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Exploiting the impact of new materials for Nano electronics devices

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ABSTRACT

Nanoelectronics is the term used in the field of nanotechnology for electronic components and research on improvements of electronics such as display, size, and power consumption of the device for the practical use. This includes research on memory chips and surface physical modifications on the electronic devices. Nanoelectronics cover quantum mechanical properties of the hybrid material, semiconductor, single dimensional nanotubes, nanowires, and so forth. Well-developed nanoelectronics can be applied in different fields, and are especially useful for detecting disease-causing agents and disease biomarkers. As a consequence, point-of-care detection became popularized due to the involvement of nanoelectronics. In this paper, the author have discussed about documented bio sensing applications of nanoelectronics.

Keywords: Nanoelectronics, nanotechnology, graphene, carbon, nanotubes etc.

INTRODUCTION

Nanoelectronics are now a reality since the critical feature sizes of semiconductor components, both logic transistors and memory, are below 22 nm. This march to the far-sub-nanometer regime has enabled an array of new applications for information and communication technologies (ICT). However, the overall sizes of practical electronic ICT systems that utilize these Nano scale components remain relatively large, typically on the order of centimeters or larger. Back in 1959, Richard Feynman [1] gave a visionary presentation in which he suggested the possibility of building computers whose dimensions were "submicroscopic." Although the progress of semiconductor technology has been extraordinary, submicroscopic and even microscopic computers remain outside of our grasp. Moreover, it is not known what minimum system size could be achieved with existing and/or projected semiconductor technologies. This book seeks to address this question by offering a physics-based analysis of the limits of physical scaling for computers and other functional ICT systems.In order to comprehend scaling limits for systems, scaling and energy limits for many electronic components are needed, including logic and memory devices, input/output (I/O) components, communication subsystems, sensors, etc. For a system-level analysis of extremely scaled ICT, several hypothetical applications will be considered. A silicon computer whose size is on the order of a cube 1–100 μm must contain logic circuitry and nonvolatile memory for program and data storage and it must be able to process the data. It also needs I/O components, an energy source, and perhaps, sensors.An area experiencing substantial growth is that of utilizing integrated intelligent sensor systems for the ubiquitous collection of data.

Applications for future integrated sensor systems include environmental monitoring, energy management, well-being, security, and safety, integrated into a broader smart city concept. Currently, sensor technologies are experiencing exponential growth, and a wide range of promising applications for electronic sensing have emerged, for example, chemical hazard detection, food storage/processing control and safety, seismic geo-imaging, agriculture, defense and security, etc.

The technological challenges that must be addressed to develop new generations of integrated sensor systems are daunting and encompass almost every facet of integrated system technology, including information processing, energetics, communication, packaging, etc. New materials and disruptive architectures, heterogeneous three-dimensional (3D) integration, and other technologies will need to be introduced to make intelligent integrated sensor systems possible. Once again, an understanding of scaling-performance projections and tradeoffs to achieve maximum performance at minimum energy and limited size is needed.

As another example where extreme system scaling is important in an autonomous ICT system embedded in the human body whose mission is to analyze the health of cells that it encounters and to report its findings to an external agent. The living cell, which is an organic autonomous system, provides an existence proof that functional and autonomous systems are possible at the scale of a few microns. This text investigates the feasibility of the design of a functional inorganic system on the same physical scale as the living cell, that is, with overall dimensions of several microns. One reason to believe that such a design might be possible is the remarkable progress that has been made in technologies for semiconductor chips, where some of the devices on the chip already have dimensions on the order of a few nanometers, and dimensional scaling is anticipated to continue for a few more generations. In addition, there is a trend to incorporate more functionality onto a single chip by including devices whose domains of operation are not only electrical but also mechanical, thermal, chemical, etc. These “System-on-a-Chip” designs may point the way to integrated chips with increasing degrees of functionality. The term “nanomorphic cell” is used herein to reflect the fact that emphasis is on inorganic integrated systems whose inspiration is derived from their biological counterparts.

To help fix ideas, imagine that the nanomorphic cell is to be injected into the body to interact with the living cells and to support certain diagnostic and/or therapeutic actions. In order to do this, it is stipulated that the nanomorphic cell must acquire data indicative of the health of the living cells that it contacts, analyze the sensed data, and communicate its findings to an external agent. Since the nanomorphic cell is untethered, it must either harvest energy from its surroundings or carry an embedded energy source.Subjectively, it seems reasonable to postulate that a micron-sized embedded system would contain only minute and harmless amounts of materials that in larger quantities might be harmful to the body and, furthermore, that the normal body waste disposal processes might manage the removal of nanomorphic cells when they have reached the end of their useful lives. The nanomorphic cell would need to employ some sort of triggering mechanism to signal its elimination from the body. Of course, this is all hypothetical and would need to be verified, for example, by careful toxicology studies. The in vivo functional nanomorphic cell is used as an example throughout the text as a vehicle to motivate the study of the impact of extreme scaling on system component performance limits.

