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Nanoelectronics, Circuits and Communication Systems

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ABSTRACT: Nanoelectronics refers 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.

Nanoelectronic devices have critical dimensions with a size range between 1 nm and 100 nm.^[1] Recent silicon MOSFET (metal-oxide-semiconductor field-effect transistor, or MOS transistor) technology generations are already within this regime, including 22 nanometers CMOS (complementary MOS) nodes and succeeding 14 nm, 10 nm and 7 nm FinFET (fin field-effect transistor) generations. Nanoelectronics is sometimes considered as disruptive technology because present candidates are significantly different from traditional transistors.

KEYWORDS: nanoelectronics, semiconductor, transistors, circuits, communication, nodes, disruptive

I. INTRODUCTION

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 micrometers to the 10 nm range as of 2019. Note that the technology node doesn't directly represent the minimum feature size. 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 1000^3 (a factor of a billion) while reducing the friction by only 1000^2 (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.^[2] 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 fibers 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.

Nanofabrication

For example, electron transistors, which involve transistor operation based on a single electron. Nanoelectromechanical systems also fall under this category. Nanofabrication can be used to construct ultradense parallel arrays of nanowires, as an alternative to synthesizing nanowires individually.^{[3][4]} Of particular prominence in this field, Silicon nanowires are being increasingly studied towards diverse applications in nanoelectronics, energy conversion and storage. Such SiNWs can be fabricated by thermal oxidation in large quantities to yield nanowires with controllable thickness.

Nanomaterials electronics

Besides being small and allowing more transistors to be packed into a single chip, the uniform and symmetrical structure of nanowires and/or nanotubes allows a higher electron mobility (faster electron movement in the material), a higher dielectric constant (faster frequency), and a symmetrical electron/hole characteristic.^[5]

Also, nanoparticles can be used as quantum dots.

Molecular electronics

Single-molecule electronic devices are extensively researched. These schemes would make heavy use of molecular self-assembly, designing the device components to construct a larger structure or even a complete system on their own. This can be very useful for reconfigurable computing, and may even completely replace present FPGA technology.

Molecular electronics^[6] is a technology under development brings hope for future atomic-scale electronic systems. A promising application of molecular electronics was proposed by the IBM researcher Ari Aviram and the theoretical chemist Mark Ratner in their 1974 and 1988 papers Molecules for Memory, Logic and Amplification (see unimolecular rectifier).^{[7][8]}

Many nanowire structures have been studied as candidates for interconnecting nanoelectronic devices: nanotubes of carbon and other materials, metal atom chains, cumulene or polyynes carbon atom chains,^[9] and many polymers such as polythiophenes.

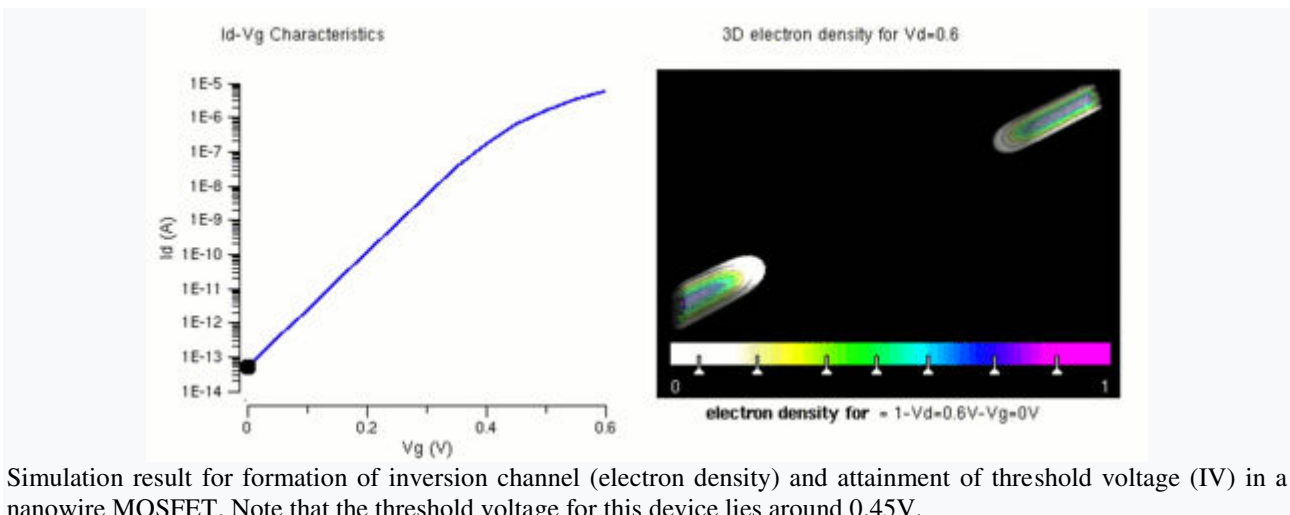
Other approaches

Nanoionics studies the transport of ions rather than electrons in nanoscale systems.

