A STUDY OF THE IMPACT OF GRAPHENE ON COMPUTING: POSSIBLE APPLICATIONS BASED ON ITS PROPERTIES

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Abstract: Graphene is a material with high potential, its properties make it advantageous in several areas, especially computing. This article's purpose is to present graphene and its properties and show possible applications based on them. Were used as groundwork graphene processors and transistors already widespread. To substantiate this article both periodic materials, such as from newspapers and magazines, as well as academic materials, or scientific articles, were used. The result obtained from this research was promising: graphene has exceptional properties that are, evidently, advantageous, since it is already being manufactured and applied.

Keywords: graphene; graphite; hardware; processor; transistor.

UM ESTUDO DO IMPACTO DO GRAFENO NA COMPUTAÇÃO: POSSÍVEIS APLICAÇÕES BASEADAS EM SUAS PROPRIEDADES

Resumo: O grafeno é um material com alto potencial, suas propriedades o tornam vantajoso em diversas áreas, especialmente na computação. Este artigo tem como objetivo apresentar o grafeno e suas propriedades, além disso mostrar possíveis aplicações baseadas nelas. Utiliza-se como embasamento processadores e transistores de grafeno já difundidos. Para a escrita deste artigo, foram usados como base tanto materiais periódicos, como por exemplo de jornais e revistas, quanto acadêmicos, ou artigos científicos. O resultado obtido com essa pesquisa se mostrou promissor: o grafeno apresenta propriedades excepcionais evidencialmente vantajosas, uma vez que este já está sendo fabricado e aplicado.

Palavras-chave: grafeno; grafite; hardware; processador; transistor.

1. INTRODUCTION

Graphene is a two-dimensional, one-atomic-thick material formed essentially by structurally arranged sp2-hybridized carbon atoms, which characterizes it as a carbon's allotrope. The name is derived from "graphite" with the addition of the suffix “-ene”, used, according to organic chemistry, to form names of organic compounds where the -C=C- group has the highest priority [1] which reflects the fact that the carbon allotrope contains numerous double bonds.

Each atom in a sample of graphene is connected to its three closest neighbors by a strong sigma bond, which contributes to a valence band of one electron extended across the layer. This is the same type of bond seen in some carbon structures, such as nanotubes and polycyclic aromatic hydrocarbons, as well as in fullerenes and glassy carbon [2, 3].

Graphene’s nanostructure and properties allow it to be, in some cases, a silicon substitute, which is already widely applied in the electronics industry [4], since graphene stands out for its better conduction of electricity and its lower heat emission [5].

In topics throughout this article, will be addressed some applications for graphene in industry, with an emphasis on electronic components, specifically processors and transistors. In addition, this article discusses topics of paramount importance such as the advantage of applying graphene to computer hardware components.

2. METHODOLOGY

For the development of this article, the methodology chosen was bibliographic research in reliable databases, through which it became possible to base the themes explored. Also for the writing, were used both journalistic material and scientific articles about graphene and its applications.

Additionally, some terms were searched in these databases, such as "graphene computing", "graphene hardware", "electronic components from graphene" and "graphene properties". Bellow, table 1 shows the expression used, followed by the database and the number of articles found referring to the searched expression.

Table 1: Phrases and Database Article.

Phrase	Database	Quantity of articles found
Graphene Computing	IEEE Xplore	419
Graphene Hardware	Science Direct	2,194
Graphene Electronic Components	MDPI	102
Graphene Properties	PubChem NCBI	19,009

Source: The Authors, 2022.

3. RESULTS AND DISCUSSION

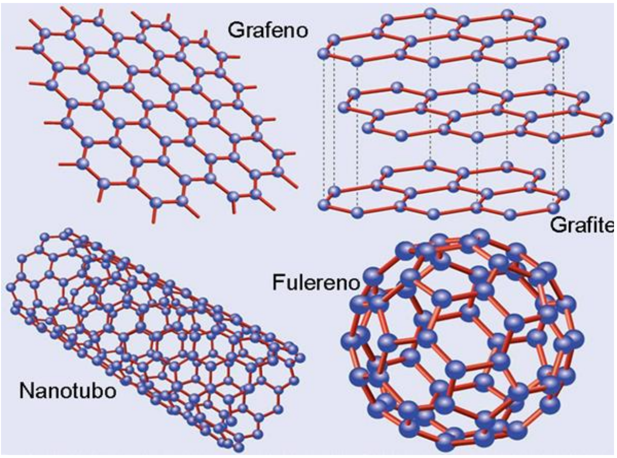
Due to its versatility, graphene has properties that can be applied in several areas, which includes computing. In this context, one of the possible uses of graphene involves increasing computational processing power by processors made entirely of graphene or with graphene coating on its contact surface.

