small chip with the most advanced computing and storage elements, made of carbon nanotubes [12], by devising a way to root out the stubborn complication of nanotubes that cause short circuits. This new technique, which the researchers believe to be VLSI (very large scale integration) -compatible Metallic Nanotube Removal (VMR), is based upon an idea first proposed by Paul Collins and colleagues at IBM in 2001, to break up the nanotubes by exposing them to high current. The Stanford team has now made the idea practical on a VLSI scale by creating a grid of electrodes that zap away the unwanted nanotubes. The same electrode grid can then be etched to produce any circuit design, including ones that make use of the Stanford-developed techniques mentioned above. Five members of the same team (Wei, Patil, Lin, Wong and Mitra) immediately followed up the VMR paper at IEDM with another presentation [13] describing the first multilayer carbon nanotube three-dimensionally integrated circuit. Like multilevel parking garages, three-dimensional circuits allow for packing of more units – in this case, transistors – into a confined area. On chips, the third dimension can also reduce the lengths of some interconnecting wires, reducing energy required for data transmission. While engineers have recently begun making progress in building three-dimensional circuits by stacking and connecting layers made with conventional materials, the Stanford work shows it can be done with nanotubes in a way that is integrated from the start as a 3-D design, yielding a higher density of connections among layers. Indicating that progress is possible with nanotubes, a prototype three-layer chip functioning as logic gates was constructed with dozens of nanotube transistors connected through nanotube and metal wiring. This used a relatively low-temperature process in which nanotubes were transferred from a quartz wafer onto a silicon chip. A remaining challenge is to increase the number of nanotubes that can be properly patterned on a given area of a chip, to allow for making the millions of transistors that modern designs require.

Penn Researchers Make Flexible, Low-voltage Circuits Using Nanocrystals

Electronic circuits are typically integrated in rigid silicon wafers, but flexibility opens up a wide range of applications. In a world, where electronics is becoming more pervasive, flexibility is a highly desirable trait, but finding materials with the right mix of performance and manufacturing cost remains a challenge.

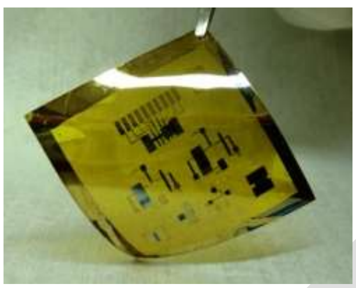

Fig.4. Flexible circuit fabricated at University of Pennsylvania

Researchers at University of Pennsylvania [14], showed that nanoscale particles, or nanocrystals of the semiconductor cadmium selenide can be "printed" or "coated" on flexible plastics to form high-performance electronics. They made a performance benchmark in amorphous silicon, which is the material that runs the display in our laptops, among other devices and showed that cadmium selenide nanocrystals devices can move electrons 22 times faster than in amorphous silicon. Besides speed, another advantage cadmium selenide nanocrystals have over amorphous silicon is the temperature at which they are deposited. Whereas amorphous silicon uses a process that operates at several hundred degrees, cadmium selenide nanocrystals can be deposited at room temperature and annealed at mild temperatures, opening up the possibility of using more flexible plastic foundations. The new aspect of their research was to use ligands that can translate very easily onto the flexible plastic; other ligands are so caustic that the plastic actually melts. Because the nanocrystals are dispersed in an ink-like liquid, multiple types of deposition techniques can be used to make circuits. The researchers, in this study, used spin-coating, in which centrifugal force pulls a thin layer of the solution over a surface and the nanocrystals can be applied through various techniques such as dipping, spraying or ink-jet printing as well.

On a flexible plastic sheet a bottom layer of electrodes was patterned using a shadow mask — essentially a stencil — to mark off one level of the circuit. The researchers then used the stencil to define small regions of conducting gold to make the electrical connections to upper levels that would form the circuit. An insulating aluminum oxide layer was introduced and a 30-nanometer layer of nanocrystals was coated from solution. Finally, electrodes on the top level were deposited through shadow masks to ultimately form the circuits. In words of Prof. Kagen, "The more complex circuits are like buildings with multiple floors. The gold acts like staircases that the electrons can use to travel between those floors". Using this process, the researchers built three kinds of circuits to test the nanocrystals performance for circuit applications: an inverter, an amplifier and a ring oscillator. With the combination of flexibility, relatively simple fabrication processes and low power requirements, these cadmium selenide nanocrystal circuits paves the way for new kinds of devices and pervasive sensors, which could have biomedical or security applications.

