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Department of Electronics and Communication Engineering

MICROELECTRONICS TO NANOELECTRONICS

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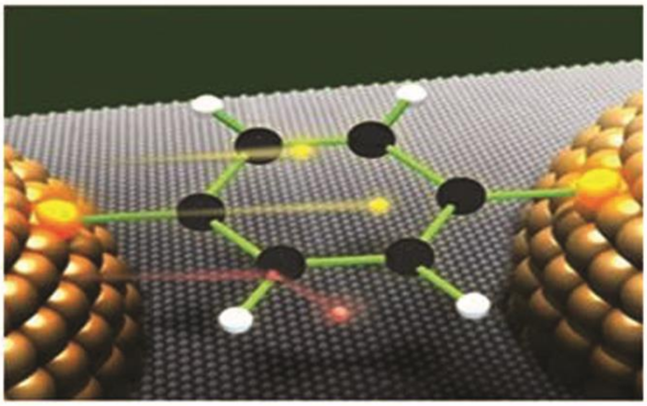

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Preface

Microelectronics relates to the study and manufacture (or microfabrication) of very small electronic designs and components. These devices are typically made from semiconductor materials. Many components of normal electronic design are available in a microelectronic equivalent.

These include transistors, capacitors, inductors, resistors, diodes and insulators and conductors can all be found in microelectronic devices. Unique wiring techniques such as wire bonding are also often used in microelectronics because of the unusually small size of the components, leads and pads. This technique requires specialized equipment and is expensive.

Nano electronics refer to the use of nanotechnology in electronic components. The term covers a diverse set of devices and materials, with the common characteristic that they are so small that inter-atomic interactions and quantum mechanical properties need to be studied extensively. Some of these candidates include: hybrid molecular/semiconductor electronics, one-dimensional nano tubes/nano wires (e.g. Silicon nano wires or Carbon nano tubes) or advanced molecular electronics. Recent silicon CMOS technology generations, such as the 22 nanometer node, are already within this regime.

NANO ELECTRONICS

M.Ragul, III year

Nanoelectronics refer to the use of nanotechnology in electronic components. The term covers a diverse set of devices and materials, with the common characteristic that they are so small that inter-atomic interactions and quantum mechanical properties need to be studied extensively. Some of these candidates include: hybrid molecular/semiconductor electronics, one-dimensional nanotubes/nanowires (e.g. Silicon nanowires or Carbon nanotubes) or advanced molecular electronics. Recent silicon CMOS technology generations, such as the 22 nanometre node, are already within this regime. Nanoelectronics are sometimes considered as disruptive technology because present candidates are significantly different from traditional transistors.

Fundamental Concepts:

In 1965 Gordon Moore observed that silicon transistors were undergoing a continual process of scaling downward, an observation which was later codified as Moore's law. Since his observation transistor minimum feature sizes have decreased from 10 micrometres to the 28-22 nm range in 2011. The field of nanoelectronics aims to enable the continued realization of this law by using new methods and materials to build electronic devices with feature sizes on the nanoscale. The volume of an object decreases as the third power of its linear dimensions, but the surface area only decreases as its second power. This somewhat subtle and unavoidable principle has huge ramifications. For example, the power of a drill (or any other machine) is proportional to the volume, while the friction of the drill's bearings and gears is proportional to their surface area. For a normal-sized drill, the power of the device is enough to handily overcome any friction. However, scaling its length down by a factor of 1000, for example, decreases its power by 10003 (a factor of a billion) while reducing the friction by only 10002 (a factor of only a million). Proportionally it has 1000 times less power per unit friction than the original drill. If the original friction-to-power ratio was, say, 1%, that implies the smaller drill will have 10 times as much friction as power; the drill is useless. For this reason, while super-miniature electronic integrated circuits are fully functional, the same technology cannot be used to make working mechanical devices beyond the scales where frictional forces start to exceed the available power. So even though you may see microphotographs of delicately etched silicon gears, such devices are currently little more than curiosities with limited real world applications, for example, in moving mirrors and shutters. Surface tension increases in much the same way, thus magnifying the tendency for very small objects to stick together. This could possibly make any kind of "micro factory" impractical: even if robotic arms and hands could be scaled down, anything they pick up will tend to be impossible to put down. The above being said, molecular evolution has resulted in working cilia, flagella, muscle fibres and rotary motors in aqueous environments, all on the nanoscale. These machines exploit the increased frictional forces found at the micro or nanoscale. Unlike a paddle or a propeller which depends on normal frictional forces (the frictional forces perpendicular to the surface) to achieve propulsion, cilia develop motion from the exaggerated drag or laminar forces (frictional forces parallel to the surface) present at micro and nano dimensions. To build meaningful "machines" at the nanoscale, the relevant forces need to be considered. We are faced with the development and design of intrinsically pertinent machines rather than the simple reproductions of macroscopic ones. All scaling issues therefore need to be assessed thoroughly when evaluating nanotechnology for practical applications.