3.1 Graphene structure

The base material for graphene synthesis is graphite, a mineral classified as semi-metal because it demonstrates metallic and non-metallic properties. Graphite is made up of only carbon with an atomic arrangement in flat layers separate from each other at a distance of 3,354 Å (Angstrom) or 0,3354 nm (nanometers), formed by a network of hexagonal rings with weak interlayer bonds. Natural graphite is an excellent thermoelectric conductor, being considered the best mineral in this category among non-metals, in addition to having high chemical, thermal (melting point in the range of 3500°C), and oxidation resistance [6].

Figure 1 presents graphene and its nanostructure arranged in hexagonal rings, graphene layers in graphite, and some examples of structures generated from graphenes, such as nanotubes and fullerenes.

Figure 1: Graphene, graphene layers in graphite and structures generated from graphene.



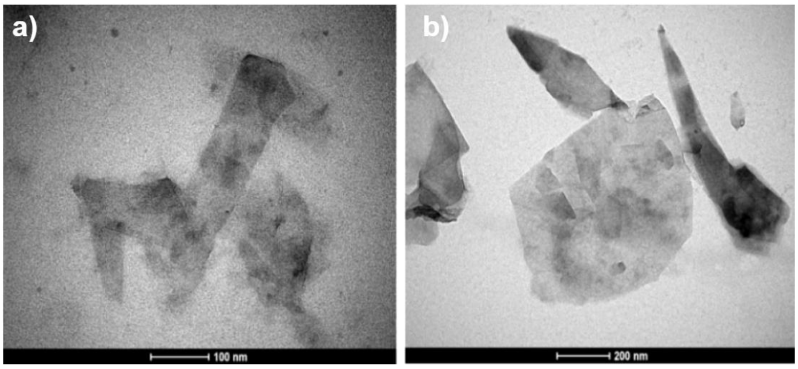
Source: SALES, 2013 [7]

3.2 Graphene production method

Graphene is obtained from graphite layers, through some known methods, among them, it is possible to emphasize the chemical exfoliation in a liquid phase, a promising method for graphene production on large scale, as it can be staggeringly produced and with successive steps until a single two-dimensional layer of one-atom-thick graphene remains.

This method works by adding organic solvents or aqueous solutions with those solvents to natural graphite and then exposes these mixtures to an energy source (usually ultrasonic waves) for a determined time. When exposing this mixture to ultrasound, it is possible to exfoliate the graphite (breaking the bonds between the graphene planes in the graphite) and, with that, obtain a polydisperse of graphenes of varying numbers of layers, as seen in Figure 2.

Figure 2: Graphene dispersions in N-methyl pyrrolidone (a) and chloroform (b) viewed under a transmission electron microscope (TEM).



Source: NASCIMENTO *et al*., 2012 [8]

Subsequently, this mixture goes through a centrifugation process to remove the non-exfoliated graphite aggregates [5].

3.3 Physicochemical properties of graphene

Regarding electrical conductivity, the carbon atom has six electrons in its entirety: two in the first orbital shell and four in the valence shell. In graphene, each carbon atom shares one valence electron with each of its three neighbors, making three sigma-type (σ) covalent bonds and a weaker pi-type (π) bond. Besides, carbon's capability of sharing one electron from the s orbital and two from the p orbital can create sp2-type hybridization. This electronic state is known as a delocalized electronic state and is largely responsible for graphene's electrical conductivity [5].

Furthermore, graphene's charge carriers, also known as zero-rest-mass electrons, behave unusually, moving at an effective speed about 300 times less than the speed of light.

In addition, at room temperature graphene has an ambipolar electric field effect, that is, when the structure is under positive polarization (applying a voltage), are promoted electrons and the conduction band becomes more populated. When it is under negative polarization, holes occur in the valence band. Thus, the resistance of graphene depends on the applied voltage, presenting a minimum value for each value. On either side of the minimum resistance value, the conductivity varies linearly with the applied voltage [5].