HISTORY OF NANOTECHNOLOGY

The history of nanotechnology traces the development of the concepts and experimental work falling under the broad category of nanotechnology. Although nanotechnology is a relatively recent development in scientific research, the development of its central concepts happened over a longer period of time. The emergence of nanotechnology in the 1980s was caused by the convergence of experimental advances such as the invention of the scanning tunneling microscope in 1981 and the discovery of fullerenes in 1985, with the elucidation and popularization of a conceptual framework for the goals of nanotechnology beginning with the 1986 publication of the book Engines of Creation. The field was subject to growing public awareness and controversy in the early 2000s, with prominent debates about both its potential implications as well as the feasibility of the applications envisioned by advocates of molecular nanotechnology, and with governments moving to promote and fund research into nanotechnology.

he early 2000s also saw the beginnings of commercial applications of nanotechnology, although these were limited to bulk applications of nanomaterials rather than the transformative applications envisioned by the field.

PROPERTIES & APPLICATIONS OF NANO ELECTRONIC DEVICES

Electrical properties of carbon nanotubes

With the reduction in power consumption and size chip, the electronic industry has been searching novel strategies to overcome these constraints with an optimal performance. Carbon nanotubes (CNTs) due to their extremely desirable electrical and thermal properties have been considered for their applicability in VLSI Design. CNTs are defined as sheets of graphene rolled up as hollow cylinders. They can basically be classified into two groups: single-walled (SWNTs) and multi-walled (MWNTs). SWNTs have one shell or wall and whose diameter ranging from 0.4 to 4 nm, while MWNTs contain several concentric shells and their diameter ranging from several nanometers to tens of nanometers. One promising direction for the VLSI Design is the use of carbon nanotubes as the active part of the device, circuit or sensor. Carbon nanotubes (CNTs) are macromolecular one-dimensional systems with unique physical and chemical properties. Such properties are derived of that all chemical bonds are satisfied and they are very strong, which also leads to total mechanical, thermal and chemical stability (Baughman et al., 2002). The electronic structure and electrical properties of CNTs are derived from those of a layer of graphite (graphene sheet). The specific electrical properties of the carbon nanotubes are obtained as result of their particular band structure and the hexagonal shape of its first Brillouin zone. CNTs can carry out high electrical current densities at low electron energies. When high electron energies are used, this quantity of energy destroys the CNT structure, which is not desirable from any point of view (Mamalis et al., 2004; Terrones, 2003, 2004). This section analyzes the electrical characteristics of carbon nanotubes and graphene nanoribbons through their physical structure with the aim of presenting the attractive interest for using them in VLSI Design. The advantages and drawbacks of the use of CNTs and graphene nanoribbons as active part of an electrical device are studied. Among physical variables of the carbon nanotube related with the electrical performance are diameter, chirality, length, position, and orientation. Each graphene sheet is wrapped in accordance with a pair of indices (n, m), which represents the number of unit vectors along two directions in the honeycomb crystal lattice of graphene. If m = 0, the nanotubes are called zigzag nanotubes, if n = m, the nanotubes are called armchair nanotubes and otherwise, they are called chiral nanotubes. Two physical properties of the graphene modify its electrical properties: symmetry and electronic structure. There are three types of electrical behavior, if n = m, the nanotube is metallic; 2) if n-m is equal to 3j, where j is a positive integer ("3j" rule), then the nanotube is semiconducting with a very small band gap, and 3) otherwise, the nanotube is a moderate semiconducting. The 3j rule has exceptions due to the curvature effects in carbon nanotubes with small diameter, which can influence in the electrical properties. A metallic carbon nanotube can present semiconducting behaviour and vice versa.