Georgia Tech Develops Inkjet-Based Circuits at Fraction of Time and Cost

Researchers from Georgia Tech, the University of Tokyo and Microsoft Research developed a novel method to rapidly and cheaply make electrical circuits by printing them with commodity inkjet printers and off-the-shelf materials [15]. For about $300 in equipment costs, anyone can produce working electrical circuits in the 60 seconds the time it takes to print the circuit. The technique, called instant inkjet circuits, allows the printing of arbitrary-shaped conductors onto rigid or flexible materials and can advance the prototyping skills of non-technical enthusiasts and novice hackers. This introduces a new approach to the rapid prototyping of fully custom-printed circuits and unlike existing methods for printing conductive patterns, the conductivity in this technique emerges within a few seconds and without the need for special equipment. The researchers used silver nanoparticle ink based on recent advances in chemically bonding metal particles, to print the circuits and avoided techniques like thermal bonding, or sintering which are time-consuming and potentially heat damaging techniques. The circuits were printed on resin-coated paper, PET film and glossy photo paper works best. Researchers also made a list of materials to avoid, such as canvas cloths and magnet sheets. The method can be used to print circuit boards, sensors and antennas with little cost, and it opens up many new opportunities. To make the technique possible, researchers optimized commercially available tools and materials including printers, adhesive tape and the silver ink. Designing the circuit itself was accomplished with ordinary desktop drawing software, and even a photocopy of a drawing can produce a working circuit. Once printed, the circuits can be attached to electronic components using conductive double-sided tape or silver epoxy adhesive, allowing full-scale prototyping in mere hours. The homemade circuits might allow thinkers to quickly prototype crude calculators, thermostat controls, battery chargers or any number of electronic devices. A single-sided wiring pattern for an Arduino micro controller was printed on a transparent sheet of coated PET film. This technology can be used in the classroom, to introduce students to basic electronics principles very cheaply, and they can use a range of electronic components to augment the experience. The researchers demonstrated the capabilities of the new technique for capacitive touch sensing - the interaction prominent in Smartphone interfaces - and the flexibility of the printed circuits at ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp 2013) in Zurich, Switzerland, Sept. 8-12. They attached a capacitive ribbon with embedded inkjet-printed circuits into a drinking glass. The capacitive ribbon sensor, when connected to a micro controller, was able to measure the level of the liquid left in the glass.

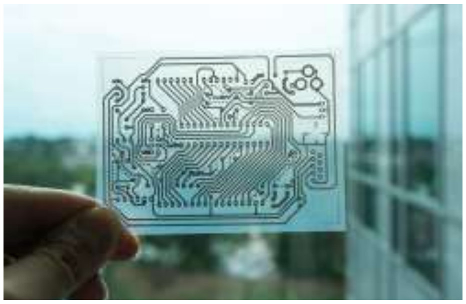

Fig.5. A single-sided wiring pattern for an arduino micro controller was printed on a transparent sheet of coated PET film

Researchers Create Highly Conductive and Elastic Conductors Using Silver Nanowires

Dr. Yong Zhu and his coworkers in North Carolina State University developed [16] highly conductive and elastic conductors made from silver Nanowires, which can be used to develop stretchable electronic devices. Stretchable circuitry can do many things that its rigid counterpart cannot. For example, an electronic “skin” could help robots pick up delicate objects without breaking them, and stretchable displays and antennas could make cell phones and other electronic devices stretch and compress without affecting their performance. However, it requires producing conductors which are elastic and able to effectively and reliably transmit electric signals regardless of whether they are deformed. Silver has very high electric conductivity, meaning that it can transfer electricity efficiently. The new technique embeds highly conductive silver nanowires in a polymer that can withstand significant stretching without adversely affecting the material’s conductivity. This makes it attractive as a component for use with broad range of applications in stretchable electronic devices. The study focuses on high and stable conductivity under a large degree of deformation, complementary to most other works using silver nanowires that are more concerned with flexibility and transparency. The fabrication approach is very simple. The silver nanowires are placed on a silicon plate and the liquid polymer is poured over the silicon substrate. The polymer is then exposed to high heat, which turns the polymer from a liquid into an elastic solid. Because the polymer flows around the silver nanowires when it is in liquid form, the nanowires are trapped in the polymer when it becomes solid. The polymer can then be peeled off the silicon plate. The fact that it is easy to make patterns using the silver nanowire conductors facilitates the use of the technique in the electronics manufacturing. When the nanowires-embedded polymer is stretched and relaxed, the surface of the polymer containing nanowires buckles. The end result is that the composite is flat on the side that contains no nanowires, but wavy on the side that contains silver nanowires. After the nanowire-embedded surface has buckled, the material can be stretched up to 50 percent of its elongation, or tensile strain, without affecting the conductivity of the silver nanowires. This is because the buckled shape of the material allows the nanowires to stay in a fixed position relative to each other, even as the polymer is being stretched. In addition to having high conductivity and a large stable strain range, the new stretchable conductors show excellent robustness under repeated mechanical loading. Other reported stretchable conductive materials are typically deposited on top of substrates and can delaminate under repeated mechanical stretching or surface rubbing.