Advantages of nano electronics

Nanoscale additives to or surface treatments of fabrics can provide lightweight ballistic energy deflection in personal body armour, or can help them resist wrinkling, staining, and bacterial growth. Clear nanoscale films on eyeglasses, computer and camera displays, windows, and other surfaces can make them water- and residue-repellent, antireflective, self-cleaning, resistant to ultraviolet or infrared light, antifog, antimicrobial, scratch-resistant, or electrically conductive. Nanoscale materials are beginning to enable washable, durable “smart fabrics” equipped with flexible nanoscale sensors and electronics with capabilities for health monitoring, solar energy capture, and energy harvesting through movement. Light weighting of cars, trucks, airplanes, boats, and space craft could lead to significant fuel savings. Nanoscale additives in polymer composite materials are being used in baseball bats, tennis rackets, bicycles, motorcycle helmets, automobile parts, luggage, and power tool housings, making them lightweight, stiff, durable, and resilient. Carbon nanotube sheets are now being produced for use in next-generation air vehicles. For example, the combination of light weight and conductivity makes them ideal for applications such as electromagnetic shielding and thermal management.

STRAIN MAGNITUDE AND DIRECTION EFFECT ON THE ENERGY BAND STRUCTURE OF HEXAGONAL AND ORTHORHOMBIC MONOLAYER MOS2

S.Muthunarayanan, III year

We report changes of the band structure of hexagonal and orthorhombic cells of the monolayer molybdenum disulphide (MoS_2) subject to various magnitudes and directions of the mechanical strains based on the first principle method. The conduction band minimum (CBM) of this two-dimensional (2-D) material has been calculated to establish the relation with both the magnitude and direction of the strains. It is found that the CBM at Γ point of the hexagonal cell decreases in a slight concave shape for the tensile strain, and a convex shape for the compressive strain. For the orthorhombic cell, we demonstrate that the effect is almost independent on the direction of the applied tensile strain. However, there is a strong directional dependence for compressive strain.

The transition-metal dichalcogenide semiconductor molybdenum disulphide (MOs 2) has attracted much attention owing to its superior electronic, optical, and catalytic properties. It has been found that the monolayer has several distinctive electronic and optical properties including a direct band gap with a band gap of about 1.8 eV, strong excitonic effects and the possibility of full optical control of the valley and spin occupation. These properties will significantly enhance the potential in applications such as lithium ion batter and nanoelectromechanical systems (NEMS) devices. A vast number of first principle calculations and experiment have been recently reported that under large mechanical strains, the band gap of the monolayer MoS2 changed from direct to indirect, more specifically the band gap has been narrowed, eventually leading to the CBM plunge to below the Fermi level. This implicates that the material becomes exhibiting metal properties. However, the study on the directional dependence of the mechanical strain has not been conducted so far. It is worth to state that in the real applications it would be hard to have a mechanical strain precisely along a certain direction and magnitude. Hence the critical issue is to study the band structure under strain in various magnitudes and directions. In this work, we investigate the band structure of hexagonal and orthorhombic monolayer MoS2 cells under a wide range of strain magnitudes in different directions using first principle method. This theoretical method has been used in many previous studies on 2D materials. Our aim is to theoretically explore the impact on the band structure of hexagonal monolayer MOs 2 i.e. CBM and band gap when the material undergoes mechanical strains. Furthermore, the directional properties of strains acting on the orthorhombic monolayer MOs 2 will be explored.