Regarding the thermal conductivity, it is possible to present the strong covalent bond established between the carbon atoms, which provides high thermal conductivity to its materials, such as graphene, considered the material with the highest thermal conductivity at room temperature, being able to reach a value above 5000 W/m [5].

Another highlight of graphene's properties is its mechanical characteristics, such as high hardness, with fracture resistance of 125 GPa (gigapascal), and high Young's modulus (a measure of the rigidity of a solid based on elasticity), with a value of 1100 GPa. [5], and chemical characteristics, such as its ability to absorb atoms or molecules and its functionality when attached to chemical groups [9]. Finally, are exemplified all the properties mentioned above and their respective values in table 2.

Table 2: Physicochemical properties of graphene and derivatives.

Physicochemical Property	Estimated Value
High surface area	~2630 m^2g^{-1}
Excellent electrical conductivity	~1738 siemens/m
Strong mechanical strength	Young's Modulus ~1100 GPa, Fracture strength ~125 GPa
Thermal conductivity	5000 $Wm^{-1}K^{-1}$
Ease of functionalization	π-π stacking interaction Electrostatic interaction

Source: LEE; PARK; CHOI, 2019 [9]

3.4 Potential of using graphene in hardware components

Since graphene is a material with remarkable physicochemical properties, the advantageous characteristics of this material allow the design of graphene or graphene-based products of different types that could improve electronic components in various aspects, from graphene applied to the coating of these materials, or even in its composition.

3.4.1 Processors

The processor, also known as CPU ("Central Processing Unit"), considered the computer's "brain", is responsible for performing logical and arithmetical processing. The more powerful it is, the greater the number of tasks that can be performed in less time [10].

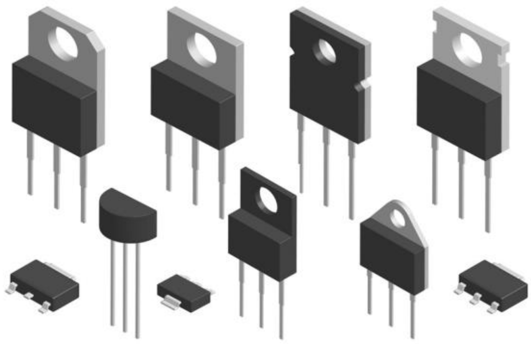
Graphene processors are a reality: in 2013, researchers at the Massachusetts Institute of Technology (MIT), working under the command of Professor Max M. Shulaker, developed a processor made with graphene nanotubes. The RISC-V-RV16XNano processor has a computational speed above 1700ZettaFlops [11].

Also in this research, were used more than 10,000,000 CNTs (Carbon Nanotubes) to form 14,702 carbon nanotube field-effect transistors (CMOS) that were further organized into 3,762 digital logic blocks, which together operated as a 16-bit microcontroller CPU [11].

3.4.2 Transistors

The transistor, exemplified in Figure 3, is an electronic device composed, basically, of three filaments: base, emitter and collector, the emitter having a positive pole function and, respectively, the collector has the negative pole function; the base works by controlling the transistor’s on/off state. When the transistor is off, there is no electrical charge on the base, so there is no electrical current passing between the emitter and collector (known as the bit 0 state). On the other hand, when a voltage is applied to the base, the circuit is closed and the current between the emitter and collector is established (bit 1 state) [12].

Figure 3: Transistor.



Source: SOUZA, 2019 [13]

Researchers at the IBM TJ Watson Research Center in New York started the process of manufacturing a graphene transistor with a cut-off frequency of 100 GHz (gigahertz). The length of the transistor gate is relatively large (240 nm), but it can be miniaturized to improve device performance, declare the researchers [13].

Although graphene transistors already exist, they may not be as advantageous when applied to computing, since they cannot be applied in digital circuits, same as used in computers. Thus, silicon, which is both a conductor with negative charges and a conductor with positive charges [12], presents an advantage: switching between these two states, which is an ability that graphene does not have.

4. CONCLUSION

Given the materials presented, it is possible to conclude that graphene is a material with high potential and that it has remarkable properties. However, this potential has not been fully explored yet, once there is a lot to be studied about graphene in computing, and, especially, in hardware. That said, researchers still need to explore graphene so that studies can get into the experimental area, to, finally, be applied.

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