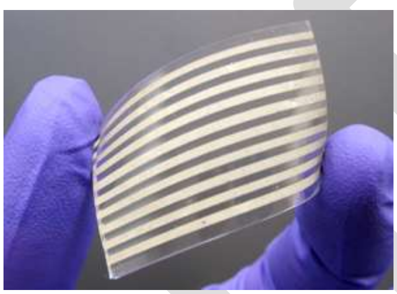

Fig.6. Silver nanowires printed to fabricate patterned stretchable conductors

Lockheed Martin Advanced Technology Center Develops Revolutionary Nanotechnology Copper Solder

Presently, nearly all solders used commercially contain lead, but there is now an urgent need for a lead-free solder because of a worldwide effort to phase out hazardous materials in electronics. The European Union implemented lead-free solder in 2006. Alternative lead-free replacement was a combination of tin, silver and copper (Sn/Ag/Cu) and was acceptable to the consumer electronics industry, which deals mostly with short product life cycles and relatively benign operating environments. However, multiple issues have arisen: high processing temperatures drive higher cost, the high tin content can lead to tin whiskers that can cause short circuits, and the fractures are common in challenging environments, making it difficult to quantify reliability. These reliability concerns become significant particularly in systems for the military, aerospace, medical, oil and gas, and automotive industries. In such applications, long service life and robustness of components are critical, where vibration, shock, thermal cycling, humidity, and extreme temperature use are common. Scientists at the Lockheed Martin Space System Advanced Technology Center (ATC) in Palo Alto [17] developed a revolutionary nanotechnology copper-based electrical interconnect material, or CuantumFuse™ solder that can be processed around 200 °C. The solder is based on the well-known melting point depression of materials in nanoparticle form. Given this nanoscale phenomenon, they produced a solder paste based on pure copper. Once fully optimized, the CuantumFuse™ solder material is expected to produce joints with up to 10 times the electrical and thermal conductivity compared to tin-based materials currently in use. Applications in military and commercial systems are currently under consideration. A number of requirements were addressed in the development of the CuantumFuse™ solder paste including, but not limited to: 1) sufficiently small nanoparticle size, 2) a reasonable size distribution, 3) reaction scalability, 4) low cost synthesis, 5) oxidation and growth resistance at ambient conditions, and 6) robust particle fusion when subjected to elevated temperature. Copper was chosen because it is already used throughout the electronics industry as a trace, interconnect, and pad material, minimizing compatibility issues. It is cheap (1/4th the cost of tin; 1/100th the cost of silver, and 1/10,000th that of gold), abundant, and has 10 times the electrical and thermal conductivity compared to commercial tin-based solder. The ATC demonstrated CuantumFuse™ with the assembly of a small test camera board. These accomplishments are extremely exciting and promising and require more research for a routine use in military and commercial applications.

INCREASING THE SPEED OF DATA TRANSMISSION: Researchers are integrating the technique of “silicon nanophotonics” into CMOS integrated circuits. This optical technique is intended to provide higher speed data transmission between integrated circuits than which is possible with electrical signals. Researchers are also striving to develop lasers with much tighter frequency control than previously achieved. This will allow much higher data rates for information transmission over fiber optics. The research works, being carried out are being discussed as under:

IBM Lights Up Silicon Chips to Tackle Big Data

IBM (NYSE: IBM) announced a major advance [18] in the ability to use light instead of electrical signals to transmit information for future computing. The breakthrough technology – called “silicon nanophotonics” – allows the integration of different optical components side-by-side with electrical circuits on a single silicon chip using, for the first time, sub-100nm semiconductor technology. Silicon nanophotonics takes advantage of pulses of light for communication and provides a super highway for large volumes of data to move at rapid speeds between computer chips in servers, large datacenters, and supercomputers, thus alleviating the limitations of congested data traffic and high-cost traditional interconnects. It provides answers to Big Data challenges by seamlessly connecting various parts of large systems, whether few centimeters or few kilometers apart from each other, and move terabytes of data via pulses of light through optical fibers. The processing module components of silicon nanophotonics such as wavelength division multiplexers (WDM), modulators, and detectors were integrated side-by-side with a CMOS electrical circuitry into a high-performance 90nm CMOS fabrication line. The single-chip optical communication transceivers can be manufactured in a conventional semiconductor foundry, providing significant cost reduction over traditional approaches. These CMOS nanophotonics technology transceivers exceed the data rate of 25Gbps per channel. In addition, the technology is capable of feeding a number of parallel optical data streams into a single fiber by utilizing compact on-chip wavelength-division multiplexing devices. The ability to multiplex large data streams at high data rates will allow future scaling of optical communications to be capable of delivering terabytes of data between distant parts of computer systems.