CELL STIFFNESS GOVERNS ITS ADHESION DYNAMICS ON SUBSTRATE UNDER SHEAR FLOW

P.Nandha Kumar, III Year

We develop an efficient numerical method to study adhesion dynamics of a single cell on a substrate under shear flow. This method is based on the coupling of Lattice Boltzmann fluid and coarse-grained cell models through immersed boundary method, and a probabilistic model is adopted to capture dynamics of ligand receptor binding for adhesion. With such a model at hand, a phase diagram of the adhesion dynamics in terms of adhesion strength Ad and stiffness of cell Ca is established. Four types of motion, including free motion, stable rolling, stop-and-go, and firm adhesion, are found through our numerical simulations, depending on the adhesion strength Ad and stiffness of cell Ca. In addition, deamination behaviour of the cell occurs when reducing the adhesion strength Ad in the regime of soft cells (high Ca). Such demargination behaviour is induced by the deformability of cell, resulting in a wall-induced lift force in the shear flow. Lastly, a scaling relation of a number of ligand-receptor bonds is obtained under the synergistic effect of Ad and Ca. The present effort provides a robust and efficient way to understand the adhesion dynamics of cells on substrate in shear flow. The obtained results are useful in understanding the biological adhesion process and developing adhesion-based microfluidic technologies.

Adhesion behaviour of cell on substrate is ubiquitous and plays a crucial role in biological processes, especially in inflammatory process and innate immune system. As a subsequent process of margination behaviour of freely suspended circulating cells in blood flow, adhesion can occur by forming specific biological bonds between receptors on their surfaces and ligands on vessel wall. Simultaneously, these in vivo processes are utilized in biomedical applications, such as using functionalized surface to capture targeted cells with specific adhesion molecules [4]. Hence, study of adhesion dynamics of cells on substrate under shear flow is of significance to guide these biological experiments or design of biomedical devices.

TRENDS IN NANOTECHNOLOGY

Rohini.M, III Year

For many, nanotechnology is viewed as merely a way to make stronger and lighter tennis rackets, baseball bats, hockey sticks, racing bikes, and other athletic equipment. But nanotechnology promises to do so much more. A more realistic view is that it will leave virtually no aspect of life untouched and is expected to be in widespread use by 2020. Mass applications are likely to have great impact particularly in industry, medicine, new computing systems, and sustainability. Here are some underlying trends to look for, many interconnected, and all expected to continue to accelerate.

Stronger Materials/Higher Strength Composites

The next generation of graphene and carbon nanotube-based devices will lead to even lighter but stronger structures than has been made possible by carbon fiber and will become increasingly obvious in cars, bicycles, and sporting equipment, says Clint Landrock, chief technology officer of NanoTech Security.

Scalability of Production

One big challenge is how to produce nanomaterial that makes them affordable. According to Dr. Timothy Fisher, Purdue University professor of mechanical engineering, technologies that can impact grand challenge problems such as food, water, energy, and environment must be scalable. “The main reason that these problems are so grand is that they are ubiquitous and therefore the related commercial markets have become commoditized. Very often, a technology that exploits a unique attribute of a nanomaterial can offer improvements in functional or engineering performance, but almost as often, these technologies require scarce materials (and therefore expensive) or slow or complicated manufacturing processes (and also expensive)."That limited scalability often hinders application despite outstanding functional performance in the laboratory or prototype stage, he explains.

More Commercialization

Over the next several years, significant advances are expected in carbon nanotube manufacturing technology, specifically in controlling the purity and structure, and in reducing costs due to economies of scale, according to David J. Arthur, CEO, Southwest Nanotechnologies, a producer of carbon nanotubes. “Advances will make the use of carbon nanotube materials even more compelling for mechanical engineers," he says. In addition to transforming the automotive, aerospace, and sporting goods fields, nanotechnology is facilitating so many diverse improvements: thinner, affordable, and more durable flat panel displays; improved armor materials to protect soldiers; sensors for medical testing; more humane and effective treatments for cancer_patients; enhanced cathode materials for safer and longer life Li-ion batteries; and the list goes on.

Sustainability

One main goal of the National Nanotechnology Initiative, a U.S. government program coordinating communication and collaboration for nanotechnology activities, is to find nanotechnology solutions to sustainability. Mike Nelson, chief technology officer, NanoInk Inc., says nanomaterial and nanostructured surfaces are increasingly employed in many advanced energy storage and conversion projects, and nanomaterial and nonmanufacturing contribute to products that are more energy efficient in both production and use.Dr. Eric Majzoub, associate director, Center for Nanoscience, University of Missouri - St. Louis, says this is done by controlling thermodynamics of solid-solid reactions through nanoscale size reduction and it can improve energy-storage materials including batteries, supercapacitors and hydrogen storage.

