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Beyond-Cmos: The near future of information

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Abstract

Beyond-Cmos technology is the future of information because with its development it will be possible to obtain faster and smaller devices, which will allow a greater number of mechanisms to be implemented in the same space, this article seeks give a brief approach to the reader to this new technology, talk about the origin of these devices through Moore's Law, MOSFET, current CMOS technology [1] and the current development of the Beyond-Cmos [2][3], one of the organizations that has researched more about this technology is the NRI, finding that one of the bases of these technologies is spintronics [5]. The development of this technology becomes indispensable in the near future because, as Moore's law predicted, current technology is reaching its limits and in a very short time the developments that researchers hope to implement will not be possible due to the limited capacity of storage and operation that have devices such as MOSFETs:

Keywords: Beyond Cmos, MOSFET, spintronics, Moore's law.

I. INTRODUCTION

The Beyond-Cmos refers to the new materials, structures, devices and architectures that will be developed in the long term, partly complying with Moore's law. An example of this is that it is believed that in the year 2020, the 32 nm CMOS will be created. Its main function is to complement the current CMOS technology to manufacture circuits with a higher switching capacity and improve the information storage capacity of these devices, because the current CMOS technology will not be able to exceed certain capacity limits.

Scientists see in Beyond-Cmos technology the alternative for the processing and storage of information that goes beyond the limits of existing technology, in addition it is believed that silicon will be replaced by graphene due to its electrical properties that are considered extraordinary and could overcome the silicon's physical limits.

The 32 nm CMOS is not the only advance of the Beyond-Cmos, since other technologies such as nano structures are being investigated, these nano structures are based on carbon nanotubes or the implementation of spintronics using the charge and spin of an electron for the information transmission.

The main reasons to start researching and developing the Beyond-Cmos technology are:

- An increase in the power consumed coincides with an insufficient increase in the speed of operation of the circuit (low mobility in the channel and an increase in leakage currents).
- The increase in power will also produce an increase in the device temperature, causing operational damage.
- Increased defects, both in lithography and design level, because when working with such small sizes it is very easy to make mistakes in the printing or the circuit design.

II. MOORE'S LAW

At the present time the technology has advanced too much, example of this, are the small circuits that can be observed in powerful processors. What best explains this phenomenon is the so-called Moore's Law.

Moore's law was devised by Intel co-founder Gordon E. Moore in 1965. It is a simple prediction: each year the number of transistors in an integrated circuit will be multiplied by two. In the year of 1975 a revision was published by Moore himself in which the period of time was changed to two years.

This premise has been fulfilled over the years and has described the technological events of the late 20th century and the beginning of the 21st century, and with it we have arrived at nanoscale transistors.

It is thought that this trend will continue until approximately 2020 [19]

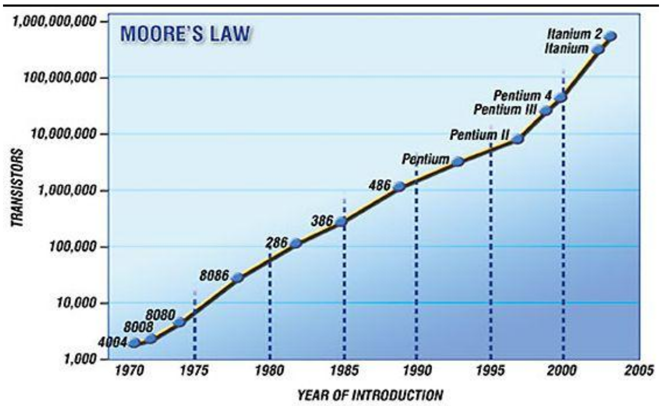

Figure 1 Moore's Law: Image taken from: http://david-lopez.net/ley-de-metcalfe-vs-ley-de-moore/

III. MOSFET

MOSFET transistors are field effect devices that use an electric field to create a conduction channel.