A New Laser for a Faster Internet

Light is capable of carrying vast amounts of information with approximately 10,000 times more bandwidth than microwaves which are the earlier carrier of long-distance communications. But to utilize this potential, the laser light needs to be as spectrally pure—as close to a single frequency—as possible. The purer the tone, the more information it can carry, and for decades researchers are trying to develop a laser that comes as close as possible to emitting just one frequency. Present day worldwide optical-fiber network is still powered by a laser known as the distributed-feedback semiconductor (S-DFB) laser, developed in the mid 1970s by Yariv's research group. The S-DFB laser's unusual longevity in optical communications stemmed from its, at the time, unparalleled spectral purity—the degree to which the emitted light matched a single frequency. The laser's increased spectral purity directly translates into a larger information bandwidth of the laser beam and longer possible transmission distances in the optical fiber—with the result that more information can be carried farther and faster than ever before. The old S-DFB laser had a successful 40-year run in optical communications—and was cited as the main reason for Yariv receiving the 2010 National Medal of Science. However, the spectral purity, or coherence, of the laser no longer satisfies the ever-increasing demand for bandwidth. The present-day laser designs—even S-DFB laser—have an internal architecture which is unfavorable for high spectral-purity operation. This is because they allow a large and theoretically unavoidable optical noise to co-mingle with the coherent laser and thus degrade its spectral purity. The researchers recently achieved unprecedented spectral purity [19] as a direct consequence of the incorporation of a nano scale corrugation within the multilayered structure of the laser. The washboard-like surface acts as a sort of internal filter, discriminating against spurious "noisy" waves contaminating the ideal wave frequency. The old S-DFB laser consists of continuous crystalline layers of materials called III-V semiconductors—typically gallium arsenide and indium phosphide—that convert into light the applied electrical current flowing through the structure. Once generated, the light is stored within the same material. Since III-V semiconductors are also strong light absorbers—and this absorption leads to a degradation of spectral purity—the researchers sought a different solution for the new laser. The highly coherent new laser still converts current to light using the III-V material, but in a fundamental departure from the S-DFB laser. It stores the light in a layer of silicon, which does not absorb light. Spatial patterning of this silicon layer—a variant of the corrugated surface of the S-DFB laser—causes the silicon to act as a light concentrator, pulling the newly generated light away from the light-absorbing III-V material and into the near absorption-free silicon.

This newly achieved high spectral purity—a 20 times narrower range of frequencies than which is possible with the S-DFB laser—is especially important for the future of fiber-optic communications. The laser beams in optic fibers carry information in pulses of light; data signals are impressed on the beam by rapidly turning the laser on and off, and the resulting light pulses are carried through the optic fibers. However, to meet the increasing demand for bandwidth, communications system engineers are now adopting a new method of impressing the data on laser beams that no longer requires this "on-off" technique. This method, called as called coherent phase communication, the data resides in small delays in the arrival time of the waves; the delays—a tiny fraction (10^{-16}) of a second in duration—can then accurately relay the information even over thousands of miles. The digital electronic bits carrying video, data, or other information are converted at the laser into these small delays in the otherwise rock-steady light wave. But the number of possible delays, and thus the data-carrying capacity of the channel, is fundamentally limited by the degree of spectral purity of the laser beam. This purity can never be absolute—a limitation of the laws of physics—but with the new laser, we have come closer to the absolute purity.

Fig.7. Highly coherent Semi-Conductor Lasers based on integral high-Q resonators in hybrid Si/III-V platforms.

REDUCTION IN POWER CONSUMPTION: Lesser power consumption in electronic devices decreases the production of heat in the circuit and reduces its operating temperature. It undoubtedly leads to an increased battery life. Following research groups working in this area needs being mentioned:

New milestone could help magnets end era of computer transistors

Semiconductor-based transistors, the on-off switches that direct the flow of electricity and form a computer’s nervous system, consume greater chunks of power at increasingly hotter temperatures as processing speeds grow. For more than a decade, researchers are pursuing magnets as an alternative to transistors because they require far less energy while switching. However, until now, the power needed to generate the magnetic field to orient the magnets for clocking them on and off was more than the power gained by moving away from transistors. UC Berkeley researchers discussed [20] overcoming this limitation by exploiting the special properties of the rare, heavy metal tantalum. They created a so-called Spin Hall effect by using nanomagnets placed on top of tantalum wire and then sending a current through it. Electrons in the current will randomly spin in either a clockwise or counterclockwise direction. When the current passes through the tantalum atomic core, its physical properties naturally sort the electrons to opposing sides based on their direction of spin. This creates the polarization which can switch magnets in a logic circuit without the need for a magnetic field. The power consumption is up to 10,000 times lower than state-of-the-art schemes for nanomagnetic computing and provides for a realistic replacement for transistors.