Nelson sees the greatest near-term impact in sustainability coming in the areas of transportation (more efficient and lighter materials for autos and aircraft, requiring less fuel) and in three other related areas: lighting, photovoltaic, and energy_storage. "The types of nano technologies being employed in all three of these are similar in terms of using nanostructured surfaces or materials to improve efficiencies from an electronic performance perspective whether it's batteries or solar cells or LED lighting," he adds.

Nanomedicine

Nowhere is the application of nanotechnology more exciting than in the biomedical field, where advances are being made in both diagnostics and treatment areas. Houston-based Nanospectra Biosciences has been developing a new therapy using a combination of gold nanoshells and lasers to destroy cancer tumors with heat. Based on work done by Rice University professors, Dr. Naomi Halas and Dr. Jennifer West, the technology promises to destroy tumors with minimal damage to adjacent healthy tissue. John Stroh, Nanospectra CEO, says he is hoping for European approval in the second or third quarter of this year and FDA approval early next year after 10 years of ongoing development and testing. In the diagnostics area, nanosensors that can detect, identify, and quantify biological substances in body fluids are leading to early disease detection and earlier treatments as well as the ability to detect environmental contaminants in the body.

NANO TECHNOLOGY APPLICATIONS

Praveena.T, **III Year**

Nanotechnology is receiving a lot of attention from companies, universities and governments. The collection of synthesis techniques collectively known as Nanotechnology presents many opportunities to reshape the electronics industry from top to bottom. Nanotechnology can offer us: • Uniform particles: metal, oxide, ceramics, composite; • Reactive particles: as above; • Unusual optical, thermal and electronic properties: phosphors, heat pipes, percolation based conductors; • Nano-structured materials: tubes, balls, hooks, surfaces; Self-assembly: liquid-based, vapor based or even by diffusion in the solid state. The 2004 iNEMI roadmap is a comprehensive survey that reviews the issues affecting the electronics supply chain. Gaps in the technology or infrastructure that can adversely affect iNEMI members are identified, and the iNEMI Research Committee was formed to priorities and disposition the tasks and identify companies, universities and government laboratories that can address them for the mutual good. Almost every roadmap chapter in 2004 identifies aspects of Nanotechnology that can enhance existing products or replace their structure or function. Some of these are outlined below.

Long term issues

Once CMOS technology dips below about 20nm resolution, quantum effects such as electron tunneling start to result in phenomena like unacceptable leakage. The only way to move below that size is to utilize these and other quantum effects in new types of minute structures, be they pure electronic or bio-electronic (remember, the most effective and energy efficient computer available sits on your shoulders!). We know that if we extrapolate Moore’s law we “hit the wall” with CMOS about 2015 and although we don’t know which technology will replace it, it may well be disruptive. On the other hand, using atomic cluster deposition as described later may allow us to extend much of the established silicon fabrication infrastructure while creating nanoscale structures.

Mid-term issues

In many areas of technology, once we hit an area of concern, we can develop a workaround. Hence clock speed, which was the measure many followed as the measure of processing capability, has been replaced in some devices by distributed processing with two processors placed on the same chip. This gets the job done without reduced heat penalty and gives us a breathing space, many upper end processors generate between 100W and 200W, but the heat issue has not gone away. Several unusual properties of nanoscale materials, enhanced thermal conductivity of Carbon nanotubes, diamond-like films, nano-metal dispersions, have the promise of aiding heat removal.

Shorter-term issues

Enhancement of shielding materials, solders, conductive adhesives, underfills etc. is now becoming possible as nano-sized materials become available and economic. Technology push and market pull the commercialization challenge many nano materials have been developed because of their interesting properties and companies have been founded on products for which there is limited market demand this tends to lead to leading edge products with very limited immediate commercial potential. On the other hand, the approach of many established companies has been the Market Pull an approach where existing solutions are sought for market needs.