Nanophotonics studies the behavior of light on the nanoscale, and has the goal of developing devices that take advantage of this behavior.

II.DISCUSSION

Current high-technology production processes are based on traditional top down strategies, where nanotechnology has already been introduced silently. The critical length scale of integrated circuits is already at the nanoscale (50 nm and below) regarding the gate length of transistors in CPUs or DRAM devices.



Nanoelectronics holds the promise of making computer processors more powerful than are possible with conventional semiconductor fabrication techniques. A number of approaches are currently being researched, including new forms of nanolithography, as well as the use of nanomaterials such as nanowires or small molecules in place of traditional CMOS components. Field effect transistors have been made using both semiconducting carbon nanotubes^[10] and with heterostructured semiconductor nanowires (SiNWs).^[11]

Memory storage

Electronic memory designs in the past have largely relied on the formation of transistors. However, research into crossbar switch based electronics have offered an alternative using reconfigurable interconnections between vertical and horizontal wiring arrays to create ultra high density memories. Two leaders in this area are Nantero which has developed a carbon nanotube based crossbar memory called Nano-RAM and Hewlett-Packard which has proposed the use of memristor material as a future replacement of Flash memory.

An example of such novel devices is based on spintronics. The dependence of the resistance of a material (due to the spin of the electrons) on an external field is called magnetoresistance. This effect can be significantly amplified (GMR - Giant Magneto-Resistance) for nanosized objects, for example when two ferromagnetic layers are separated by a nonmagnetic layer, which is several nanometers thick (e.g. Co-Cu-Co). The GMR effect has led to a strong increase in the data storage density of hard disks and made the gigabyte range possible. The so-called tunneling magnetoresistance (TMR) is very similar to GMR and based on the spin dependent tunneling of electrons through adjacent ferromagnetic layers. Both GMR and TMR effects can be used to create a non-volatile main memory for computers, such as the so-called magnetic random access memory or MRAM.

Novel optoelectronic devices

In the modern communication technology traditional analog electrical devices are increasingly replaced by optical or optoelectronic devices due to their enormous bandwidth and capacity, respectively. Two promising examples are photonic crystals and quantum dots. Photonic crystals are materials with a periodic variation in the refractive index with a lattice constant that is half the wavelength of the light used. They offer a selectable band gap for the propagation of a certain wavelength, thus they resemble a semiconductor, but for light or photons instead of electrons. Quantum dots are nanoscaled objects, which can be used, among many other things, for the construction of lasers. The advantage of a quantum dot laser over the traditional semiconductor laser is that their emitted wavelength depends on the diameter of the dot. Quantum dot lasers are cheaper and offer a higher beam quality than conventional laser diodes.

Displays

The production of displays with low energy consumption might be accomplished using carbon nanotubes (CNT) and/or Silicon nanowires. Such nanostructures are electrically conductive and due to their small diameter of several nanometers, they can be used as field emitters with extremely high efficiency for field emission displays (FED). The principle of operation resembles that of the cathode ray tube, but on a much smaller length scale.

Quantum computers

Entirely new approaches for computing exploit the laws of quantum mechanics for novel quantum computers, which enable the use of fast quantum algorithms. The Quantum computer has quantum bit memory space termed "Qubit" for several computations at the same time. In nanoelectronic devices, the qubit is encoded by the quantum state of one or more electrons spin. The spin are confined by either a semiconductor quantum dot or a dopant.^[12]

Radios

Nanoradios have been developed structured around carbon nanotubes.^[13]

Energy production

Research is ongoing to use nanowires and other nanostructured materials with the hope to create cheaper and more efficient solar cells than are possible with conventional planar silicon solar cells.^[14] It is believed that the invention of more efficient solar energy would have a great effect on satisfying global energy needs.