Nature Materials Study: Boosting Heat Transfer with Nanoglue

A team of interdisciplinary researchers at Rensselaer Polytechnic Institute [21] has developed a new method which significantly increases the heat transfer rate across two different materials. The study, published in the journal Nature Materials, is useful for new advances in cooling computer chips, lighting-emitting diode (LED) devices, in collecting solar power, harvesting waste heat, and in other applications. This was achieved by sandwiching a layer of ultrathin "nanoglue" between copper and silica. The research team demonstrated a four-fold increase in thermal conductance at the interface between the two materials. Less than a nanometer—or one billionth of a meter—thick, the nanoglue is a layer of molecules that form strong links with the copper (a metal) and the silica (a ceramic), which otherwise do not stick together well. This kind of nano-molecular locking improves adhesion, and also helps to sync up the vibrations of atoms that make up the two materials which, in turn, facilitates more efficient transport of heat particles called phonons. Beyond copper and silica, the research team has demonstrated their approach works with other metal-ceramic interfaces.

Heat transfer is a critical aspect of many different technologies. As computer chips grow smaller and more complex, manufacturers are constantly in search of new and better means for removing excess heat from semiconductor devices to boost reliability and performance. With photovoltaic devices, for example, better heat transfer leads to more efficient conversion of sunlight to electrical power. LED makers are also looking for ways to increase efficiency by reducing the percentage of input power lost as heat. The ability to enhance and optimize interfacial thermal conductance should lead to new innovations in these and other applications. Interfaces between different materials are often heat-flow bottlenecks due to stifled phonon transport. Inserting a third material usually only makes things worse because of an additional interface created. However, introducing an ultrathin nanolayer of organic molecules that strongly bond with both the materials at the interface gives rise to multi-fold increases in interfacial thermal conductance, contrary to poor heat conduction seen at inorganic-organic interfaces. This method to tune thermal conductance by controlling adhesion using an organic nanolayer works for multiple materials systems, and offers a new means for atomic- and molecular-level manipulation of multiple properties at different types of materials interfaces. Also, it was done rather unobtrusively by the simple method of self-assembly of a single layer of molecules.

Fig.8. Boosting Heat Transfer with Nanoglue

This study establishes the correlation between interfacial bond strength and thermal conductance, which serves to underpin new theoretical descriptions and opens up new ways to control interfacial heat transfer. It is truly remarkable that a single molecular layer can bring about such a large improvement in the thermal properties of interfaces by forming strong interfacial bonds. This is also a fascinating example of the interplay between the physical, chemical, and mechanical properties working in unison at the nanoscale to determine the heat transport characteristics at dissimilar metal-ceramic interfaces.

BUILDING BETTER DISPLAYS

The "quantum dots" can replace the fluorescent dots used in current displays and these displays will be simpler to make, will use reduced power consumption and will have decreased weight and thickness. The "active matrix" display using a new class of transparent transistors and circuits made of "nanowires" is a step toward realizing applications such as e-paper, flexible color monitors and "heads-up" displays in car windshields. Carbon Nanotube (CNT) technology – a breakthrough technique, can be used to develop large, flat panel displays with superior quality, longer lifetimes and lower costs than current offerings.

Engineers make first 'active matrix' display using nanowires

Electronic displays like television screens contain millions of pixels located at the intersections of rows and columns that crisscross each other. The OLEDs are devices that rival the brightness of conventional pixels in flat-panel television sets, computer monitors and displays in consumer electronics. OLEDs are used in cell phones, MP3 displays and prototype television sets, but their production requires a complex process, and it is difficult to manufacture OLEDs which are small enough for high-resolution displays.

Nanowire-transistor electronics can solve this problem. The nanowires are tiny cylindrical structures that are assembled on glass or thin films of flexible plastic. The researchers [22] used nanowires as small as 20 nanometers - a thousand times thinner than a human hair - to create a display containing organic light emitting diodes, or OLEDs. Nanowire electronics was fabricated at room temperature in a simple process that is practical for commercial manufacturing. The fabrication method is scalable and provides a low-cost way to produce high-resolution displays. Unlike conventional computer chips - called CMOS, for complementary metal oxide semiconductor chips - the nanowire thin-film transistors can be produced less expensively under low temperatures, making them ideal to incorporate into flexible plastics which melt under high-temperature processing. The nanowire transistors were made of a transparent semiconductor called indium oxide, a potential replacement for silicon in future transparent circuits. The OLEDs used in the display consisted of nanowire transistors, electrodes made of a material called indium tin oxide and plastic capacitors that store electricity. All of the materials are transparent until activated to emit light. The researchers successfully selectively illuminated a specific row of active-matrix OLEDS in a display about the size of a fingernail. Conventional liquid crystal displays in flat-panel televisions and monitors are backlit by a white light, and each pixel acts as a filter that turns on and off to create images. OLEDS, however, emit light directly, eliminating the need to backlight the screen and making it possible to create more vivid displays that are thin and flexible. This first "active matrix" display using a new class of transparent transistors and circuits is undoubtedly a step toward realizing applications such as e-paper, flexible color monitors and "heads-up" GPS navigational displays right on the windshield of your car. Imagine having a local map displayed on your windshield so that you need not to take your eyes off the road. Future research is expected to include work to design displays that can control individual OLEDs to generate images. A unique aspect of these displays is that they are transparent. Until the pixels are activated, the display area looks like lightly tinted glass. The technology can also be used to create antennas that aim microwave and radio signals more precisely than current antennas. Such antennas can improve cell phone reception and will make it more difficult to eavesdrop on military transmissions on the battlefield.