APPLICATIONS: NANODEVICES, NANOELECTRONICS, AND NANOSENSORS

Sahana.R, III Year

In the past decade, our ability to manipulate matter from the top down, combined with advances and in some cases unexpected discoveries in the synthesis and assembly of nanometer-scale structures, has resulted in advances in a number of areas. Particularly striking examples include the following:

- The unexpected discovery and subsequently more controlled preparation of carbon nanotubes and the use of proximal probe and lithographic schemes to fabricate individual electronic devices from these materials
- The ability in only the last one or two years to begin to place carefully engineered individual molecules onto appropriate electrical contacts and measure transport through the molecules
- The explosion in the availability of proximal probe techniques and their use to manipulate matter and thereby fabricate nanostructures
- The development of chemical synthetic methods to prepare nanocrystals, and methods to further assemble these nanocrystals into a variety of larger organized structures
- The introduction of biomolecules and supermolecular structures into the field of nanodevices
- The isolation of biological motors, and their incorporation into nonbiological environments

Current Technological Advances

A number of examples of devices in the microelectronics and telecommunications industries rely on nanometer-scale phenomena for their operation. These devices are, in a sense, “one-dimensional” nanotechnologies, because they are micrometer-scale objects that have thin film layers with thicknesses in the nanometer range. These kinds of systems are widely referred to in the physics and electronics literature as two-dimensional systems, because they have two classical or “normal” dimensions and one quantum or nanoscale dimension. In this scheme, nanowires are referred to as one-dimensional objects and quantum dots as zero-dimensional. In this document, and at the risk of introducing some confusion, we have chosen to categorize nanodevices by their main feature nanodimensions rather than by their large-scale dimensions. Thus, two-dimensional systems such as two-dimensional electron gases and quantum wells in our notation are one-dimensional nanotechnologies, nanowires are two-dimensional nanotechnologies, and quantum dots are three-dimensional nanotechnologies. Examples include high electron mobility transistors, heterojunction bipolar transistors, resonant tunneling diodes, and quantum well optoelectronic devices such as lasers and detectors. The most recent success story in this category is that of giant magneto resistance (GMR) structures. These structures can act as extremely sensitive magnetic field sensors. GMR structures used for this purpose consist of layers of magnetic and nonmagnetic metal films. The critical layers in this structure have thicknesses in the nanometer range. The transport of spin-polarized electrons that occurs between the magnetic layers on the nanometer length scale is responsible for the ability of the structure to sense magnetic fields such as the magnetic bits stored on computer disks. GMR structures are currently revolutionizing the hard disk drive magnetic storage industry worth $30-40 billion/year .Our ability to control materials in one dimension to build nanometer-scale structures with atomic scale precision comes from a decade of basic and applied research on thin film growth, surfaces, and interfaces.

The extension from one nanodimension to two or three is not straightforward, but the payoffs can be enormous. Breakthroughs in attempting to produce three-dimensional nanodevices include the following:

- Demonstration of Coulomb blockade, quantum effect, and single electron memory and logic elements operating at room temperature
- Integration of scanning probe tips into sizeable arrays for lithographic and mechanical information storage applications
- Fabrication of photonic band-gap structures
- Integration of nanoparticles into sensitive gas sensors

Goals for the next 5-10 years: Barriers and Solutions

In order to exploit nanometer-scale phenomena in devices, we must have a better understanding of the electronic, magnetic, and photonic interactions that occur on and are unique to this size scale. This will be achieved through experiment, theory, and modeling over the next decade. In addition, new methods to image and analyze devices and device components will be developed. These might include three-dimensional electron microscopies and improved atomic-scale spectroscopic techniques.

Over the same time period, we believe that it will become possible to integrate semiconductor, magnetic, and photonic nanodevices as well as molecular nanodevices into functional circuits and chips. The techniques now being developed in biotechnology will merge with those from nanoelectronics and nanodevices. Nanodevices will have biological components. Biological systems will be probed, measured, and controlled efficiently with nanoelectronic devices and nanoprobes and sensors. There will be significant progress in nanomechanical and nan biomechanical systems, which will exhibit properties that are fundamentally different from their macroscopic counterparts. There are important applications for instruments that will fly into space: nanocomponents are needed to achieve overall instrument sizes in the micron or millimeter range. Some of the same issues apply to battlefield sensors for situational awareness. Finally, a significant goal is the development of nanometer-scale objects that manipulate and perform work on other nanometer-scale objects, efficiently and economically achieving the same things we currently rely on scanning tunneling microscopy (STM) or atomic force microscopy (AFM) to carry out. A first step towards this goal might be the integration of nanometer-scale control electronics onto micromachines.In the information technology arena, nanodevices will both enable and require fundamentally new information processing architectures. Early examples of possible architectural paradigm shifts are quantum computation, quantum dot cellular automata molecular electronics and computation using DNA strands. Such architectures will fundamentally change the types of information technology problems that can be attacked. Effective implementation of these types of architecture will require nanodevices. Other paradigm shifts include the emergence of quantized magnetic disks single photonic systems that will allow efficient optical communication; nanomechanical systems a broad class of structures and devices that merge biological and non-biological objects into interacting systems and use of nanocomponents in the shrinking conventional circuit architectures Research on nanodevices using nanoscale wiring and molecular logic, as well as new principles for devices such as spin electronics, have made significant inroads in the past year or two.