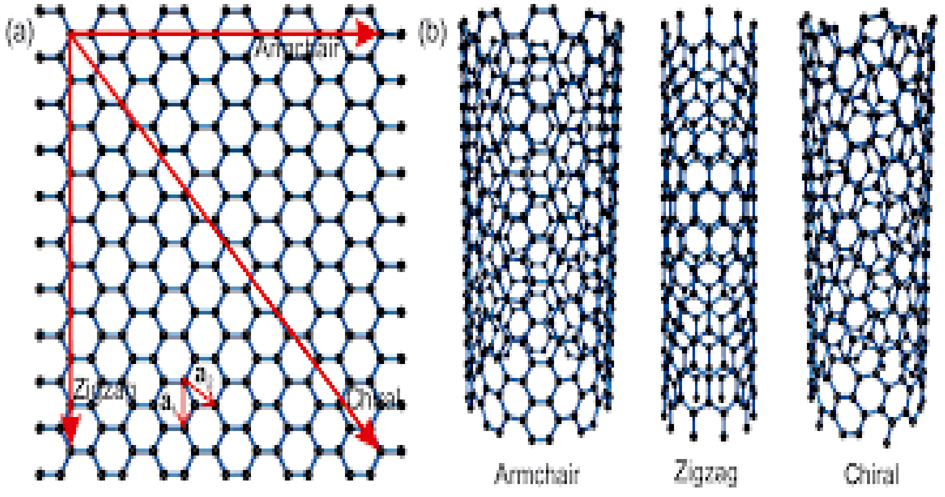

Figure 1: Carbon Nanotubes

Wearable, flexible electronics

The age of wearable electronics is upon us as witnessed by the fast growing array of smart watches, fitness bands and other advanced, next-generation health monitoring devices such as electronic stick-on tattoos.If current research is an indicator, wearable electronics will go far beyond just very small electronic devices or wearable, flexible computers. Not only will these devices be embedded in textile substrates but an electronics device or system could ultimately become the fabric itself. Electronic textiles (e-textiles) will allow the design and production of a new generation of garments with distributed sensors and electronic functions. Such e-textiles will have the revolutionary ability to sense, act, store, emit, and move – think biomedical monitoring functions or new man-machine interfaces – while ideally leveraging an existing low-cost textile manufacturing infrastructure.

Molecular Electronics

Distinct from nanoelectronics, where devices are scaled down to Nano scale levels, molecular electronics deals with electronic processes that occur in molecular structures such as those found in nature, from photosynthesis to signal transduction. Molecular electronics aims at the fundamental understanding of charge transport through molecules and is motivated by the vision of molecular circuits to enable miniscule, powerful and energy efficient computers.

Graphene

Upon its experimental evidence in 2004, graphene has soon entered in the quest for the search of a new material for replacement for CMOS-compatible structures. Graphene is a monolayer of *sp2*-bonded carbon atoms packed in a hexagonal lattice, arrangement that makes it rigorously a two-dimensional material. Graphene has gathered the interest of the scientific and technological communities and, the investigation as well as implementation has been exponentially increasing due to the existing technology platform and knowledge, mostly borrowed from the decades-long carbon nanotube community. We refer the Reader to more specific literature for an in-depth and detailed description of the remarkable and interesting properties of this material. In the present context, we will focus on some of the properties and characterization that are valuable and of great importance for interconnect applications.

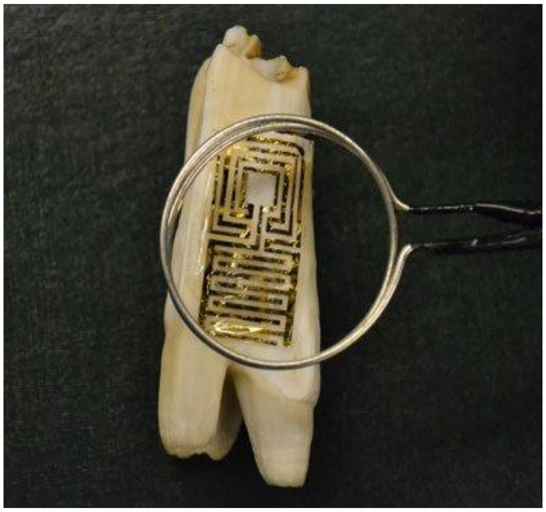

Figure 2: Optical image of the graphene wireless sensor

Graphene is a zero band gap semiconductor, in which electrons behaves as massless Dirac fermions and which could in principle offer less power consumption and enhanced performance due to increased carrier velocities. The ambipolar nature of graphene makes it a very versatile material since it can be used both as an *n*- and *p*-channel material. In fact, charge carriers have been observed to “puddle” in graphene layers at zero field so that both *n*- and *p*-carriers can co-exist within the same layer. Although graphene is a rather new material, a timeline for potential real applications in expected rather soon within the current decade (according to International Technology Roadmap for Semiconductors—Emerging Research Materials Section in 2009. Graphene elevated value of electron mobility at room temperature has rather quickly opened the way to the investigation of a variety of physical phenomenon, ranging from mesoscopic physics, Berry’s phase and unusual quantum Hall effect. In the case of supported graphene devices, there is a fundamental upper limit of 40,000 cm^2/vs. at room temperature due to trapped charges in the substrate itself. Efficient screening and/or complete removal of the underlying substrate are indeed required in order to enhance the mobility of graphene. Further, it has been shown that in suspended and annealed graphene-based devices, the value of the mobility exceed 200,000 cm^2/Vs, which so far represents the highest value for a semiconductor or a semimetal. The mobility is little affected by chemical doping or high electric-field-induced carrier concentrations, suggesting the possibility of achieving rather easily ballistic transport regime on a sub-micrometer scale at 300 K.