The new OLEDs have brightness nearly comparable to that of the pixels in commercial flat-panel television sets. The OLEDS have an average brightness of more than 300 candelas per square meter, compared with 400-500 candelas per square meter for commercially available liquid-crystal display televisions. The researchers successfully created OLEDS of the proper size for commercial displays, about 176 by 54 microns, the size which will be ideal for small displays in cell phones, personal digital assistants and other portable electronics.

Motorola Labs Debuts First Ever Nano Emissive Flat Screen Display Prototype

Motorola Labs developed [23] a working 5-inch color video display prototype based on proprietary Carbon Nanotube (CNT) technology – a breakthrough technique for creating large, flat panel displays with superior quality, longer lifetimes and lower costs than current offerings. This can be optimized for a large screen High Definition Television (HDTV) which is less than 1-inch thick. The development of such a flat panel 5-inch prototype display is possible due to Motorola Labs Nano Emissive Display (NED) technology, a scalable method of growing CNTs directly on glass to enable an energy efficient design that excels at emitting electrons. Through this cost-effective process and design, Motorola showcases the potential to create longer-lasting NED flat panel displays with high brightness, excellent uniformity and color purity. This NED technology is demonstrating full color video with good response time and a low manufacturing cost which is expected to be less than $400 for a 40-inch NED panel. Motorola prototype is low cost display driven electronics (similar to LCD, much lower than Plasma) with color 5" video section of a 1280 x 720, 16:9, 42-inch HDTV with a small panel thickness of 3.3 millimeters (about 1/8th of an inch), high quality brightness and vivid colors produced using standard Cathode Ray Tube (CRT) and showing display characteristics which meet or exceed CRTs, such as fast response time, wide viewing angle and wide operation temperature.

BETTER MEMORY UNITS - RAM AND HARD DISKS

Magnetic Random Access Memory developed at University of Illinois

Magnetic Random Access Memory (MRAM) is a contemporary spin on decades-old core memory technology that uses magnetic fields rather than electrical charges to reliably store and randomly access data. A team of researchers at University of Illinois at Chicago [24] has demonstrated that nanometer-sized permalloy rings, shaped into tiny rectangles, can store and access data almost instantly. The MRAM developed at UIC does not need refreshing the memory. That means we can store data, recall it and it remains there. It is non-volatile. The conventional DRAM (dynamic random access memory) stores information as electrical charges.

Therefore it needs to be constantly refreshed. This means, as at present, as battery dies, we lose information. But with MRAM, even if the battery dies, magnetized layer of memory stays magnetized and the data stays there, hopefully, forever.

Square-shape of the magnetized memory rings is the key to make MRAM work. The researchers initially investigated the memory properties of circular rings, but found that square and rectangular-shaped rings sitting on nano-scale memory cells are more reliable design for storing data, keeping data stable, switching the magnetic field and making it possible to retrieve information. However, the technology remains largely in the development phase with improvements needed in patterning the magnetic material. The square rings are uniform down at sizes below 50 nanometers. Square and rectangular rings exhibit two stable states of opposite polarity at remanence that can be used for data storage. It has also been shown that unlike circular rings that switch only through the vortex state, the square and rectangular rings also exhibit a unique inter-mediate horseshoe state depending on the direction of magnetization. The choice of the stable intermediate state and thus the switching mechanism, in the square and rectangular rings, can be controlled. This offers a good platform for the development of the magnetic storage technology. Presently MRAM square ring cells that work well as a circuit are comparatively large -- often as big as 500 nanometers. Everything is determined by shape, and small variations in the shape of magnetic material leads to drastic changes in switching properties. All these MRAM cells should switch exactly together, and this needs to be controlled precisely. Unlike with everyday DRAM memory chips used in personal computers and other consumer electronic devices, MRAM holds the promise of providing instant access memory without the boot-up delays which is now common after turning on the device power. Also, MRAM is not prone to memory loss caused by radiation particles, so it may prove to be the memory storage device of choice in future spacecraft electronics, such as space probes, launch vehicles, laboratories and earth-orbiting satellites.