Scientific and Technological Infrastructure

The exploration and fabrication of nanodevices requires access to sophisticated and sometimes expensive tools. More and better access to such equipment as well as rapid prototyping facilities is needed. Of equal importance is the recognition that success in nanodevices will draw upon expertise from a broad range of traditional disciplines. Therefore, it is imperative that programs be established that facilitate and strengthen cross-fertilization among diverse disciplines and that allow rapid adoption of new methods across field boundaries.

R&D Investment and Implementation Strategies

Nanodevices are in some ways the most complicated nanotechnological systems. They require the understanding of fundamental phenomena, the synthesis of appropriate materials, the use of those materials to fabricate functioning devices, and the integration of these devices into working systems. For this reason, success will require a substantial funding level over a long period of time. There is strong sentiment for single investigator funding as well as for structured support of interdisciplinary teams.

- Development of new systems and architectures for given functions
- Study of interfaces and integration of nanostructures into devices and systems
- Multiscale, multiphenomena modeling and simulation of complex systems

Priorities in Modes of Support

- Establishment of consortia or centers of excellence for the research priorities identified above, by using vertical and multidisciplinary integration from basic research to prototype development
- Encouragement of system integration at the nanoscale in research and education

Organic Nanostructures

The Electrical Conductivity of a Single Molecule Contact person. By combining chemical self-assembly with a mechanical device that allows them to break a thin gold wire with nanometer scale control, researchers have succeeded in creating a “wire” consisting of a single molecule that can connect two gold leads. Using this structure, they have been able to begin to measure and study the electrical conductivity of a single molecule.

MOLECULAR ELECTRONICS

Praveen.S, III Year

If the reduction in size of electronic devices continues at its present exponential pace, the size of entire devices will approach that of molecules within a few decades. However, well before this happens, both the physics upon which electronic devices are based and the manufacturing procedures used to produce them will have to change dramatically. This is because current electronics are based primarily on classical mechanics, but at the scale of molecules, electrons are quantum mechanical objects. Also, the cost of building the factories for fabricating electronic devices, or fabs, is increasing at a rate that is much larger than the market for electronics; therefore, much less expensive manufacturing process will need to be invented. Thus, an extremely important area of research is molecular electronics, for which molecules that are quantum electronic devices are designed and synthesized using the batch processes of chemistry and then assembled into useful circuits through the processes of self-organization and self-alignment. If molecular electronics achieves the ultimate goal of using individual molecules as switches and carbon nanotubes as the wires in circuits, we can anticipate non-volatile memories with one million times the bit area density of today's DRAMs and power efficiency one billion times better than conventional CMOS circuitry. Such memories would be so large and power-efficient that they could change the way in which computation is performed from using processors to calculate on the fly to simply looking up the answer in huge tables. A major limitation of any such process is that chemically fabricated and assembled systems will necessarily contain defective components and connections. This limitation was addressed in a 1998 paper entitled.

Opportunities for Nanotechnology. By describing a silicon-based computer that was designed to operate perfectly in the presence of huge numbers of manufacturing defects, researchers from Hewlett-Packard (HP) and the University of California–Los Angeles (UCLA) presented an architectural solution to the problem of defects in molecular electronics. The logical design of a defect-tolerant circuit: (a) shows a "fat tree" architecture in which every member of a logical level of the tree hierarchy can communicate with every member at the next level; in the case of a defective component, this structure enables one to route around and avoid the defect; (b) shows how this architecture is implemented using cross bars, which are very regular structures and look like something that can be built chemically. The complexity required for a computer is programmed into the cross bars by setting the switches to connect certain elements of the tree together. Using silicon circuitry, two completely separate sets of wires (address and data lines) are required for the cross bars, and seven transistors are required for each switch, since a continual application of electrical power is required to hold the sense of the switches.