One interesting graphene wearable prototype is a flexible, transparent substrate that can be directly applied to the wearer’s skin. The patch detects and monitors exposure to ultraviolet (UV) rays and, with advanced internet of things (IoT) connectivity, and can alert the user once they have reached a pre-defined threshold of exposure to sunlight. This could help prevent a range of harmful conditions, from sunburn to melanoma.Using the same key technology as the previous application, researchers are increasingly hopeful of integrating graphene-based sensors and substrates into fitness trackers with unprecedented levels of functionality. Currently, commercial devices such as smart watches often feature rudimentary heart-rate monitors based on infrared (IR) sensors, and movement trackers based on integrated accelerometers. With superior biocompatibility, graphene sensors could offer more detailed insights into a wide range of health and wellness signals, including hydration, oxygen saturation, continuous blood pressure monitoring and temperature. Additionally, graphene sensors are being developed for pregnant mothers in the form of a wearable patch that can monitor and track fetal movements in real time, sending potential indications of a problem to medical professionals.

THE IMPACT OF NANOTECHNOLOGY

The impact of nanotechnology extends from its medical, ethical, mental, legal and environmental applications, to fields such as engineering, biology, chemistry, computing, materials science, and communications. Major benefits of nanotechnology include improved manufacturing methods, water purification systems, energy systems, physical enhancement, Nano medicine, better food production methods, nutrition and large-scale infrastructure auto-fabrication. Nanotechnology's reduced size may allow for automation of tasks which were previously inaccessible due to physical restrictions, which in turn may reduce labour, land, or maintenance requirements placed on humans. Potential risks include environmental, health, and safety issues; transitional effects such as displacement of traditional industries as the products of nanotechnology become dominant, which are of concern to privacy rights advocates. These may be particularly important if potential negative effects of nanoparticles are overlooked. Whether nanotechnology merits special government regulation is a controversial issue. Regulatory bodies such as the United States Environmental Protection Agency and the Health and Consumer Protection Directorate of the European Commission have started dealing with the potential risks of nanoparticles. The organic food sector has been the first to act with the regulated exclusion of engineered nanoparticles from certified organic produce, firstly in Australia and the UK, and more recently in Canada, as well as for all food certified to Demeter International standards.

CONCLUSIONS AND FUTURE CHALLENGES

Carbon-based nanostructures, and in particular carbon nanotubes and graphene nanoribbons, due to their numerous potential and outstanding properties, have rather quickly attracted the interest within different scientific communities in the quest towards replacement of presently used interconnects. The presented paper has provided the reader with a broad overview of such types of materials and architectures which might be suitable to replace current copper/low-k interconnects at various locations onto an integrated circuit. In particular, carbon nanotubes and graphene nanoribbons both hold great potentials at one or more interconnect levels. Although great advances have so far been achieved since the discovery of CNTs in the early 90s and more recently with the experimental evidence of graphene, many challenges and issues are still open regarding their complete exploitation in working devices. Carbon nanotubes and graphene nanoribbons have shown promising results in terms of RC delay, thermal management and conductance, both on individual objects as well as on assemblies in specific architectures; however, much remains to be advanced in order to achieve a full implementation of these architectures into commercially available IC in the next few years.

In fact, while moving towards the 16-nm technology node, crucial bottlenecks are now going to be faced. When downsizing elements below 100 nm size, interconnects face a number of important challenges. As the lateral dimension of interconnects approaches the mean free path of copper the impact of grain boundary scattering, surface scattering, and the presence of a high-resistivity material as a diffusive barrier layer causes a rapid increase in the overall resistivity. Thus, these phenomena cannot be neglected any further. A full integration of CNTs and GNRs in a real MPU requires the precise and strict control of material properties as well as processes to place those elements at desired locations. At the Nano scale, where at times only few hundreds/thousands of atoms are involved, it becomes of crucial importance to understand the nature of interfaces and any possible dynamics taking place at an interface. In this scenario in fact, metal contacts and electrodes on Nano scale objects behave differently when compared to micro- and macroscopic devices.

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