UCLA engineers develop new energy-efficient computer memory using magnetic materials

The researchers at UCLA have developed an improved memory [25], which they call Magnetoelectric Random Access Memory or MeRAM, which uses electric voltage instead of a flowing electric current for creating magnetic field. It uses nanoscale structures called voltage-controlled magnet-insulator junctions, which have several layers stacked on top of each other, including the two composed of magnetic materials. However, while magnetic direction of one layer is fixed, that of the other is manipulated via an electric field. The devices are specially designed to be sensitive to electric fields. When the electric field is applied, it results in voltage — a difference in electric potential between the two magnetic layers. This voltage accumulates or depletes the electrons at the surface of these layers, writing bits of information into the memory. MeRAM is an ultra-fast, high-capacity class of computer memory and has a great potential to be used in future memory chips for almost all electronic applications, including smart-phones, tablets, computers and microprocessors, as well as for data storage, like the solid-state disks used in computers and large data centers. MeRAM is up to 1,000 times more energy-efficient than current technologies. Its key advantage over existing technologies is that it combines extraordinary low energy with very high density, high-speed reading and writing and non-volatility — the ability to retain data when no power is applied, similar to hard disk drives and flash memory sticks. But MeRAM is much faster. Currently, magnetic memory is based on a technology called spin-transfer torque (STT), which uses the magnetic property of electrons — referred to as spin — in addition to their charge. STT utilizes an electric current to move electrons to write data into the memory and therefore requires a certain amount of power, which means that it generates heat when data is written into it. Further, its memory capacity is limited by how close to each other bits of data can be physically placed, a process which itself is limited by the currents required to write information. The low bit capacity, in turn, translates into a relatively large cost per bit, limiting STT's range of applications. The technology used in MeRAM replaces STT's electric current with voltage to write data. This eliminates the need to move large numbers of electrons through wires and instead uses voltage — the difference in electrical potential — to switch the magnetic bits and write information into the memory. This results in computer memory that generates much less heat, making it 10 to 1,000 times more energy-efficient. Further the memory is more than five-times as dense, with more bits of information stored in the same physical area, which substantially brings down the cost per bit.

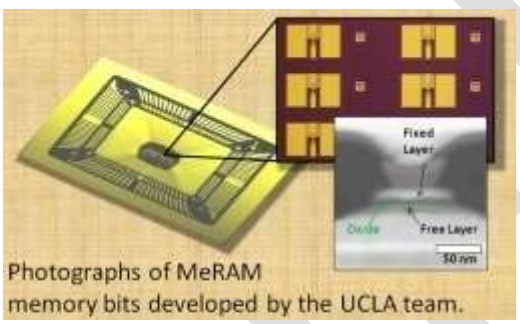

Fig.9. MeRAM memory bits developed by UCLA team

Race Track Memory based on Nanowires

Team of researchers at IBM [26] describes the fundamentals of a computer memory technology known as "racetrack" memory which combines the high performance and reliability of flash with the low cost and high capacity of the hard disk drive. Therefore the electronic devices will be capable of storing far more data in the same amount of space than is possible today, with lightning-fast boot times, far lower cost and unprecedented stability and durability. Racetrack memory is so named because the data "races" around the wire "track" and leads to solid state electronic memory device which is without any moving parts and is therefore, more durable. This technology is capable of holding far more data in the same amount of space than is possible today. For example, it can enable a handheld device such as an MP3 player to store around 500,000 songs or around 3,500 movies – 100 times more than is possible today –at far lower cost and far less power consumption. The device not only stores vastly more information in the same space, but also requires much less power and generates much less heat, and is practically unbreakable. Currently, there are two main ways to store digital information; solid state random access flash memory, commonly used in devices such as mobile phones, music players and digital cameras, and the magnetic hard disk drive, commonly used in desktop and laptop computers and some handheld devices. Both classes of storage devices are evolving at a very rapid pace but the cost of storing a single data bit in a hard disk drive remains approximately 100 times cheaper than in flash memory. But hard disk drive is intrinsically slower and, with many moving parts, has mechanical reliability issues which are not present in flash technology. Flash memory, however, has its own drawbacks – while it is fast to read data, it is slow to write data, and it, too, has a finite lifespan. Flash, can be reused only a few thousands of times because it eventually breaks as it is slightly damaged by each use or "rewrite." However, the racetrack memory has no moving parts, and, rather than storing data as ensemble of electronic charge, uses the "spin" of the electron to store data, it has no wear-out mechanism and so can be rewritten endlessly without any wear and tear.