The word MOS means "Metal Oxide Semiconductor" and refers to a type of structure widely used in electronics, where an oxide is used as a dielectric or insulator. FET means "Field Effect Transistor", they are transistors that lead by an electric field, similar to a capacitor.

This means that a MOSFET is a transistor in which an electric field is used to control its condition and its dielectric is an oxide metal.

The main advantage of the MOSFET transistor is that it uses low power to carry out its purpose and the dissipation of energy in terms of loss is very small, which makes it an important component in modern computers and electronic devices such as cell phones, digital watches, small robot toys and calculators. [7] [8]

IV. CMOS

The complementary MOS logic or CMOS is a technology that makes use of nMOS and pMOS field effect transistors. In the Complementary MOS logic family, CMOS (Complementary Metal-Oxide Semiconductor), the complementary term refers to the use of two types of transistors in the output circuit. MOSFET (MOS Field-Effect transistor) of n-channel (NMOS) and p-channel (PMOS) are used in the same circuit, to obtain several advantages over the P-MOS and N-MOS families. CMOS technology is now dominant because it is faster and consumes even less power than the other MOS families. These advantages are somewhat overshadowed by the high complexity of the Integrated Circuit manufacturing process and a lower integration density. [6] [11]

V. MOSFET REDUCTION

In the year 1974 Robert H. Dennard established a methodology that improved the performance of the MOSFET, this procedure consisted in reducing the dimensions of the transistor, by reducing its dimensions a greater number of transistors can be integrated in a silicon area. In the first microprocessors of the 70's had transistors of 10μm, while today it has reached tens of nanometers. [7]

VI. BEYOND-CMOS

Thanks to this escalation and the limits in the CMOS, a new technology known as Beyond-CMOS is emerging. Beyond-Cmos technology refers to new materials, structures, devices and architectures that are developed in the long term (when CMOS technology reaches its physical limits) and are expected to be in production by 2020. The main function of this technology is to complement the CMOS technology to manufacture circuits with a greater storage capacity.

The various investigations on the Beyond-Cmos include a series of ideas in which are magnetic devices, MEMS, response electronics and devices based on 2-dimensional materials. Among the most outstanding investigations are:

- **Circuits and architectures**: circuits based purely on emerging devices and hybrid circuits. Massively-parallel architectures, processors for applications such as image processing and pattern recognition, as well as circuits for radio frequency systems are investigated.
- **Magnetic logic**: Denominated as mLogic, the logic based on new magnetic devices is a proposed technology for the future of electronic systems based on energy limitations. They are designed using all magnetic devices without the integration of semiconductors, turning each logic gate into its own non-volatile storage element. The mLogic systems could be powered by a low voltage of 100mV.
- **MEMS and NEMS**: Embedded and specialized miniature systems that involve one or more components or micro-machined structures that act as sensors or actuators to enable functions at a higher level within the structure of a more complex system. The MEMS technology is on a micrometric scale, while the NEMS technology refers to the nanometric scale.
- **Resistive switching electronics**: These materials offer new functionalities to traditional CMOS such as memory cells, non-linear two-terminal selection devices, RF signal switches, oscillator relaxation and surge protection devices. The materials include simple metal oxides and phase change chalcogenides.
- **Devices based on 2D materials**: Materials such as graphene offer unique electrical and optical characteristics that can be used to create new devices. It is believed that they can be used for applications such as neural networks and photonics.

Spintronics is the technology that is most used in the development of the Beyond-Cmos, it is used to solve the problem of the power dissipated in the integrated with high density of transistors, which is proposed to use the quantum mechanical spin of an electron, which can be seen as a tiny magnetic moment that reaches an electron, thanks to the control of the polarity of the spin a great advantage is generated that helps the energy dissipated in a transistor be considerably reduced.

On a substrate there are millions of transistors, and the transistor density is usually measured in one cm^2, if the density of transistors is 10^8 in cm^2 then the total power dissipated in this area could reach around 50W to 100W per unit of area. [4]

The MOSFET reach a size of up to 6 nm in an integrated component but the problem in this case is the energy dissipation that can be generate since its consumption as we observed above is too high to have many transistors. This problem could find a solution with the development of Beyond-Cmos.