In 1999, researchers from HP Labs and UCLA experimentally demonstrated the most crucial aspect for such a system, an electronically addressable molecular switch that operates in a totally “dry” environment (Collier et al. 1999). As illustrated in Figure 6.3, logic gates were fabricated from an array of configurable molecular switches, each consisting of a monolayer of electrochemically active rotaxane molecules sandwiched between metal electrodes. In the “closed” state, current flow is dominated by resonant tunnelling through the electronic states of the molecules. The switches are irreversibly opened by applying an oxidizing voltage across the device. In this case, since the memory of the molecules is not volatile, only one set of wires is needed to set and read the state of the molecules, and in principle, one molecule can replace seven transistors in a conventional silicon circuit. In the demonstration, several devices were configured together to produce OR logic gates. The high/low current levels of those gates were separated by factors of 15 and 30, respectively, which is a significant enhancement over that for conventional wired-logic gates.

NANOELECTRONIC DEVICES

Nadhiya Srinithi.S, III year

Nanoelectronics offers a broad set of opportunities by focusing on quantum devices and addressing their potential for high performance through increases in Resonant tunnelling devices are being explored with demonstrated successes in multivalued logic and various logic circuits and memory circuits. SET logic and memory concepts are being explored with focus on memory applications. Molecular electronics and self-assembly approaches have shown a path towards manufacturing alternatives and device options for regimes beyond traditional scaling. Spin devices in the form of nan magnetics using the magneto resistive effect in magnetic multilayers have demonstrated their use for non-volatile, radiation-hard memory. Quantum cellular automata and coupled quantum dot technology are being explored and their potential assessed for transistorless computing. By exploring Si-based heterojunctions, band gap engineering, vertical device structures, and quantum devices, inroads are being made into extending CMOS capabilities. Potential applications are in digital radar, electronic support measures (ESM) receivers, ATM data stream processing, wide bandwidth communications, digital image processing, waveform generation, and the broad area of analog to digital (A/D) applications. Demonstrations have shown the efficacy of resonant tunnelling devices in various network environments. The long-term vision for nanoelectronics sees the use of quantum devices in other high performance systems especially in telecommunications for signal processors and electronics for A/D converters in detectors. Resonant Tunneling Devices in Nanoelectronics Contact person: G. Pomrenke, Defence Advanced Research Projects Agency (on detail from Air Force Office of Scientific Research)Resonant tunnelling and other tunnelling devices have had a history spanning almost three decades; however, it was not until 1997 that these devices could be seriously considered as part of functional circuits. The crucial technology for advancing these quantum devices has been epitaxial growth and process control at the nanoscale. This has meant control at the atomic layer level, resulting in flexible manufacturing, long-term process repeatability, and first-pass success. The resonant tunnelling diode (RTD) consists of an emitter and collector region, and a double-tunnel barrier structure that contains a quantum well. This quantum well is so narrow (5-10 nm) that it can only contain a single so-called “resonant” energy level.

The principle of this device is that electrons can travel from the emitter to the collector only if they are lined up with this resonant energy level. Initially, with a low voltage across the device (at point A), the electrons are below the point of resonance, and no current can flow through the device. As the voltage increases, the emitter region is warped upwards, and the collector region is warped downwards. Eventually, the band of electrons in the emitter line up with the resonant energy state and are free to tunnel through to the right. This gives an increase in the current up to the peak at point B. As the voltage across the device increases, the electrons are pushed up past the resonant energy level and are unable to continue tunneling. This can be observed by the drop in current to the valley at point C. As the voltage continues to increase, more and more electrons are able to flow over the top of the tunnel barriers, and the current flow rises. The current-voltage characteristic of this device is similar to that of the Esaki tunnel diode, in that it exhibits a peak and a valley in the curve. The difference is that RTDs have a much lower device capacitance, which allows them to oscillate faster, and their current-voltage characteristics .DARPA's Ultra Electronics Program accomplished the invention and simulation of a compact adder circuit with GHz speeds using redundant digit, multivalued logic world's first demonstration of an integration process for yielding the core circuit elements needed for adders signal processors, and multivalued logic circuits. The technology developed was subsequently transferred into circuit development efforts, which have led to the demonstration of a 4 bit 2 GHz analog-to-digital converter, 3 GHz quantizer, 3 GHz sample and hold clock circuits, shift registers, and ultralow power .The "invention" of functional devices based on quantum confinement occurred in the early 1980s. In the optoelectronic area a good example is the self-electrooptic effect device (SEED), based on the quantum-confined Stark effect, for photonic switching applications. Another example is the vertical cavity surface-emitting laser (VCSEL), the backbone of optical communications. The technology offers two-fold speed increases, almost 10 times lower component counts, and 10 to 2,000 times lower power over conventional devices.