There is also research into energy production for devices that would operate in vivo, called bio-nano generators. A bio-nano generator is a nanoscale electrochemical device, like a fuel cell or galvanic cell, but drawing power from blood glucose in a living body, much the same as how the body generates energy from food. To achieve the effect, an enzyme is used that is capable of stripping glucose of its electrons, freeing them for use in electrical devices. The average person's body could, theoretically, generate 100 watts of electricity (about 2000 food calories per day) using a

bio-nano generator.^[15] However, this estimate is only true if all food was converted to electricity, and the human body needs some energy consistently, so possible power generated is likely much lower. The electricity generated by such a device could power devices embedded in the body (such as pacemakers), or sugar-fed nanorobots. Much of the research done on bio-nano generators is still experimental, with Panasonic's Nanotechnology Research Laboratory among those at the forefront.

Medical diagnostics

There is great interest in constructing nanoelectronic devices^{[16][17][18]} that could detect the concentrations of biomolecules in real time for use as medical diagnostics,^[19] thus falling into the category of nanomedicine.^[20] A parallel line of research seeks to create nanoelectronic devices which could interact with single cells for use in basic biological research.^[21] These devices are called nanosensors. Such miniaturization on nanoelectronics towards in vivo proteomic sensing should enable new approaches for health monitoring, surveillance, and defense technology.^{[22][23][24]}

III.RESULTS

Electrical engineering

Electrical circuit, a complete electrical network with a closed-loop giving a return path for current

- Analog circuit, uses continuous signal levels
- Balanced circuit, paths are impedance-matched
- Circuit analysis, the process of finding the voltages across, and the currents through, every component in an electrical circuit
- Circuit diagram, a graphical representation of an electrical circuit
- Digital circuit, uses discrete signal levels
- Electronic circuit, contains "active" (nonlinear) electronic components capable of performing amplification, computation, and data transfer
 - Asynchronous circuit, or self-timed circuit, a sequential digital logic circuit that is not governed by a clock circuit or global clock signal
 - Integrated circuit, a set of electronic circuits on a small "chip" of semiconductor material
 - Mixed-signal integrated circuit, contains both analog and digital signals
 - Synchronous circuit, a digital circuit in which the changes in the state of memory elements are synchronized by a clock signal
- Printed circuit board, on which electronic components are supported and connected using copper tracks on a non-conductive substrate
- Series and parallel circuits, two ways in which electrical components may be interconnected
- Simple filters, including:
 - LC circuit or tank circuit, consisting of an inductance and a capacitance
 - RC circuit, comprises a resistance and a capacitance
 - RL circuit, comprises a resistance and an inductance
 - RLC circuit, comprises a resistance, an inductance, and a capacitance
- Telecommunication circuit, on which information is transmitted
- Nonlinear circuit, a circuit with nonlinear elements.²¹

Mathematics and computer science

- Circuit (computer theory), a theoretical structure simulating electrical and data paths
 - Boolean circuit, a mathematical model for digital logic circuits
 - Integer circuit, a mathematical object of computational complexity
- Circuit complexity, a branch of computational complexity theory
- Cycle (graph theory), a closed path, with no other repeated vertices than the starting and ending vertices
- Circuit of a matroid

Other sciences

- Biological neural network, in neuroscience
- Hydraulic circuit, in fluid mechanics
- Magnetic circuit, in physics, one or more closed loop paths containing a magnetic flux
- Monetary circuit theory, a heterodox theory of monetary economics, also called circuitism
- Pneumatic circuit, in fluid mechanics
- Synthetic biological circuit, in synthetic biology²²

Arts, entertainment, and media

- Circuit (film), a 2001 gay-themed film set in the world of gay circuit parties
- Mario Kart: Super Circuit, a 2001 Game Boy Advance game and the third game in the Mario Kart series
- "Circuit", a character from the Munna Bhai film series
- Circuit, a character from Power Rangers Time Force

In Church

- Circuit (LCMS), a local grouping of congregations in the Lutheran Church–Missouri Synod
- Methodist Circuit, a form of church governance in Methodism

In Government and law

- Circuit (administrative division), an administrative country subdivision in East Asia
- Circuit court, the name of court systems in several common law jurisdictions

Sports

- Circuit training, a form of high-intensity aerobics
- ITF Pro Circuit, pro tennis tours of the International Tennis Federation
 - ITF Men's Circuit
 - ITF Women's Circuit

In Transportation and racing

- Circuit (airfield), also called pattern, a standard path followed by aircraft when taking off or landing
- Circuit, a race track or one complete traverse of a track
 - Formula One circuits (see list of Formula One circuits)
 - Kart circuit, a race track designed for kart racing

Other uses

- Circuit (software), a collaboration service software by Unify
- Circuit, slang for hangouts or events frequented by a given social circle
- Circuit party, a gay dance event²³

Implications

A communications system or communication system is a collection of individual telecommunications networks systems, relay stations, tributary stations, and terminal equipment usually capable of interconnection and interoperation to form an integrated whole. The components of a communications system serve a common purpose, are technically compatible, use common procedures, respond to controls, and operate in union.