What is sought is to create a spintronic block that is composed of three elements:

1. A nano magnet with a fixed magnetization, called a fixed layer.

2. A second nano magnet that has a magnetization that can be in parallel (P) or anti parallel (AP) to the magnetization of the fixed layer.
3. An interface between the two layers mentioned above, this interface is called the tunnel barrier.

This arrangement of nano magnets is also known as Magnetic Tunnel Junction structure or MTJ. Due to the physical capacities of the spin, a low resistance is associated to the P state, while a high electrical resistance is associated to the AP state.

An MTJ is possible to make it commute between the state P and the state AP by applying a small magnetic field, this made possible the construction of the first generation of magnetic memories of random access (MRAM). [5] [12]

Positive current changes the MTJ from the AP state to the P state, while negative current changes the MTJ from the P state to the AP state. This is the basis of the second generation of MRAM. That second generation of memories reaches writing speed of 10 ns.

A reduction in the area of the device of 2 mm², a reduction of the delay of 15ps and a reduction of the power consumption of 2.2 mw was observed.

However, the main advantage of one of these hybrid circuits is the possibility of implementing cognitive algorithms avoiding the von Neumann bottleneck.

The Nanoelectronics Research Initiative (NRI) is one of the organizations that have researched the Beyond-Cmos and has published articles and results of experiments based on these devices. One of the studies realized says that in logic circuits, the power dissipated in standby is due to the leakage current in the transistor, which flows between the power supply and the ground of the network, even when there is no input voltage. In the transistors there are two leakage components in the OFF state: the source to drain current and the leakage current through the dielectric gate.

The drain current per unit thickness and the leakage current per unit area have been calculated.

The situation becomes more complex in the context of a circuit in which several voltages are applied to the terminals of the transistor and thus, switch in ON and OFF states. In an inverter dependent on the input, a transistor is a low resistance Rl, in the ON state, while the other is in high resistance, OFF state. The voltage that falls on the transistor ON is negligible, and thus, the current is filtered by the transistor OFF. The power in standby for the inverter is the same as for a single transistor and is given by the sum of two leakage components.

$$Sint = Ssd + Sg$$

In a multi-input gate, such as the NAND, the nFET transistors in the pull-down network have larger widths to compensate for their series resistance. The ON and OFF states are determined by combinations of the input conditions.

The Nano magnets in spintronic circuits are non-volatile. In time intervals that the power supply is off, and therefore no current flows through the nano magnet, the nano magnets are able to preserve their state. Soon the spintronics circuits in theory, would not have expense of power in state of standby. Actually, the standby power is controlled by current driving transistors. Even if the input voltage is set to a value such that the conduction transistor does not transmit any current. It is assumed that for circuits designed by current, the standby power is equal to Sint for each nano magnet. It is slightly different for voltage-designed circuits, its current will not flow through the ground, instead it will charge a capacitor with negligible leaks. This is also assumed only for the escape gate.

This led to the investigation of the Logical Arithmetic Unit (ALU).

An ALU is an example of a state machine, even a rudimentary processor. For our purpose, we consider the ALU structure of the figure.

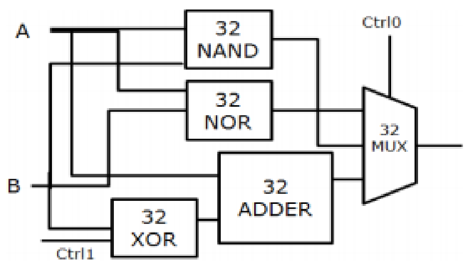

Figure 2: ALU

The heart of the ALU is a block that executes basic mathematical operations (AO). All operations are elaborated for 32-bit numbers.

The operations of addition and subtraction require carry propagation from one bit to another, therefore, as these sequential operations are, there will be a delay for carry propagation and a power dissipated in standby by the devices involved.