After more than three decades of exploring space, the National Aeronautics and Space Administration has completed an initial reconnaissance of our solar system. The next missions will involve sending spacecraft to destinations that are much more difficult to travel to, like the Sun or Pluto. Also, spacecraft will be required to perform more difficult tasks, such as landing on a celestial body, collecting a sample of its material, and returning it to Earth. To carry out such technically challenging missions at an affordable cost, NASA has created the Deep Space Systems Technology Program, known as X2000. Every two to three years starting in the year 2000, the program will develop and deliver advanced spacecraft systems and body structures to missions bound for different areas of the solar system and beyond. In order to achieve reduction in the size of spacecraft, the avionics systems of the spacecraft are being reduced in size with each delivery of X2000, in part by means of integrating nanotechnology with microtechnology.The leftmost column shows the Mars Pathfinder spacecraft, which represents the current state of the art.The first delivery for X2000 is an integrated avionics system that subsumes the functionalities of command and data handling, attitude control, power management and distribution, and science payload interface. Advanced packaging technologies as well as advanced design automation techniques are used to define a highly integrated, modular, building-block architecture for highly reliable and long-term survivable deep-space planetary missions. Advanced low-power techniques and architectures will drastically reduce overall power consumption compared to currently available flight hardware. “System on a Chip” (SOAC) will prototype single-chip and multichip module solutions that lead towards an avionics system on a chip. This chip will integrate the avionics system that is being developed for the X2000 avionics deliverable. That is, the chip will include power management, sensor technology, and telecommunications modules, together with CPU and storage technology. To accomplish this, nanotechnology will be needed to miniaturize and integrate the different subsystems. The goal for the year 2020 is to establish and maintain a world-class program to research revolutionary computing technologies (RCT) that will not only take us beyond the limits of semiconductor technology scaling but also will enable the vision of a “thinking spacecraft.” A thinking spacecraft would be a totally autonomous, highly integrated, extremely capable spacecraft that operates at ultralow power. To achieve this goal, without a doubt, we need to employ nanoscience. In spite of the phenomenal advances in digital computing in recent years and those expected in the near future, even future supercomputers cannot compete with biological systems in performing certain ill-defined tasks such as pattern recognition, sensor fusion, fault-tolerant control, and adaptation to the environment. Biological systems address these types of problems with extreme ease and very low power. The forth column from the left in depicts two different technologies based on nanoscience that may have a great impact on the capabilities of our spacecraft by the year 2020:

- Quantum computing, that is, a joint venture between computer science and quantum physics. Although, the concept of a quantum computer is simple, its realization is not. Two issues motivate quantum computing: - Quantum mechanical concepts must be applied to solve intractable (NP-complete) computing problems. - From a computer miniaturization point of view, the size limit of a bit of information is important. Recently, this issue has attracted increased attention, due to the current development of nanotechnology and the design problems of semiconductor and metal devices that are approaching the quantum size limit. Consequently, the idea of quantum computing, in which the elements that carry the information are atoms, has attracted the attention of many scientists.
- Biomimetics, that is, systems or technologies inspired by architectures, functions, mechanisms, and principles found in biological systems, for example: - One gram of DNA could possibly store all the data in the Library of Congress. - The human brain contains about 1014 interconnects and operates at 1016 operations per second, using ultra low power and imprecise computing elements. - Humans are endowed with an immune system that provides recovery from illness—a “self-repair system.”
- As devices become smaller, lighter, and consume less power, NASA will be able to design and fly space probes on missions that are not currently possible.