Telecommunications is a method of communication (e.g., for sports broadcasting, mass media, journalism, etc.). Communication is the act of conveying intended meanings from one entity or group to another through the use of mutually understood signs and semiotic rules.²⁴

Types

By media

An optical communication system is any form of telecommunication that uses light as the transmission medium. Equipment consists of a transmitter, which encodes a message into an optical signal, a communication channel, which carries the signal to its destination, and a receiver, which reproduces the message from the received optical signal. Fiber-optic communication systems transmit information from one place to another by sending light through an optical fiber. The light forms a carrier signal that is modulated to carry information.

A radio communication system is composed of several communications subsystems that give exterior communications capabilities.^{[1][} A radio communication system comprises a transmitting conductor^[4] in which electrical oscillations^{[5][6][7]} or currents are produced and which is arranged to cause such currents or oscillations to be propagated through the free space medium from one point to another remote therefrom and a receiving conductor^[4] at such distant point adapted to be excited by the oscillations or currents propagated from the transmitter.^{[8][9][10][11]}

Power line communication systems operate by impressing a modulated carrier signal on power wires. Different types of powerline communications use different frequency bands, depending on the signal transmission characteristics of the power wiring used. Since the power wiring system was originally intended for transmission of AC power, the power wire circuits have only a limited ability to carry higher frequencies. The propagation problem is a limiting factor for each type of power line communications.

By technology

A duplex communication system is a system composed of two connected parties or devices which can communicate with one another in both directions. The term duplex is used when describing communication between two parties or devices. Duplex systems are employed in nearly all communications networks, either to allow for a communication "two-way street" between two connected parties or to provide a "reverse path" for the monitoring and remote adjustment of equipment in the field. An antenna is basically a small length of a qwert conductor that is used to radiate or receive electromagnetic waves. It acts as a conversion device. At the transmitting end it converts high frequency current into electromagnetic waves. At the receiving end it transforms electromagnetic waves into electrical signals that is fed into the input of the receiver. several types of antenna are used in communication.²⁰

Examples of communications subsystems include the Defense Communications System (DCS).

Examples: by technology

- Telephone
- Mobile phone
- Tablet computer
- Television
- Telegraph
- Edison Telegraph
- TV cable
- Computer

By application area

A tactical communications system is a communications system that (a) is used within, or in direct support of tactical forces (b) is designed to meet the requirements of changing tactical situations and varying environmental conditions, (c) provides securable communications, such as voice, data, and video, among mobile users to facilitate command and control within, and in support of, tactical forces, and (d) usually requires extremely short installation times, usually on the order of hours, in order to meet the requirements of frequent relocation.

An Emergency communication system is any system (typically computer based) that is organized for the primary purpose of supporting the two way communication of emergency messages between both individuals and groups of

individuals. These systems are commonly designed to integrate the cross-communication of messages between a variety of communication technologies.

An Automatic call distributor (ACD) is a communication system that automatically queues, assigns and connects callers to handlers. This is used often in customer service (such as for product or service complaints), ordering by telephone (such as in a ticket office), or coordination services (such as in air traffic control).

A Voice Communication Control System (VCCS) is essentially an ACD with characteristics that make it more adapted to use in critical situations (no waiting for dial tone, or lengthy recorded announcements, radio and telephone lines equally easily connected to, individual lines immediately accessible etc..)²¹

Key components

Sources

Sources can be classified as electric or non-electric; they are the origins of a message or input signal. Examples of sources include but are not limited to the following:

- Audio files (MP3, WAV, etc...)
- Graphic Image Files (GIFs)
- Email Messages
- Human voice
- Television Picture
- Electromagnetic radiation

Input transducers (sensors)

Sensors, like microphones and cameras, capture non-electric sources, like sound and light (respectively), and convert them into electrical signals. These types of sensors are called input transducers in modern analog and digital communication systems. Without input transducers there would not be an effective way to transport non-electric sources or signals over great distances, i.e. humans would have to rely solely on our eyes and ears to see and hear things despite the distances.