Each input is stored in an RF unit for later transmission to the AO, it operates the 32-bit numbers and stores them in a new RF. The entire process is governed by two clocks shifted half cycle one with respect to the other.

In this logical algorithmic unit, parameters such as delay per unit of stored energy and power dissipated in steady state were measured. [3]

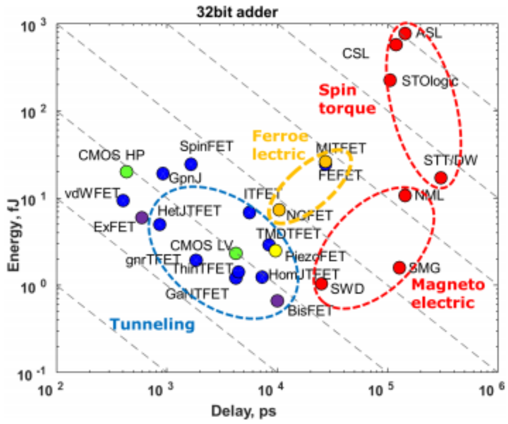

Figure 3: Switching energy versus delay of a 32-bit adder

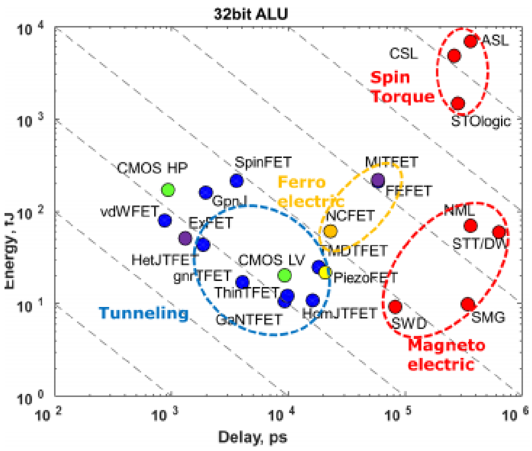

Figure 4: Energy switching versus delay of a 32-bit ALU

As can be seen in figures 3 and 4, spintronic devices change more slowly than electronic devices. Among these, spin transfer torsion spintronic devices (current driven) require more energy to change state. Magneto-electric spintronic devices (voltage driven) have lower energies, by an order of magnitude lower compared to that of HP CMOS. Ferroelectric transistors (such as FEFET and MITFET) are faster than non-volatile options: spintronic devices. These qualitative relationships remain the same for a sequential logic circuit, such as a 32-bit ALU (Figure 4).

However, it can be noted that the spin torque technology is the one that can provide the most energy, although it is also the one that later on to work.

VII. AUTHORS OPINION

The Beyond-Cmos are the future of information because its storage capacity reaches impossible levels with current technology. Moore's law until now has been correct in its calculations and due to this limit presented by the current CMOS technology, various organizations such as the NRI have focused their efforts on creating a technology capable of supporting the pace of thought and creation of the current human being.

That is, if we take into consideration that this technology is now beginning to have light and its first contributions are likely to arrive until 2020, since despite all the research carried out, the size and enormous capacity of these devices propose to the researchers some problems to solve and be able to start implementing them in commercial technology.

VIII. CONCLUSIONS

Although this technology is not yet on the market, due to the number of researches and developments that have been achieved, and the limits that are being reached with current technology, it is very likely that by the year 2020 some device will be commercially developed. based on the Beyond-Cmos.

One of the basic technologies for developing this type of device is spintronics because in traditional electronic systems, only the flow of electric charge is controlled. On the other hand, devices developed based on spintronics could also be supported in the flow of spins, increasing a degree of freedom in developed systems. For this reason, the spintronics is expected to achieve devices that can work faster and use less heat, encouraging the further implementation of the miniaturization of the systems created.

Despite the fact that Beyond-Cmos technology is a relatively current topic, indications of this technology can be found in 1974 when the size of the MOSFET began to be reduced, starting the base of operation of the Beyond-Cmos, the difference between this size reduction and the Beyond-Cmos lies in the materials used in the development of these techniques.

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