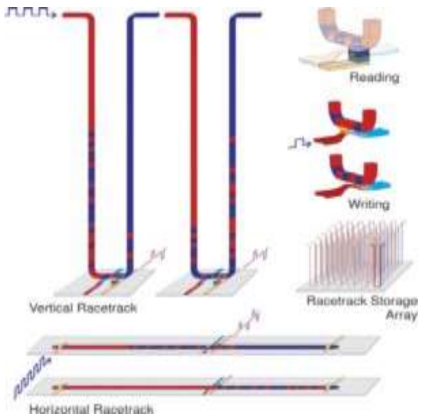

Fig.10. Computer memory technology named as "Race Track Memory" developed at IBM.

The domain walls are the boundaries between magnetic regions or "domains" in magnetic materials. The manipulation of magnetic domain walls for storing information, however, was always expensive, complex, and used significant power to generate the fields necessary to do so. The researchers, however, showed that the domain wall can be moved by interacting the spin polarized current with magnetization in the walls which results in a spin transfer torque on these walls. The use of spin momentum transfer considerably simplifies the memory device since the current is passed directly across the domain wall without the need for any additional field generators. The magnetic domains, thus, can be used to store information in columns of magnetic material (the "racetracks") arranged perpendicularly or horizontally on the surface of a silicon wafer. Magnetic domain walls are then formed, within the columns delineating regions magnetized in opposite directions (e.g. up or down) along a racetrack. Each domain has a "head" (positive or north pole) and a "tail" (negative or south pole). Successive domain walls along the racetrack alternate between "head to head" and "tail to tail" configurations. The spacing between consecutive domain walls (that is, the bit length) is controlled by pinning sites fabricated along the racetrack. The researchers, in this study, described the use of horizontal permalloy nanowires to demonstrate the successive creation, motion and detection of domain walls by using sequences of properly timed nanosecond long spin-polarized current pulses. The cycle time for the writing and shifting of the domain walls was a few tens of nanoseconds. These results illustrated the basic concept of a magnetic shift register relying on the phenomenon of spin momentum transfer to move series of closely spaced domain walls – an entirely new take on the decades-old concept of storing information in movable domain walls. Furthermore, the racetrack can also move into the third dimension (3D) leading to the construction of a novel 3D racetrack memory device. This is a paradigm shift from traditional two-dimensional arrays of transistors and magnetic bits found in silicon-based microelectronic devices and hard disk drives. By moving into the third dimension, racetrack memory stands to open new possibilities for developing less expensive, faster devices because it is also not dependant on miniaturization as dictated by Moore's Law.

Imec and Nantero launch joint carbon nanotube memory program for high-density next-generation memory below 20nm

Imec, a world-leading research institution in nanoelectronics and Nantero Inc., a nanotechnology company have decided to develop the carbon-nanotube-based memory developed by Nantero [27] known as NRAM, and its application in high-density next-generation memories with a size under 20nm. Carbon nanotube memory NRAM is based on the carbon nanotubes (CNTs) which are cylindrical carbon molecules about a nanometer across and up to a millimeter long. CNTs exhibit extraordinary strength, unique electrical properties and efficient heat conduction, is highly promising material for future memories. Researchers at Nantero Inc. has already fabricated high-yielding 4Mb arrays of NRAM in CMOS production environments, with several important performance advantages such as the write speed is as fast as 3 nanoseconds, the endurance is unlimited which was over a trillion cycles, a low operating power requirement and superior high temperature retention. Nantero and imec will develop and demonstrate this form of memory for future applications below 20nm such as terabit-scale memory arrays and ultra-fast gigabit-scale nonvolatile cache memories. NRAM, with suitable endurance and speed specifications, is useful in Non-Volatile Memory applications and is a good alternative to DRAM which is presently everyday memory chip used in personal computers and other consumer electronic devices and is currently facing scaling limitations beyond 18nm.

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CONCLUSION

The researchers all over the world are exploring possibilities to use nanotechnology in improving working and fabrication of electronic devices. They have succeeded in reducing size of these devices by making molecular level, junction-less, memory (eliminating need for capacitor), Trigate, faster graphene and Organic (NOMFET) transistors. Improvement in fabrication methods such as successfully printing Nano-level circuits with Inkjet printers using silver ink and printing circuits on flexible plastics which will lead to flexible motherboards, mobiles and laptops are remarkable developments. There are sincere efforts in designing nanolevel circuits with less power consumption and faster heat dissipation. Research work on Silicon Nanophotonics and spectrally purer laser will improve the rate of data transmission. Research groups have designed better displays and monitors with sharper and intense output imaging using Nanowire and Carbon Nanotube technologies. Improved Random Access Memories MRAM, MeRAM, NRAM and hard disks such as Race Track Memory with thousand times more storage capacity are going to be the promising part of future electronic gadgets.

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