Other examples of input transducers include:

- Microphones
- Cameras
- Keyboards
- Mouse
- Force sensors
- Accelerometers

Transmitter

Once the source signal has been converted into an electric signal, the transmitter will modify this signal for efficient transmission. In order to do this, the signal must pass through an electronic circuit containing the following components:

1. Noise filter
2. Analog-to-digital converter
3. Encoder
4. Modulator
5. Signal amplifier

After the signal has been amplified, it is ready for transmission. At the end of the circuit is an antenna, the point at which the signal is released as electromagnetic waves (or electromagnetic radiation).

Communication channel

A communication channel is simply referring to the medium by which a signal travels. There are two types of media by which electrical signals travel, i.e. guided and unguided. Guided media refers to any medium that can be directed from transmitter to receiver by means of connecting cables. In optical fiber communication, the medium is an optical (glass-like) fiber. Other guided media might include coaxial cables, telephone wire, twisted-pairs, etc... The other type of media, unguided media, refers to any communication channel that creates space between the transmitter and receiver. For radio or RF communication, the medium is air. Air is the only thing between the transmitter and receiver for RF communication while in other cases, like sonar, the medium is usually water because sound waves travel efficiently through certain liquid media. Both types of media are considered unguided because there are no connecting cables between the transmitter and receiver. Communication channels include almost everything from the vacuum of space to solid pieces of metal; however, some mediums are preferred more than others. That is because differing sources travel through subjective mediums with fluctuating efficiencies.

Receiver

Once the signal has passed through the communication channel, it must be effectively captured by a receiver. The goal of the receiver is to capture and reconstruct the signal before it passed through the transmitter (i.e. the A/D converter, modulator and encoder). This is done by passing the "received" signal through another circuit containing the following components:

1. Noise Filter
2. Digital-to-analog converter
3. Decoder
4. Demodulator
5. Signal Amplifier

Most likely the signal will have lost some of its energy after having passed through the communication channel or medium. The signal can be boosted by passing it through a signal amplifier. When the analog signal converted into digital signal.²²

Output transducer

The output transducer simply converts the electric signal (created by the input transducer) back into its original form. Examples of output transducers include but are not limited to the following:

- Speakers (Audio)
- Monitors (See Computer Peripherals)
- Motors (Movement)
- Lighting (Visual)

Other

Some common pairs of input and output transducers include:

1. Microphones and speakers (audio signals)
2. Keyboards and computer monitors
3. Cameras and liquid crystal displays (LCDs)
4. Force sensors (buttons) and lights or motors

Again, input transducers convert non-electric signals like voice into electric signals that can be transmitted over great distances very quickly. Output transducers convert the electric signal back into sound or picture, etc... There are many different types of transducers and the combinations are limitless.

IV.CONCLUSIONS

Nanotechnology, often shortened to nanotech, is the use of matter on atomic, molecular, and supramolecular scales for industrial purposes. The earliest, widespread description of nanotechnology referred to the particular technological goal of precisely manipulating atoms and molecules for fabrication of macroscale products, also now referred to as molecular nanotechnology.^{[1][2]} A more generalized description of nanotechnology was subsequently established by

the National Nanotechnology Initiative, which defined nanotechnology as the manipulation of matter with at least one dimension sized from 1 to 100 nanometers (nm). This definition reflects the fact that quantum mechanical effects are important at this quantum-realm scale, and so the definition shifted from a particular technological goal to a research category inclusive of all types of research and technologies that deal with the special properties of matter which occur below the given size threshold. It is therefore common to see the plural form "nanotechnologies" as well as "nanoscale technologies" to refer to the broad range of research and applications whose common trait is size.²⁰

Nanotechnology as defined by size is naturally broad, including fields of science as diverse as surface science, organic chemistry, molecular biology, semiconductor physics, energy storage,^{[3][4]} engineering,^[5] microfabrication,^[6] and molecular engineering.^[7] The associated research and applications are equally diverse, ranging from extensions of conventional device physics to completely new approaches based upon molecular self-assembly,^[8] from developing new materials with dimensions on the nanoscale to direct control of matter on the atomic scale.

Scientists currently debate the future implications of nanotechnology. Nanotechnology may be able to create many new materials and devices with a vast range of applications, such as in nanomedicine, nanoelectronics, biomaterials energy production, and consumer products. On the other hand, nanotechnology raises many of the same issues as any new technology, including concerns about the toxicity and environmental impact of nanomaterials,^[9] and their potential effects on global economics, as well as speculation about various doomsday scenarios. These concerns have led to a debate among advocacy groups and governments on whether special regulation of nanotechnology is warranted.²⁴

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